Quantifying Changes in Wetland Area and Habitat Types Monitoring and Adaptive Management Activity Implementation Plan

1 Introduction

The Deepwater Horizon (DWH) oil spill settlement in 2016 provides the Natural Resource Damage Assessment (NRDA) Trustees (Trustees) up to $8.8 billion, distributed over 15 years, to restore natural resources and services injured by the spill. As described in the DWH oil spill Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (PDARP/PEIS; DWH NRDA Trustees. 2016a), the Trustees selected a comprehensive, integrated ecosystem approach to restoration. The Final PDARP/PEIS considers programmatic alternatives, composed of Restoration Types, to restore natural resources, ecological services, and recreational use services injured or lost as a result of the DWH oil spill incident. As shown in the PDARP/PEIS, the injuries caused by the DWH oil spill affected such a wide array of linked resources over such an enormous area that the effects must be described as constituting an ecosystem-level injury. The PDARP/PEIS and information on the settlement with British Petroleum Exploration and Production Inc. (called the Consent Decree) are available at the Gulf Spill Restoration website.

Given the unprecedented temporal, spatial, and funding scales associated with the DWH oil spill restoration effort, the Trustees recognized the need for robust Monitoring and Adaptive Management (MAM) to support restoration planning and implementation. As such, the following proposed MAM activities will provide essential data towards the programmatic goals established in the PDARP/PEIS to "Provide for Monitoring, Adaptive Management, and Administrative Oversight to Support Restoration Implementation" to ensure that the portfolio of restoration projects provides long-term benefits to natural resources and services injured by the spill (Appendix 5.E of the PDARP/PEIS). This framework allows the Trustees to evaluate restoration effectiveness, address potential uncertainties related to restoration planning and implementation, and provide feedback to inform future restoration decisions. The integrated restoration portfolio emphasizes the broad ecosystem benefits that can be realized through coastal habitat restoration in combination with resource-specific restoration in the ecologically interconnected northern Gulf of Mexico ecosystem (DWH Trustees 2016). Most of the planned restoration projects identified in the integrated restoration portfolio (DWH Trustees 2016) are concentrated in coastal Louisiana and in conjunction with the Louisiana Coastal Master Plan (CPRA 2017a). The MAM activities proposed below allows for the continuation, improvement, and expansion of wetland area and habitat zonation data analysis in order to establish proper baseline conditions as large-scale restoration projects proceed.

2 Purpose of this document

This MAM Activities Implementation Plan (MAIP) describes the MAM activity, "*Quantifying Changes in Wetland Area and Habitat Types*" to address MAM priorities described in the PDARP/PEIS. This MAM activity is intended to support evaluation of regional restoration outcomes within the Louisiana Restoration Area; perform data aggregation and data management; resolve critical information gaps and uncertainties for restoration planning; inform restoration decision-making; and perform monitoring to inform the design and implementation of future restoration projects. This document provides information about the activities to be implemented and the data gaps and uncertainties they will address; describes their applicability to the PDARP/PEIS; describes their consistency with the programmatic alternative selected by the DWH Trustees in the PDARP/PEIS; OPA, and Compliance with NEPA.

This MAM activity is consistent with the DWH Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (PDARP/PEIS). The Louisiana Trustee Implementation Group (LA TIG) can use the data provided by this effort to assess changes in wetland area and zonation of wetland habitat types, allowing for assessment of the influence of the comprehensive, integrated portfolio of restoration projects at the coast-wide or sub-region within Louisiana and relative to other drivers and long-term trends.

2.1 Monitoring and Adaptive Management: Quantifying Changes in Wetland Area and Habitat Types

This MAM Activities Implementation Plain (MAIP) describes MAM Activity for quantifying changes in wetland area and zonation of wetland habitat type to address the following priorities of various restoration types described in the PDARP/PEIS:

- Wetlands, Coastal, and Nearshore (WCNH; Section 5.5.2 in PDARP/PEIS)
    - Goals addressed
        - Contribute to reduction in net marsh loss in coastal Louisiana
        - Maintain elevational landscape sufficient to support wetland vegetation
        - Restore habitats injured by the spill in a range of salinity zones
        - Provide benefits to estuarine dependent fish and invertebrates (nekton and benthic) at a variety of life stages through habitat restoration
    - Rationale
        - The activities described here will provide high spatial/temporal resolution geospatial datasets required for assessing changes in wetland area and habitat type zonation
        - The activities described here will synthesize existing remote sensing and in situ monitoring data to assess wetland elevation/hydroperiod requirements for commonly occurring wetland plant community types
- Monitoring and Adaptive Management (Section 5.5.15 in PDARP/PEIS)
    - Goals Addressed
        - Increase the likelihood of successful restoration
        - Provide feedback for management decisions
    - Rationale
        - The geospatial datasets produced by the MAM Task 1 and Task 2 activities will be used as baseline monitoring for ecosystem restoration, continue after projects are in operation, and can serve as baseline/reference datasets going back to 1985 (onset of LandSAT era). These datasets will be used to assess project impact on land loss and habitat change in the context of background

variability and trends, and allow for adaptive management decisions for future restoration efforts. These datasets will also better inform the development of SMART Objectives by fulfilling identified MAM needs WCNH 1.a (*quantifying and assessing historic, current, and future predicted emergent vegetated wetland habitat in coastal Louisiana and determine appropriate quantification for implemented and long term land area*) and WCNH 3.a (*quantify and assess historic, current, and predicted emergent vegetated habitat area in coastal Louisiana and determine appropriate quantification for implemented and long term vegetated marsh salinity community types*). This effort will also help address MAM needs referenced in Cross Restoration Type (CRT) 1.a.(Evaluate the efficacy of various strategies in land creation/ restoration (diversions, marsh platform creations, barrier island restoration, ridge restoration)).

- The datasets and information produced by the MAM Task 3 activities will be used to better inform the development of SMART Objective 2a by fulfilling identified MAM need 2a (*synthesize available data and/or quantify appropriate land elevation for different marsh vegetation types*).

2.1.1 MAM Activity Description

2.1.1.1 Background

Coastal wetlands are dynamic environments and the data and methods used to analyze change in those settings must be robust to those dynamics. Historically, assessments of trends of wetland area change over a specific time interval have been conducted by comparing image pairs that bracket the time interval in question. This approach has been applied to assessing restoration impacts on wetland area, where a pre- and post-construction land area assessment is made by comparing images that temporally bracket construction of the restoration project, and the difference between the two is taken to be a measure of the land-area response to the project. Assessments of wetland area at any given time can vary widely, solely as a result of environmental conditions present at the time of imagery acquisition. Water level variability, whether tidal, riverine, or wind-driven, has been shown to produce more than +/- 10% variability in remotely sensed land area estimates in highly dynamic areas (Couvillion, 2021). Because this approach assumes all the measurable difference in land area between the image pairs reflects persistent change in the landscape configuration, background environmental variability can be misconstrued as persistent gains or losses in wetland area over the assessed time interval. As such, assessments of land area change rates based solely on comparing land area between a pair of images lacks the temporal resolution necessary to constrain natural background environmental variability and isolate restoration impacts.

Similarly, precipitation and Mississippi River discharge can vary markedly from year to year and can force large interannual variations in salinity and vegetation community zonation, making it challenging to discern restoration impacts from climatological impacts under existing protocols that survey vegetation communities once every several years.

