PROJECT INFORMATION

Project Director's Name*	J. Brian Davis
Organization*	Mississippi State University
Project Title*	The Efficacy of Marsh Terraces in Enhancing and Restoring Gulf Coastal Wetlands
Reporting Period*	10/11-2018-12/14/2021

Note to Grantees: In sections 1 to 5, we ask you to highlight your accomplishments (including outputs and outcomes) through this grant award. <u>These sections of the final grant report will be made available to the public.</u>

1. GOALS AND ACCOMPLISHMENTS

1.1 Please restate the goals and objectives of your project.*

The objectives of this project are: 1) To quantitatively measure various geological ad biological outcomes of constructed marsh terrace in coastal Louisiana; 2) to use geological, biological, landscape, and physical design metrics to parameterize and develop predictive models of terrace performance and persistence; and, 3) use project results to develop guidance for the design and application of marsh terracing to maximize its contribution to coastal restoration, sustainability, and ecosystem productivity.

More specific goals include six aspects of terrace performance that we are using to assess the benefits of marsh terraces and determine how they are influenced by elements of their design and application. Specifically, the proposed project is evaluating (1) hydro- and sediment-dynamics including total suspended solids, sediment transport, retention, and accretion, (2) shoreline erosion (3) submerged aquatic vegetation production, (4) emergent marsh creation, (5) avian resource use, and (6) terrace longevity.

1.2 Describe the accomplishments of your project. You should include both the anticipated accomplishments that you outlined in your project proposal as well as any *unanticipated* accomplishments that have since occurred. Describe any activities you have conducted, programmatic progress made, or project benchmarks and milestones met.*

We view our project as being both very challenging but also accomplished and rewarding. The two primary challenges included Hurricanes Laura and Zeta in fall 2020 that removed us from the field for one year. However, we recovered and continued data collection in 2021. We were very active in scientific and other circles during this project. We had one Postdoctoral research assistant, one doctoral student, 2 master's students, and several university undergrads or technicans that assisted in different phases of the project.

Drs. Linhoss, Morillo and colleagues delivered 9 conference presentations, and that team published 2 scientific papers and has a third one under review.

Dr. Skarke and his team provided 6 conference presentations, a handful of which were parts of Linhoss et al. (and vice versa). Sr. Skarke et al. published one paper, have one in review, and a third being developed.

Madie McFarland and Drs. Davis, Brasher, and Woodrey delivered 11 conference oral presentations, 2 poster presentations, and several reports at various local, regional, and national meetings. McFarland is in the final stages of completing her MS Thesis with anticipated graduation in May 2022. Her field data collection was delayed in the second year (Hurricanes Laura and Zeta) and she resumed in spring-summer 2021.

Madie and her work have also been featured in various venues including Ducks Unlimited, Inc., The Wildlfie Society, a university Tweet, and in an appearance in the MSUs Graduate School Newsletter, August 2021.

This project involved many collaborations with other agencies, colleagues, and private landowners. Relative to specific objectives of the hydrology and wave modeling:

Objective 1: Quantitatively measure various geological and biological outcomes of constructed marsh terrace in coastal Louisiana and Texas.

1. A remote sensing study was conducted to monitor long-term erosion and deposition within marsh terraces. The objective of the study was to quantify erosion and deposition of multiple marsh terrace fields performance over time. The results of this study showed more predominant deposition (55%) than erosion (45%) in 20 marsh terrace fields during a 10 to 14-year period of analysis. Terrace fields with high channel density and thereby an external sediment supply showed more deposition compared with low channel density fields.

https://doi.org/10.3390/w12020336

• Objective 2: Use geological, biological, landscape, and physical design metrics to parametrize and develop predictive models of terrace performance and persistence.

2. The numerical wave model SWAN was used to simulate wave climates in marsh terrace sites, conduct wave model validation, and determine the effectiveness of marsh terraces for the reduction of significant wave height (Hs). The results from this study modeled and measured small (0.03–0.14 m) and high–frequency waves (0.80–1.29 s) in the marsh terrace fields. Model validation revealed agreement between modeled and observed data, particularly for Hs and direction. Additionally, a comparison of wave climates in terraced and unterraced marsh environments indicated an average Hs reduction of 45% (min:18%, max: 84%) when terraces were present. https://doi.org/10.1016/j.ecoleng.2021.106529.

• Objective 3: Use project results to develop guidance for the design and application of marsh terracing to maximize its contribution to coastal restoration, sustainability, and ecosystems productivity.