2.1.1.2 Objectives

The objectives of this activity are to develop geospatial datasets that can be used to assess historical trends in wetland area, assess restoration project impacts to wetland area and zonation of wetland habitat types that account for historical trends and interannual variability in those metrics, and to advance our understanding of elevation thresholds where vegetation productivity is sufficient to promote elevation gain rates that offset relative sea-level rise (RSLR). This activity will fill knowledge gaps necessary to fulfill the MAM needs to develop SMART objectives 1a (Quantify and assess historic, current, and future predicted emergent vegetated wetland habitat area in coastal Louisiana), 2a (synthesize available data and/or quantify appropriate land elevation for different marsh vegetation types), and 3a (quantify and assess historic, current, and predicted emergent vegetated wetland habitat area in coastal Louisiana and determine appropriate quantification for implemented and long term vegetated marsh salinity community types). The study area for this activity will be the Louisiana Coastal Area, and the habitat types to be mapped have recently been incorporated into existing monitoring (Coastwide Reference Monitoring System) and modeling (2023 Louisiana Coastal Master Plan) efforts.

2.1.1.3 Tasks

Task 1. Improved Wetland Area Change, Monitoring and Assessment of Restoration Impacts

Purpose

The selection, monitoring, and management of coastal restoration projects requires a method of accurately and rapidly quantifying and assessing historical, current, and future predicted emergent vegetated wetland habitat area. Additionally, the development of SMART objectives requires data to inform the development of objectives based on historical trends and observed wetland area benefits from implemented projects. New sensors and methodologies have improved the ability to assess wetland area; however, integrating this newly available data while maintaining an ability for comparison to historical information requires the development of new techniques and methodologies for remotely sensed analyses.

Coastal wetland area change is a dynamic process occurring as a result of multiple compounding and interacting stressors. The spatiotemporal variability in these stressors, and their contribution to observed wetland loss, is not well understood. Development of SMART objectives would benefit from improved information regarding rates of historical wetland loss and how those rates have varied in time and space. Previous analyses have been limited in their ability to discern changes at temporal scales necessary to account for normal environmental variability and better quantify historical rates of wetland area change and potentially relate that variability to causal mechanisms. As part of this effort, wetland area change will be analyzed at finer spatial and temporal scales than have previously been examined to quantify spatially variable change. Additionally, this effort will investigate the incorporation of spatially variable estimates of water level, allowing this important factor to be accounted for, and remaining, unexplained variability identified. When possible, particular events, such as episodic impacts, and their impacts on rates of wetland area change will be identified and quantified.

A second component of this Task involves the evaluation of wetland area benefit from coastal restoration projects. In an attempt to mitigate the coastal wetland loss crisis being experienced in coastal Louisiana, several programs have instituted restoration efforts. While individual projects are commonly evaluated to assess land area pre- and post-construction, there has not yet been a comprehensive evaluation of the impact of the restoration efforts. Additionally, the current assessments of land building from project construction do not allow for the assessment of land sustained by restoration projects, nor do they provide an understanding of how wetland area benefits have changed through time. The purpose of this component of Task 1 is to provide a comprehensive wetland area benefit analysis of all constructed restoration projects intended to benefit land area.

A separate effort has evaluated all Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) projects for land built and land sustained. However, that effort did not include coastal restoration projects from other funding sources or agencies. In this effort we will conduct an exhaustive search and compile project boundaries and project information on all coastal restoration projects, including NRDA projects. Additionally, this effort will investigate relationships between project type, cost, location, and design features and the outcomes of those projects to help inform the development of SMART objectives. This information will be used to tailor objectives to projects based on these variables and develop ranges of reasonable, measurable targets for expected wetland area benefit. Outputs from this task could also be used as critical datasets to inform the Barrier Island Comprehensive Monitoring #3 (BICM3) (CPRA_WCNH_01), Barrier Island System Management (BISM) (CPRA_WCNH_02), and the NOAA proposal " Nekton References and Targets: Assessing the abundance and density of fish and invertebrates associated with Louisiana's marsh habitat " (NOAA_WCNH_01).

Objectives

The overall objective of Task 1 is to determine historical trends of wetland area change and develop improved methods for current and future monitoring of wetland area thereby enabling the isolation and assessment of restoration impacts. Specific objectives include:

1. Quantify wetland area in all available cloud-free images of both Landsat and Sentinel 2 imagery using fractional estimation techniques fostering the comparability of these datasets
2. Analyze wetland area trends in the above-mentioned data sets to develop rates of historical wetland area change and examine relationships between historical rates of change and other variables including landscape position, elevation, RSLR, et al.
3. Project the above-mentioned rates of wetland area change to develop without-action (WOA) conditions specific to restoration areas, and difference observed change with WOA condition, thereby enabling the calculation of both wetland area built and wetland area sustained by the project.
4. Develop cumulative estimates of restoration impacts on wetland area by geographic regions such as basins, as well as categories of interest such as project type.
5. In a journal article, interpret and discuss the results of project efficacy with respect to project design, investment, and stressors influencing the project to help explain differences in observed project effects, which will inform the development of SMART objectives.
6. Use the data sets and the results of the analyses mentioned above to help inform SMART objectives.

Methods

Historical Assessment of Landsat and Sentinel-2 imagery - Coastwide

Prior assessments of coastal wetland area change in Louisiana have typically assumed wetland area change is a linear, time-invariant phenomenon (Barras, 2008; Couvillion, et al. 2011). In part this was due to insufficient observations and/or methodologies to assess non-linear trends. In most cases, however, the process of wetland area change is not a continuous, linear process; it can also occur through a series of punctuated events, with intermittent periods of rapid change that punctuate y longerperiods of relative stability. More recent assessments have improved wetland area change assessment by assessing non-linear trends; however, additional imagery and new analyses can further segment temporal patterns of wetland area change (Couvillion, et al. 2017, Couvillion, 2020). The identification and quantification of wetland area change over these shorter time intervals can help illuminate the processes driving these changes. Recent advances in cloud computing have enabled the sequential analysis of entire image collections, providing the increased temporal resolution necessary to assess this natural variability while segmenting these periods of interest. This assessment proposes to analyze all cloud-free dates of Landsat (1985-present) and Sentinel-2 imagery (2015-present) (Data Source: EROS, ESA). The imagery will be corrected for surface reflectance to minimize the impact of atmospheric variability and facilitate the comparison of imagery among dates. Cloud-contaminated images will be excluded from analysis using cloud and cloud shadow data available for both Landsat and Sentinel-2 imagery. Previous analyses indicate that following these cloud exclusions, the resulting image collections contain, on average, approximately 7 Landsat images per year for a given location or approximately 24 Sentinel-2 images per year. This temporal resolution of data will vastly improve upon past analyses, which typically analyzed past trends using one observation per year or fewer.

Indices which facilitate the quantification of wetland area will be calculated in each image from the above-mentioned filtered image collections including the modified normalized difference water index (mNDWI; Xu, 2005, 2006) and the Normalized Difference Vegetation Index (NDVI; Kriegler et al. 1969). Relationships will be established between high-resolution aerial imagery (~1m) and these coarser-resolution (10m-30m) satellite images in the above-mentioned indices as well as spectral bands from the original imagery indicative of the percent of land and percent of water in a given pixel.

Aquatic vegetation will be identified in each image so that it may be accounted for and its effect removed from wetland area change analyses. Analyses which fail to recognize and account for aquatic vegetation often misinterpret change in aquatic vegetation as change in wetland area. Such a misinterpretation could negatively impact the accurate quantification of wetland area change, and consequently, the monitoring of restoration impacts on wetland area. While the primary impetus for identifying FAV and SAV is to avoid misinterpretation, those outputs can be useful to other efforts, and as such, will be provided with the spatial data products resulting from this effort.

Relationships among wetland area estimates and water level variability

Previous assessments have not directly accounted for water level variability and its impact on coastal wetland area estimates. Water level is known to be one of the most significant contributors to variability in wetland area estimates however, the lack of spatially distributed gauges with a sufficient period of record has led to more simplistic means of accounting for variable water levels in past analyses. In this analysis we will investigate the use of estimated water level based on relationships of specific locations to long term gauges. In ongoing investigations, Snedden et al. have shown CRMS inundation data and Grand Isle sea level anomalies are highly correlated across the LA restoration area over interannual time scales (CRMS, NOAA). Building upon that effort, in this study we will investigate relationships between remotely sensed wetland area estimates and water level at the time of acquisition (TOA) of those images.

Assessing Wetland Area Impact of Constructed Coastal Restoration Projects

Assessing not only the land building but also land sustaining effects of restoration projects necessitates a comparison to a without-action (WOA) condition. The observed with-action (WA) condition must be compared to a counterfactual condition describing what would have happened without that action. The projection of said WOA condition necessitates the establishment of historical rates of wetland change free from the impacts of normal environmental variability and extrapolating those historical rates into the future.

We will create WOA projections, including uncertainty ranges, using the historical, pre-construction trends and compare those to post-construction observations to calculate wetland area benefit attributable to all constructed coastal restoration projects. Importantly, these analyses will quantify uncertainty in our estimates of restoration impact for a given project. Previous analyses of CWPPRA projects have been conducted, but this effort will expand that effort to all coastal restoration projects and improve upon that previous effort by directly incorporating and accounting for water level variability. An example of this type of analysis is shown below (Figure 1) in a restoration assessment for the CWPPRA project BA 42:

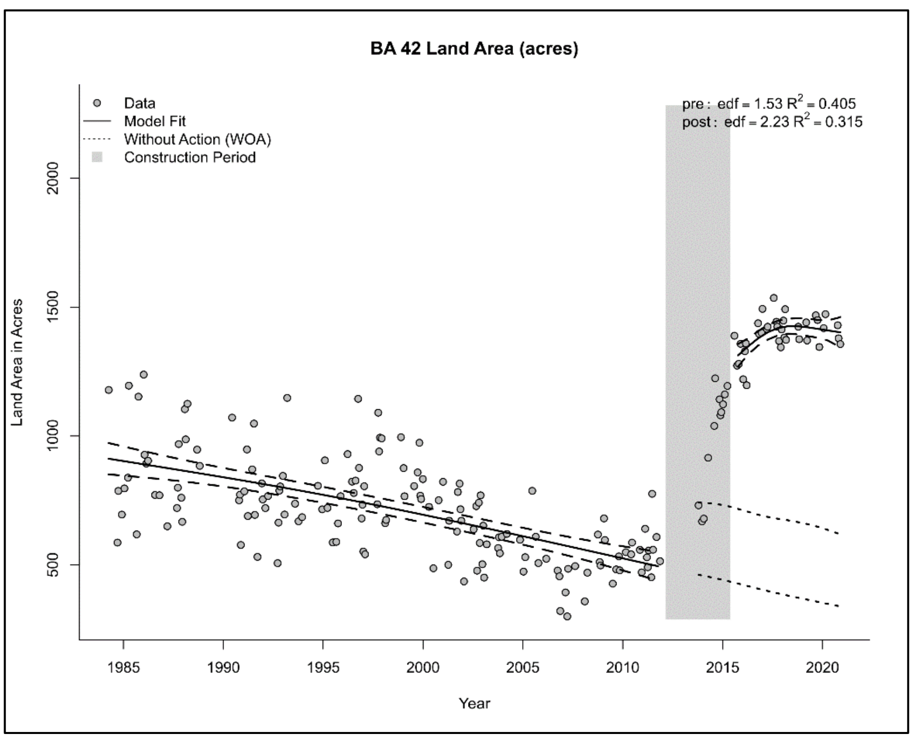

Figure 1. An example project (CWPPRA BA-42) level assessment of restoration land area benefit which projects pre-construction trends which then enable the calculations of land built as well as land sustained.

The analysis for each project will then be used to develop cumulative impact assessments for particular geographic regions, such as that shown in Figure 2 (cumulative assessment of CWPPRA projects in Barataria Basin), or by project type or other parameters of interest.

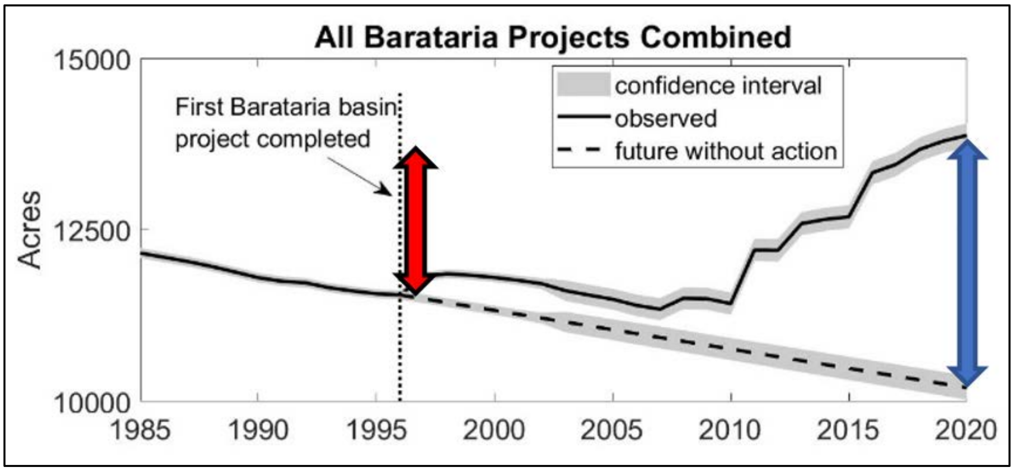

Figure 2. An example of a cumulative restoration benefit assessment which accounts for trends of wetland area (blue arrow) vs. an assessment that does not account for historical trends (red arrow).

Products

The proposed MAM activity will produce

1. Historical trends of change in wetland area throughout coastal Louisiana and the peer-reviewed geospatial dataset will be made publicly available via the USGS Science Base data repository.
2. Projections of wetland area under WOA conditions in project areas.
3. Observed, post-construction wetland area in project areas and the resulting calculations of land built and land sustained for each project, from construction completion through the end of the period of observation.
4. Development of improved methodologies for post-restoration monitoring of wetland area analyses to compare pre- and post-construction trends to assess project impacts.
5. A report or journal article outlining findings and the cumulative estimates of restoration impacts on wetland area by geographic regions such as basins, as well as categories of interest such as project type.
6. Assistance in the development of SMART Objectives WCNH 1.a and 3.a for land building/sustenance.

Task 2. Assess wetland habitat type over annual time steps with current and historical Landsat and Sentinel imagery

Purpose

Under existing climate change scenarios, coastal wetland ecosystems are anticipated to experience profound impacts to coastal hydrology, which may drive shifts in marsh vegetation species composition.