3. The numerical wave model SWAN was used to assess the effectiveness of different terrace designs (chevron, linear, and rectangular) at reducing Hs during low winds and cold front passages in coastal Louisiana. The results of this study showed that 1) The chevron terrace shape provided the greatest reduction in Hs during all wind conditions compared to the square and linear terrace shapes, reducing Hs by up to 54%. 2) Hs reduction was not primarily affected by the terrace spacings (100, 110, and 120 m) examined in this study. 3) Based on economics and wave attenuation outcomes, the chevron design with a 120 m terrace spacing provides the most optimal outcome with an estimated construction cost/ha of $6,332 in a 250,000 sq m site. (Under review, Ecological Engineering).

Regarding the hydrodynamic, sediment transport, shoreline erosion, and terrace longevity aspects of this project, we present the results of an extensive field data collection effort to assess the spatiotemporal relationship between wind conditions, wave parameters, water level, soil shear strength, and suspended sediment concentration, in four marsh terrace sites in southwestern Louisiana. Data include time series of wind vectors collected with a sonic anemometer, wave spectra and water level collected with four acoustic Doppler profilers and a wave buoy, and over 250 discreet observations of soil shear strength collected with soil vane shear, penetrometer, and cohesive strength testing instruments. Results collected between November 2018 and February 2021 indicate that the periods of greatest wave erosion and sediment transport potential, based upon soil shear strength, occurred during the passage of strong cold fronts in the fall, winter, and spring. The highest winds, largest waves, and highest suspended sediment concentrations were associated with the passage of cold fronts, which occurred with a frequency of approximately 4–7 days. These results indicate that the optimal orientation for terraces, with regard to reducing wave fetch and mitigating resultant erosion, is perpendicular to the two prevailing wind directions associated with cold front passage, which are approximately 235°/55° and 270°/90°.

2. Outputs

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

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** denotes required fields*

2. OUTPUTS

Outputs are tangible or measurable deliverables, products, data, or publications produced during the project period.

2.1. Please indicate the number of students (K-12, undergraduate, or graduate), postdoctoral scholars, citizen scientists, or other trainees involved in the project. *

Please enter 0 if none were involved.

K-12 students	0
Undergraduate students	4
Graduate students	3
Postdoctoral scholars	1
Citizen Scientists	several (landowners)
Other Trainees	2

2.1a. Other Trainees *

Please describe who are the "other trainees" involved in your project.

Support staff overviewing thousands of UAV photos of marsh vegetation.

2.2. Has your project generated any data and/or information products? *

Generation of data includes transformations of existing data sets and generation of data from existing resources (e.g., maps and images). Information products include publications, models, software, code, curricula, and digital resources.

(Check all that apply.)

Responses Selected:

Data
Information Products

2.3. Briefly describe how you fulfilled the approved Data Management Plan and, if applicable, any changes from the approved plan. *

Before conducting any field work, the team met several times and used a rigorous process to ensure that we would accurately identify terrace, reference, and control sites to be used in this study. This provided the basis for all of our environmental (soils/erosion, waves/hydrology) and avian sampling objectives.

Because there were as many as 80-100 terrace projects in coastal Louisiana during our project planning phase, it was important for us to select study areas representative of the very different Chenier and Deltaic systems. Thus, we employed a stratified random sampling scheme for site selection. We ultimately selected 24 paired sites to represent the Chenier Plain and Mississippi Deltaic Plain regions of coastal Louisiana. Ducks Unlimited, Inc. developed a conservation planning database of existing terrace projects that we used to ensure broad spatial sampling across a gradient of terrace designs and marsh fragmentation. The database was reviewed to exclude sites that did not fit our functional definition of terrace field. For this project, terraces that were used at any time to help contain dredge material or had not undergone one full growing season were excluded from this study. In some cases, boundaries of terrace fields were redefined to ensure greater consistency with our definitions. However, it is important to note that terrace field boundaries are artificial and do not necessarily reflect the total intended impact area. Nonetheless, this rigorous sampling scheme helped us fulfill the intended objectives of this project.

Dr. Skarke was responsible for the following project data as described in the approved Data Management Plan: “physical sediment core samples, digital observations of wave and current hydrodynamics, digital observation of turbidity, and digital acoustic imagery of marine benthic habitats.”

All physical sediment samples were destroyed through standard laboratory analysis and therefore unavailable for preservation. All digital imagery of marine benthic habitats is optical in nature and contained in the UAS data archive produced by Mr. Hathcock and detailed in a separate portion of this report. In accordance with the Data Management Plan, all digital observations of wave and current hydrodynamics, and digital observation of turbidity for the project will be submitted to the Gulf of Mexico Research Initiative GRIIDC repository. A Unique Dataset Identifier (UDI): H3.x876.000:0001 has been created and will serve as a reference for these data in perpetuity.

Davis, McFarland (MS Student), Brasher, and Woodrey were responsible for the Waterfowl Aerial Survey and Secretive Marsh Bird data collection and both were successfully completed with no changes in the DMP.