These impacts include altered salinity and inundation regimes associated with either sea-level rise or changes in freshwater delivery brought about by altered precipitation regimes. In addition to long-term trends in salinity and sea-level, these parameters can show a high degree of year-to-year variability brought about by variations in precipitation and river discharge that have been linked to naturally occurring, cyclical climate variability such as the El Nino-Southern Oscillation (ENSO; Ronelewski and Halpert 1986; Schmidt et al. 2001, Snedden, in review). For example, salinities throughout coastal Louisiana during 2011, which followed two years with large precipitation deficits, far exceeded those that occurred in 2019 after three consecutive years of precipitation surpluses (Figure 3, top). In some locations average annual salinity in 2019 was over 20 ppt less than in 2011 (Figure 3, bottom).

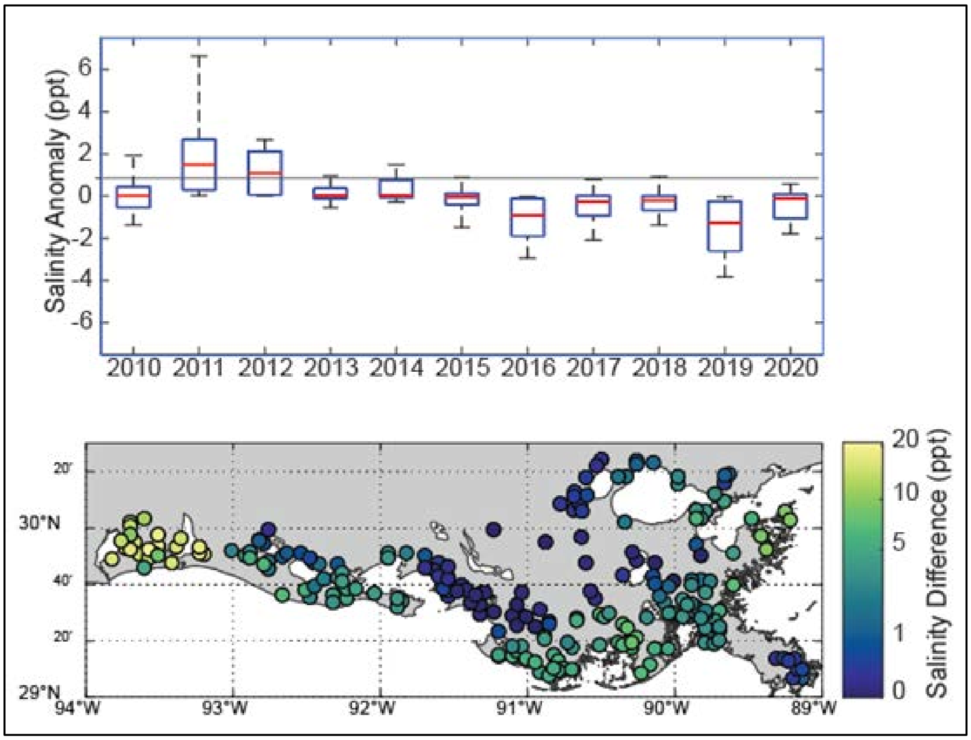

Figure 3. (top) Distribution of annual average salinity during 2010-2020. Red horizontal lines are median values of 223 Coastwide Reference Monitoring System (CRMS) sites analyzed. Blue boxes represent interquartile range, whiskers indicate 10th and 90th percentiles. (bottom) Difference in average annual salinity between 2011 and 2019 (2011 minus 2019) at 223 CRMS sites.

One of the goals specified in the PDARP for the restoration type "Create, Restore, and Enhance Coastal Wetlands" (PDARP Appendix D.1.1) is to *restore or maintain salinity gradients across the estuarine landscape*. Marsh vegetation community zonation generally integrates and reflects the prevailing environmental conditions such as salinity more reliably and visibly than any other factor or set of factors, though the second-order details such as lag times and salinity anomaly thresholds for community type transitions remain largely unresolved. As such monitoring vegetation community zonation is a useful monitoring approach for assessing the degree to which restoration efforts that aim to influence salinity regimes are achieving their goals.

For the past several decades, aerial surveys of vegetation species composition at over 4,000 sites across coastal Louisiana have been conducted at roughly decadal recurrence intervals (most recently in 2021). These data are used to classify sites into marsh classifications (fresh, intermediate, brackish, saline;

Chabreck and Linscombe 1997; Chabreck and Linscombe 2001; Sasser et al., 2008; Sasser et al., 2014) and vegetation community types (Visser 1998; Visser 2000; Visser et al. 2002). Over the last 25 years, vegetation surveys have been conducted in 1997, 2001, 2007, 2013, and 2021. The first four of those surveys all occurred after marked precipitation deficits (Figure 4) led to substantially elevated salinities (Snedden, in review), which can manifest itself in plant community zonation (Visser et al. 2002;, Forbes and Dunton 2006; Snedden 2019). In contrast, the most recent 2021 survey occurred shortly after a precipitation surplus had persisted for three years. If the degree to which restoration projects succeed in *restoring or maintaining salinity gradients across estuarine landscapes* is to be accurately assessed, and if *coastwide and basin-specific marsh salinity community targets are to be identified through analysis and synthesis of available historical data* (MAM SMART Objective 3a), the natural background variability must first be constrained. Doing so will require longer records of vegetation community zonation that are delineated at much higher sampling frequency.

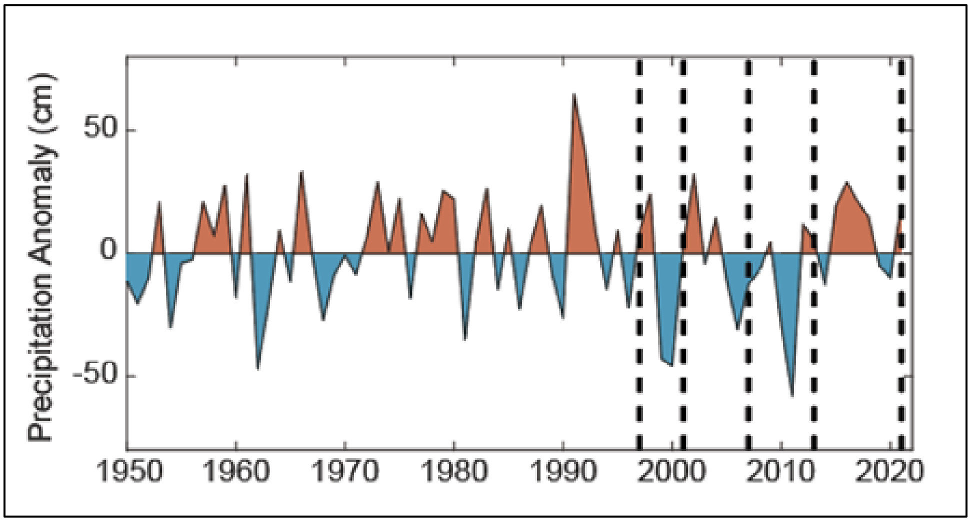

Figure 4. Annual precipitation anomalies across coastal Louisiana, 1950 – 2021. Vertical lines indicate years aerial vegetation surveys were conducted.

Recently, a new, neural network-based approach to classifying coastal wetland vegetation communities was developed (Snedden 2019) that has since become incorporated into the Coastwide Reference Monitoring System (CRMS) and modeling/planning efforts (Baustian et al. 2020). The approach is well-suited for ongoing, long-term monitoring programs because the classifier is stable to the addition of new samples as they become available. It has been used to classify vegetation communities from the aerial survey data (Figure 5, top), and those classified survey locations have subsequently been used as training data in supervised classification of Sentinel multispectral imagery into community types at the pixel scale (10m; Figure 5, bottom). Preliminary analyses have indicated correct classification rates (into 11 community types) of nearly 80%. Using this approach, *this MAM activity will produce geospatial datasets of Snedden (2019) habitat zonation at 10m resolution annually with high accuracy going back to 2015, and for each year going forward.*

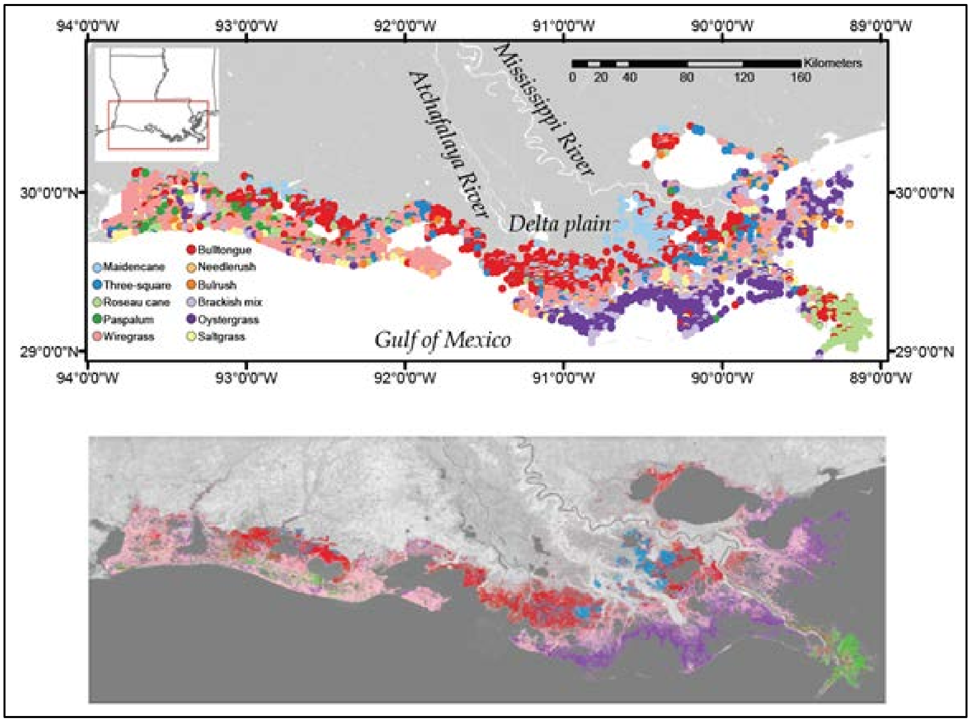

Figure 5. (top) 2013 aerial survey data classified according to Snedden (2019). (bottom) 2015 Sentinel imagery similarly classified.

Sentinel imagery collection began in 2015. However, long-term trends and cyclical variability could be better resolved with longer records of vegetation community zonation (i.e., going back further than 2015). Landsat imagery collection begin in 1985 – providing nearly 40 years of temporal coverage, but the quality and resolution (30m vs 10m) are inferior to Sentinel. It remains unclear how technological limitations would translate into classification accuracy. *This MAM activity will perform and evaluate similar classifications on Landsat historical imagery, and if the approach produces similarly reliable and useful results, maps of Snedden (2019) vegetation zonation at 30m resolution will be produced each year going back to 1985.* If technological limitations of Landsat sensors (e.g., spatial resolution, number of spectral bands) preclude useful classification and mapping deliverables, these limitations will be documented in the final report (see deliverables, below).

Objectives

1. Provide high-quality geospatial datasets of marsh vegetation community types (Snedden 2019) classified at the pixel level with Sentinel imagery, at annual time steps going back to 2015.
2. Develop methodology for and evaluate the accuracy of classifying marsh vegetation community types (Snedden 2019) at the pixel level with Landsat imagery, annual time steps going back to 1985. If useful, provide high-quality geospatial datasets at annual time steps going back to 1985.
3. Use these geospatial datasets to inform the development of SMART objectives by region, restoration type, and project type.

Methods

Overall, this method will utilize aerial vegetation survey data, as well as patterns observed in multi-temporal, remotely sensed imagery to classify vegetation community types in coastal Louisiana. This classification will proceed in a hierarchical fashion, first creating more generalized classifications, and later dissecting specific classes of interests such as wetlands into more specific community assemblages. These classifications will be created annually for Landsat and Sentinel-2 imagery, and the resulting classifications will be used to analyze trends and change amongst coastal wetland vegetation communities through time.

Land use/Land Cover (LULC) classifications require:

1. Sufficient training data with adequate representation of all classes of interest
2. Imagery and/or ancillary datasets which contains bands, indices, or patterns of indicative of the categories of interest.
3. A classification system capable of recognizing patterns of association among the two datasets mentioned above.

In this case, we will utilize aerial vegetation survey data from 1997, 2001, 2007, 2013, and 2021 as the primary source of training and validation data for the wetland vegetation community type assessments. Two thirds of the survey sites will be used for training, and the remaining third will be used for validation after classification is complete. In years in which it is available, CRMS in situ vegetation cover data may be used as additional training data beyond that provided by the aerial surveys. Vegetation survey sites will be classified into vegetation community types according to Snedden (2019). For years in which no training data are available (I.e., years in which aerial surveys were not performed), a method of change detection will be used to identify areas which have changed (as determined by remotely sensed imagery) between the most recent survey data, and the classification year of interest. This method evaluates the spectral reflectance of a given site relative to the observed variability at that site in a known year (a year in which training data is available) as well as relative to the spectral characteristics of the vegetation community type. If the spectral reflectance values of that site are deemed to have changed from the known year, that site is excluded from the training set in the unknown year (year for which field data is unavailable).

The imagery used for classification will consist of a series of images collected throughout a given year of interest. Annual composites, where noise is removed through temporal averaging, of this multitemporal imagery will be assembled, and these composite images will serve as the basis imagery for classification. Data reduction techniques such as harmonic analysis and principal components analysis will be used to generate layers indicative of vegetation community types, and indices such as the Normalized Difference Vegetation Index (NDVI) will be calculated and added to the pool of data layers upon which the classification will be based. Following the compilation of training datasets (CRMS and aerial vegetation survey data) and the datasets to be classified (composite imagery) , a series of machine learning algorithms, including Random Forest (RF) and Classification and Regression Trees (CART), will be applied to identify and exploit patterns among these two sets of information, and these patterns will be used as the basis for classification decisions After classifying a composite image into the vegetation community types for a given year, classification accuracy will be assessed with the survey data set aside for validation. Confusion matrices (Fig 6) will be assembled that compare community types to which pixels are classified with their corresponding observed community type from the validation data, and kappa statistics (Cohen 1968; Naesset 1996) as well as overall and community-specific correct classification rates will be calculated.