Per our Objectives: "Waterfowl aerial survey data will incorporate rigorous and successful methodology largely based on Pearse et al. (2012). Surveys are flown using fixed-wing manned-aircraft. The number and species of waterfowl are recorded by habitat type on each survey line. Habitat type and a GPS location are also recorded when birds are counted. These surveys are the primary means whereby LDWF estimates waterfowl abundance relative to habitat types and other covariates. Some of this data will be corroborated using data from the UAS."

Aerial Waterfowl Surveys:

Nineteen aerial waterfowl surveys were conducted during autumn-winters of 2018-2019 and 2019-2020. Surveys generally spanned mid-October through mid-March each year. A total of 17 species and 36,903 total waterfowl were identified over the entire survey period in both terraced and control sites. We provide detailed results in Section 5.1 of this report.

Secretive Marsh Birds:

Of the >81 existing marsh terrace projects in south Louisiana, we scrutinized and used 17 sites (21%) that met our criteria for surveying SMBs. Over the two spring and summer field seasons, 2019 and 2021, we detected 12 species and 4,301 individuals of secretive marsh birds (SMB). We provide detailed results in Section 5.1 of this report.

Another objective of our work was assesing submerged aquatic vegetation (SAV) at our sites as a means to explain waterfowl and SMB abundances. These data and results are preliminary and will be published after completion of the McFarland thesis (anticipated May 2022). This was an important part of the project where we incorporated UAS survesy and compared them to rake surveys that we conducted in the marsh. In brief:

SAV surveys:

The purpose of this analysis was to 1) determine effects of marsh terracing on SAV abundance in southern Louisiana and 2) the usefulness of UAS collected RGB imagery compared to boat based methods for sampling SAV in terraced and non-terraced sites.

In the Delta region, we used paired terrace and non-terraced sites near Galliano, LA. We collected samples from the two sites in August 2019 and October 2020. We evaluated presence or absence of SAV for both rake and UAS imagery that we collected from 30 points in each site. We provide detailed results in Section 5.1 of this report.

If your project has generated data, please download the Excel worksheet entitled [GRP Data Management Reporting]. Use the "Data Report" tab in the worksheet to create an inventory of data sets that you produced and to verify deposit in a curation facility. Upon completion, please upload the worksheet to your task list. If you need guidance on how to complete the Data Report, please e-mail gulfgrants@nas.edu. A member of GRP's data management staff will reach out to you.

If your project has produced publications, websites or data portals, GIS applications, models or simulations, software packages or digital tools, code, curricula, or other interactive media, please download the Excel worksheet entitled GRP Information Management Reporting. Use the "Information Products Report" tab in the worksheet to create an inventory of these products and to verify deposit in a curation facility. Upon completion, please upload the worksheet to your task list. If you need guidance on how to complete the Information Products Report, please e-mail gulfgrants@nas.edu. A member of GRP's data management staff will reach out to you.

2.4. Aside from data and information products, what other tangible or measurable deliverables or products (e.g., workshops, trainings, and outreach events) were produced during the project period? *

Upon completion of this form, you may upload supplemental material that represent the tangible or measurable deliverables or products to complement this narrative report.

• In May 2021, project investigators (PIs and students) coordinated a special session at the State of the Coast conference to highlight recent progress in understanding the ecological and restoration benefits of constructed marsh terraces. Three of the 4 presentations in this session were delivered by the 3 students supported on this project.

3. Data Management

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

3. DATA MANAGEMENT

In this section, please provide a response to each question to complement the **Data Report** in the GRP Data Reporting Excel worksheet.

3.1 If you listed multiple data sets in the data reporting table, please briefly describe how these data sets relate to one another. *

The aerial NAS data (any mosaics or individually reprojected images) are at https://uas.hpc.msstate.edu/nasem.php.

3.2. Please provide a list of additional documentation to describe the data listed in the reporting table (e.g., code books, lab manuals, workflow procedures). Enter none if you did not produce any additional documentation to describe the data. *

None

3.3. Beyond depositing data and metadata in a repository, what other activities have you undertaken or will undertake to ensure that others (e.g., researchers, decision makers, and the public) can easily discover project data? What other activities have you undertaken to ensure that others can access and re-use these data in the future? *

As we continue to prepare publications, we will seek to utilize the public data distribution infrastructure of journal publishers to distribute datasets resulting from this project, as detailed in the data management plan.

3.4. Are any data products you produced sensitive, confidential, and/or proprietary? *

No

4. Information Products

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

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** denotes required fields*

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4. INFORMATION PRODUCTS

In this section, please provide a response to each question to complement the **Information Products Report** in the **GRP Information Products Management** Excel worksheet.