CONFUSION MATRIX (paste values in here)

Classified As

Actual	Maidencane	Three-Square	Roseau Cane	Paspalum	Wiregrass	Bulltongue	Needlerush	Bulrush	Brackish Mix	Oystergrass	Saltgrass	Total	% correct
Maidencane	**3749**	202	58	89	12	498	0	0	0	0	0	**4608**	**0.81**
Three-Square	177	**3591**	196	510	572	283	17	6	6	5	23	**5386**	**0.67**
Roseau Cane	44	195	**2202**	254	246	125	4	18	4	11	49	**3152**	**0.70**
Paspalum	86	483	229	**4053**	728	316	21	17	9	9	46	**5997**	**0.68**
Wiregrass	22	667	222	861	**14914**	45	126	165	53	17	287	**17379**	**0.86**
Bulltongue	484	293	184	297	68	**7373**	0	1	0	3	28	**8731**	**0.84**
Needlerush	0	17	5	8	110	2	**1017**	141	145	121	24	**1590**	**0.64**
Bulrush	0	16	15	21	146	1	178	**1347**	179	177	53	**2133**	**0.63**
Brackish Mix	0	9	4	7	49	0	177	183	**933**	123	22	**1507**	**0.62**
Oystergrass	0	4	10	7	27	0	160	173	170	**4528**	58	**5137**	**0.88**
Saltgrass	3	28	39	50	226	22	41	50	38	65	**851**	**1413**	**0.60**
Total	**4565**	**5505**	**3164**	**6157**	**17098**	**8665**	**1741**	**2101**	**1537**	**5059**	**1441**	**57033**	
													0.78 Correct Classification Rate

Figure 6. Confusion matrix (preliminary) for classification of 2015 Sentinel imagery with 2013 aerial survey data. Bold font in cells along the matrix's diagonal indicate counts of correct classification. Off-diagonal cells indicate counts of misclassifications. Correct classification rates for each community type are indicated in the far right-hand column. Overall correct classification rate (78%) is indicated in the lower right.

The resulting geospatial datasets will convey the highest spatial resolution (10m/30m) classification of wetland vegetation community types in coastal Louisiana to date. Additionally, the high (annual) temporal resolution of the successive classifications, combined with the resulting 40-year historical record of annual Landsat-based classification will facilitate isolation of project impacts to wetland vegetation community zonation from impacts arising from cyclical climate variability. As these zonation patterns are strongly indicative of prevailing salinity conditions, the geospatial datasets described here will be critical to assessing the degree to which projects succeed in *restoring or maintaining salinity gradients across estuarine landscapes* (PDARP Appendix D.1.1).

In addition to classifying Sentinel/Landsat imagery into vegetation community types as described above, we will apply methods such as multinomial logistic regression (Snedden and Steyer 2013) or multilayer perceptrons (Park et al. 2006) to estimate probability of occurrence for each vegetation community type as a function of salinity, and also delineate salinity optima and ranges for the various community types. These analyses will be performed on a 2010-2020 dataset that spans an entire ENSO cycle. Output from these analyses may be used to parameterize or assess validity of future predictive modeling efforts (e.g., future Coastal Master Plan iterations). The approaches, findings, and interpretations related to these analyses will be included in the final report.

Products

The proposed MAM activity will produce

1. Peer-reviewed geospatial datasets of Sentinel imagery classified according to Snedden (2019) for each year 2015-2023, to be made publicly available at ScienceBase.gov.
2. Peer-reviewed geospatial datasets of Landsat imagery classified according to Snedden (2019), for each year 1985-2023, to be made publicly available at ScienceBase.gov.
3. A final report, and/or peer reviewed publication detailing methodology, results, and interpretation of major findings.

Task 3. For different marsh vegetation community types, determine land elevation thresholds required for landscape sustainability

Purpose

One of the techniques specified in the PDARP for the restoration type "Create, Restore, and Enhance Coastal Wetlands" (PDARP Appendix D.1.1) is to *create or enhance coastal wetlands through the placement of dredged material*. The long-term sustainability of these created marshes will depend largely on the inundation regime those created wetlands experience, which is determined by their vertical position within a rising tidal frame. Optimal flooding promotes healthy and productive vegetation communities that, through ecogeomorphic feedbacks, can sequester organic matter into the soil profile at a rate that promotes increases in marsh elevation to keep pace with eustatic sea-level rise (ESLR; Morris et al. 2002), all while maintaining critical habitat for commercially and recreationally important aquatic organisms and other organisms they rely upon as prey. With the understanding that nekton can only access critical marsh habitats when they are inundated, the inverse relationship between inundation and wetland plant performance for multiple dominant taxa in coastal Louisiana (Snedden et al. 2015; Figure 7) suggests the restoration objectives of promoting healthy plant communities and creating critical nekton habitat may be at odds with each other. *This MAM activity aims to determine, for predominant vegetation communities in coastal Louisiana, if relations exist between plant performance, elevation change rate, and inundation duration that can be used to inform target elevations that optimize the sustainability of created marshes and nekton access to those habitats, or parameterize tradeoffs between nekton access and plant performance.* Quantifying these potential thresholds would inform the development of SMART objective 2 (*Maintain elevational landscape sufficient to support wetland vegetation*), by *synthesizing available data and quantifying appropriate land elevation for different marsh vegetation types*).

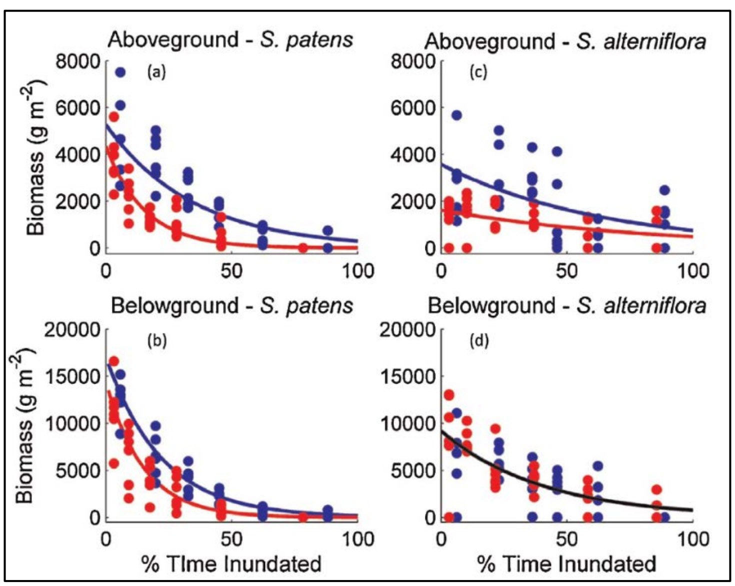

Figure 7. Aboveground (top) and belowground (bottom) biomass for *Spartina patens* (left) and *Spartina alterniflora* (right) growing in marsh organs under brackish (blue) and saline (red) conditions. Data values are indicated by circles; regressions (exponential) are represented by lines. Taken from Snedden et al. (2015).

Objectives

1. For each vegetation community type (Snedden 2019), identify and quantify relationships between NDVI (a proxy for wetland plant performance) and inundation duration through least-squares regression.
2. For each vegetation community type, identify and quantify relationships between NDVI and marsh elevation change rate through least-squares regression.
3. For each community type, use functions obtained in objectives (1) and (2) to inform target inundation regimes and elevations for each vegetation community type. These target inundation regimes can then be used to inform target elevations for created and restored marshes.

Methods

Vegetation productivity is a crucial component of the functioning and sustainability of coastal marshes. It is essential for providing food and habitat for other species, providing important human services, as well as being a driver of processes associated with accretion and elevation change. Further, the relationship between vegetation productivity and the remotely sensed metric 'Normalized Difference Vegetation Index' (NDVI) is well established both theoretically and empirically across many ecosystems (reviewed in Petoroelli et al. 2005).

There is likely a complex, multivariate relationship between NDVI, wetland inundation dynamics, and wetland elevation change. We will build a hypothetical, causal model of these relationships in the form of a graphical casual model (Cronin and Schoolmaster 2018), use this structure to inform the fitting strategies to achieve unbiased estimates for the relationships among them, and then fit the derived models to existing data using existing long-term datasets that include plant performance (as indicated by NDVI) and environmental drivers (e.g., salinity, water level) for 11 vegetation community types (Snedden 2019). This approach will entail intersecting pixels (10m) of NDVI composites with their spatially corresponding CRMS vegetation plot (2m), where salinity, water level, and elevation, as well as plant community type, are known. We have conducted preliminary analyses that apply regression models to this approach that show clear relationships between NDVI and metrics of inundation and salinity for several community types, and these relationships will be more rigorously quantified.

In a similar fashion, we will extend this analytical approach to quantify potential relationships between NDVI and marsh elevation change by incorporating CRMS rod sediment elevation table (rSET) data into the analyses, as one of the primary drivers of marsh resilience in response to sea-level rise is adaptive changes to the elevation of the marsh platform brought about by vegetation production (Morris et al. 2002). Vegetative production facilitates adaptive elevation changes in two major ways, (1) trapping sediment which enhances mineral matter deposition and accumulation, and (2) production of above- and belowground biomass, which enhances organic matter accumulation in the soil profile (Morris et al. 2002).

For community types where significant relationships between NDVI, elevation change rate and inundation are estimated, we will synthesize the two analyses to serve as the informative basis for delineating target elevation ranges for created marshes of various vegetation communities. First, using the parameterized community-specific relationships between NDVI and elevation change, the corresponding NDVI value for a target elevation change rate (e.g., the ESLR rate) can be predicted

(Figure 8, left). This NDVI value can subsequently be used to determine the corresponding inundation duration (Figure 8, right), from which a probability distribution of target marsh elevations can be estimated using a relevant nearby water level record. If we find uncertainty is dominating the signal between specific variables for certain community types, the causal structure modeling approach is an ideal approach in that it can inform what additional information may be needed to facilitate more precise estimates. Finally, to improve our understanding of these dynamics and inform restoration planning, we can address counterfactual questions such as how the plant performance (NDVI) at a particular location would have changed if a different vegetation community type had been present.

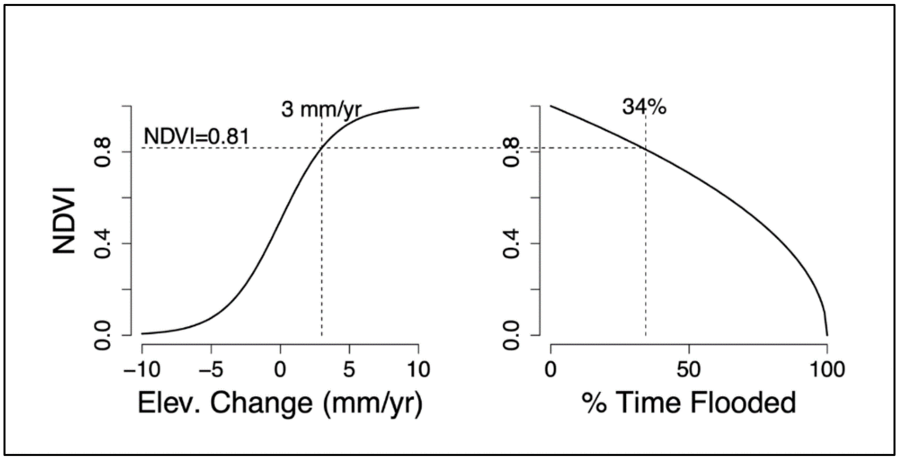

Figure 8 (left) Example of relation between elevation change rate and NDVI quantified through regression for a particular community type. This relation suggests that for elevation rates that exceed ESLR (3 mm/yr), NDVI values should equal or exceed 0.81. (right) Example of relation between % time flooded and NDVI quantified through regression for the community type in question. This relation suggests that to achieve the desired NDVI value (>= 0.81), the created marsh should be situated in the tidal frame such that its % time flooded is less than 34%.

Products

1. A report and/or peer-reviewed publication that documents approach, methods, major findings (I.e., NDVI-elevation change relations, NDVI-inundation relations), and interpretation of the findings (I.e., optimal elevations for created marshes, for specific marsh communities identified in Snedden 2019)
2. Peer-reviewed, high-quality datasets and code used in this analysis will be posted on ScienceBase.gov.

2.1.1.4 Budget

The total budget requested for this MAM activity is $659,012. The breakdown of this request by organization is outlined in Tables 1 and 2.

Table 1. U.S. Geological Survey budget for the quantifying changes in wetland area and habitat types activity by general cost category by fiscal year (FY).

Category	FY23	FY24	FY25
Federal labor and travel	$128,048.30	$132,273.89	$142,638.93
Contracts and supplies	$2,400.00	$2,400.00	$3,000.00
Indirect costs	$49,845.72	$52,146.41	$57,351.75
Total	$180,294.02	$186,820.30	$202,990.68
Grand Total			**$570,105.00**

The total budget request for the USGS is $570,105.00. Estimated cost is based on the costs for FY22. Travel may include expenses to present results at scientific conferences. The indirect rate (21.171% for FY22) was increased by 0.5% to account for minor potential increases in indirect rates. The DOI indirect rate of 16.84% was included for Federal labor. Similarly, labor rates were increased by 3.3% per year to account for inflation.

Table 2 includes cost estimates from trustees for engaging in this activity. Trustee engagement would likely include approximately 15–20 hours per person/per year in Years 1 & 2 for review of approach and results, and 15-20 hours for document review in Year 3.

Table 2. Trustee engagement costs for the quantifying changes in wetland area and habitat types activity by fiscal year (FY).

Trustee	FY23	FY24	FY25	Total
CPRA	$20,000	$20,000	$20,000	$60,000
NOAA	$6,600	$6,930	$7,277	$20,807
LDWF	$2,600	$2,700	$2,800	$8,100
Total by year	$29,200	$29,630	$30,077	
Grand total				$88,907

2.1.2 Activity Implementation

2.1.2.1 Timeline

TASK	YEAR 1				YEAR 2				YEAR 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Improved Wetland Area Change, Monitoring, and Assessment of Restoration Impacts												
A Intersect Sentinel-2 with Landsat Imagery	X	X										
B Land area analysis			X	X	X	X	X	X				
C Assemble/disseminate data release									X			
D Report/publication preparation										X	X	X
2.Assess wetland habitat type over annual time steps with current and historical Landsat and Sentinel Imagery.												
A compile/classify training data	X											
B compile/QA imagery	X	X										
C classify imagery/analysis results		X	X	X	X	X	X	X				
D assemble/disseminate data release									X			
E Report / publication preparation									X	X	X	X
3 For different marsh vegetation community types, determine land elevation thresholds required for landscape sustainability												
A Compile in-situ data	X	X										
B Compile/QA imagery			X									
C causal structure modeling				X	X	X	X					
D assemble/disseminate data release								X	X			
E report/publication preparation								X	X	X	X	X

2.1.2.2 Data Management and Reporting

Data management by USGS includes all QA/QC, annual reports, datasets, final reports, and graphics/tables. These program products will be disseminated through ScienceBase.gov, and will adhere to the USGS Fundamental Science Practices protocols. Data storage and accessibility will be consistent with the guidelines in Section 3.1.3 of the MAM Manual. All annual reports and final products will be delivered to the LA TIG https://gulfspillrestoration.noaa.gov, and will be available to the public. All QA/QC'd products will follow established standards and will be made available through the LA TIG for storage and public access on the DIVER Restoration Portal (Section 10.6.5 of SOP; DWH NRDA Trustees, 2016). In the event of a public records request related to data and information that are not already publicly available, the Trustee to whom the request is addressed would provide notice to the other LA TIG members prior to releasing any data that are the subject of the request.

2.2 Consistency of MAM Activity with the PDARP/PEIS

This MAM activity is consistent with and supports multiple programmatic goals (section 5.3) in the PDARP/PEIS, including a variety of restoration types (section 5.5) and restoration approaches (Appendix 5.D). This MAM activity supports the programmatic goals of, (1) Restore and conserve habitat; (2) Replenish and Protect Living Coastal and Marine Resources; and (3) Provide for monitoring, adaptive management, and administrative oversight to support restoration implementation. This MAM activity will support a variety of restoration types described in the PDARP/PEIS, mainly Sections 5.5.2, *Wetlands, Coastal, and Nearshore Habitats* and 5.5.15, *Monitoring and Adaptive Management*. However, the MAM activity also supports the goals of the restoration type sections of 5.5.3, *Habitat Projects on Federally Managed Lands*. The PDARP/PEIS makes numerous references to creation and restoration of multiple habitat types, including herbaceous marshes of different salinities (reflected by vegetation composition). This MAM activity will provide high resolution data for monitoring and adaptive management of important resources, including monitoring change in wetland area and habitat zonation, and determining recovery from injury during the DWHOS. Therefore, this MAM activity will continue to provide data for future, planned coastal ecosystem restoration in Louisiana's Coastal Master Plan, provide important resource management data and is an essential part of Operations, Maintenance, and Adaptive Management Plans (OMAM) for large-scale restoration projects in Louisiana. Below, the rationale for how this data supports and is consistent with a variety of restoration approaches found in the PDARP/PEIS appendices 5.D and 5.E. Restoration approaches listed in the PDARP/PEIS are appropriate under the Oil Pollution Act (OPA).

- Habitat Restoration Approaches (D.1)
    - Create, Restore, and Enhance Coastal Wetlands (D.1.1)
        - The PDARP specifies *marsh creation through placement of dredged material* as a technique under this approach. Target elevations for created marshes that balance nekton habitat access with ideal inundation regimes for wetland plant productivity and organic matter accumulation are currently not well-informed.
        - The PDARP specifies *restoring hydrologic connections to enhance coastal habitats* a means to promote broad salinity gradients across estuarine landscapes. Emergent marsh vegetation community zonation patterns are reliable, integrative indicators of those salinity gradients.
        - Geospatial datasets produced by this MAM activity could be used to update models for project planning, act as baseline, construction phase, and post-construction monitoring data for projects and regions, and provide the ability to adaptively manage project outcomes as benefits and impacts become better resolved.
    - Restore and Preserve Mississippi River Processes (D.1.2)
        - The PDARP specifies managing river diversions from the Mississippi-Atchafalaya River system as a long-term strategy to restore injured wetlands by reducing widespread loss of existing wetlands.
        - Diversion projects considered under this restoration approach would be specifically designed to build new marshes
        - Geospatial datasets produced by this MAM activity could be used to update models for project planning, act as baseline, construction phase, and post-

construction monitoring data for projects and regions, and provide the ability to adaptively manage project outcomes as benefits and impacts become better resolved.

3 Evaluation of NEPA Requirements

The Trustees' approach to compliance with NEPA summarized in this section is consistent with, and tiers where applicable from the PDARP/PEIS Section 6.14.4. Resources considered and impacts definitions (minor, moderate, major) align with the PDARP/PEIS. Relevant analyses from the PDARP/PEIS are incorporated by reference. Such incorporation by reference of information from existing plans, studies or other material is used in this analysis to streamline the NEPA process and to present a concise document that briefly provides sufficient evidence and analysis to address the Louisiana TIG's compliance with NEPA (40 CFR 1506.3, 40 CFR § 1508.9). All source documents relied upon are available to the public and links are provided in the discussion where applicable.

As discussed in Chapter 6 of the PDARP/PEIS, a TIG may propose funding a planning phase (e.g., initial engineering, design, and compliance) in one plan for a conceptual project, or for studies needed to maximize restoration planning efforts. This would allow the TIG to develop information needed leading to sufficient project information to develop a more detailed analysis in a subsequent restoration plan, or for use in the restoration planning process. Where these conditions apply and activities are consistent with those described in the PDARP/PEIS, NEPA evaluation is complete and no additional evaluation of individual activities is necessary at this time.

NEPA Review of MAM Activity

The activities and tasks described here consist exclusively of desktop analysis of existing literature, existing data resources, developing new geospatial datasets, as needed, development of a report, and engagement of stakeholders. This activity will include data collation and data analysis with no field data collection. Consequently, there will be no impact to resources as defined with the PDARP/PEIS.

NEPA Conclusion

After review of the proposed activities against those actions previously evaluated in the PDARP/PEIS, the Louisiana TIG determined that the environmental consequences resulting from this MAM activity falls within the range of impacts described in Section 6.4.14 of the PDARP/PEIS, thus no additional NEPA evaluation is necessary at this time.

4 Compliance with Environmental Laws and Regulations

The Louisiana TIG has completed technical assistance with the appropriate regulatory agencies for this project. Due to the nature of the project, which consists of data analysis and purchase of equipment with no proposed field activities, permits and consultations are not required. Other projects proposed under Louisiana MAM may directly fund field work, thus existing permits and consultations will be reviewed to determine if they are sufficient to complete the work or if additional compliance work is needed.

Federal environmental compliance responsibilities and procedures follow the Trustee Council Standard Operating Procedures (SOP), which are laid out in Section 9.4.6 of that document. Following the SOP, the Implementing Trustees for each activity will ensure that the status of environmental compliance (e.g., completed vs. in progress) is tracked through the Restoration Portal.

Documentation of regulatory compliance will be available in the Administrative Record that can be found at the DOI's Online Administrative Record repository for the DWH NRDA (https://www.doi.gov/deepwaterhorizon/adminrecord). The current status of environmental compliance can be viewed at any time on the Trustee Council's website: http://www.gulfspillrestoration.noaa.gov/environmental-compliance/.

5 Activity Close Out

In accordance with Section 9.5.1.6 of the TC SOPs, the Implementing Trustee shall provide the LA TIG with a closeout report after all activities and expenditures have been accomplished. The Final Report shall include a description and any documentation of the completed activity, estimated benefits to natural resources, the final funding balances and any transfers described in Section 7 of the TC SOPs, a summary of the results of monitoring, and any recommendations on adaptive management for the activity. Upon request, the Implementing Trustee shall provide the LA TIG with additional information and supporting documents to complete the closeout report.

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