4.1. Please select the type(s) of information products that your project produced. *

Responses Selected:

1. Scholarly publications, reports or monographs, workshop summaries, or conference proceedings
5. Models or simulations

Scholarly publications, reports or monographs, workshop summaries, or conference proceedings *

Please provide a list of citations for project publication, reports and monographs, workshop summaries, and conference proceedings.

Dissertation:

Osorio, R.J.; Assessment and Optimization of Marsh Terracing for Wetland Restoration in the northern Gulf of Mexico using Remote Sensing and a Wave Model Approach. Dissertation, Mississippi State University, 2021

MS Theses:

McFarland, M. B. 2022. An evaluation of avian use of marsh terraces in Gulf Coastal wetlands of Louisiana. Thesis, Mississippi State University (In progress, May 2022).

French, J. E. 2020. Optimization of marsh terracing as a wetland restoration technique: Mitigation of cohesive sediment erosion by waves associated with frontal passage. Thesis, Mississippi State University.

Publications:

• Osorio, R. J., Linhoss, A., Skarke A., French, J., Brasher M & Baghbani, R. (2022). Modeling Wave Climates and Wave Energy Attenuation in Marsh Terrace Environments in the Northern Gulf of Mexico; Ecological Engineering, 176, 106529. https://doi.org/10.1016/j.ecoleng.2021.106529

• Osorio, R. J., Linhoss, A., & Dash, P. (2020). Evaluation of Marsh Terraces for Wetland Restoration: A Remote Sensing Approach. Water, 12(2), 336. https://doi.org/10.3390/w12020336

Manuscript submitted:

• Osorio, R. J., Linhoss, A., Skarke A., Brasher M (2022). Assessment of Marsh Terrace Designs for Wave Reduction Utilizing a Wave Model; Mississippi State University (Under Review, Ecological Engineering).

Manuscripts planned for submission:

French, J., A. Skarke, A Linhoss, R. Osario, M. Brasher (In Preparation), Optimization of marsh terracing as a wetland restoration technique: Prescribing terrace design to reduce sediment erosion by wind driven waves associated with passage of cold front storms, Planned submission to Wetlands.

Students:

• PhD student: Raul J. Osorio, PhD

• Postdoctoral scholar : Mohamedmehdi Armandei, PhD

Scientific and Conference Presentations:

Raul J. Osorio, Anna Linhoss, Adam Skarke, Michael Brasher (2021). Assessment of marsh climates and marsh terrace designs for wave reduction in coastal Louisiana. In: Young Coastal Scientists and Engineers Conference (YCSEC); October 2018; Myrtle beach, SC.

Raul J. Osorio, Anna Linhoss, Adam Skarke, Padmanava Dash, Michael Brasher (2021). Marsh Terraces Assessment Using a Remote Sensing Approach and a Wave Model. In: Proceedings of the State of the Coast Conference (SOC); June 2021; Virtual event.

French, J. E., A. Skarke, and M. Brasher (2020), Effect of tropical storm and frontal passage on marsh erosion in terraced coastal wetlands. Abstract CP24D-1166 presented at 2020 Ocean Sciences Meeting, San Diego, CA., 16-21 Feb.

French, J. E., Skarke, A. D., Linhoss, A., Brasher, M., & Osorio, R. (2020, December). The optimization of marsh terracing as a wetland restoration technique: Mitigating cohesive sediment erosion from wind driven waves. In AGU Fall Meeting Abstracts (Vol. 2020, pp. B052-0013).

Raul J. Osorio, Anna Linhoss, Adam Skarke, Michael Brasher, Joseph French (2020). Assessment of wave regimes for optimal implementation of marsh terracing in the northern Gulf of Mexico, a modeling approach. In: Proceedings of the 2020 Bays and Bayous Symposium; December 2020; Virtual event.

Raul J. Osorio, Anna Linhoss, Mehdi Armandei, Adam Skarke, Michael Brasher, Joseph French, Madelyn McFarland, Brian Davis (2020). Evaluation of Marsh Terraces as a Restoration Technique Utilizing a Wave Model. In: Proceedings of the Gulf of Mexico Oil Spill & Ecosystem Science Conference (GoMOSES); February 2020; Tampa, FL.

Skarke, A., M. Brasher, B. Davis, A. Linhoss, R. Moorhead, M. Woodrey, M. Armandei, J. French*, M. McFarland, R. Osorio, F. Vizcarra (2019), Optimizing Marsh Terrace Design for Wetland Restoration and Avian Habitat Associations. 25th Biennial Coastal and Estuarine Research Federation Conference, Mobile, AL, November 3-7.

French, J., A. Skarke, R. Osorio, A. Linhoss, M. Brasher (2019), Assessing the Efficacy of Marsh Terracing for Coastal Wetland Restoration in Louisiana. 25th Biennial Coastal and Estuarine Research Federation Conference, Mobile, AL, November 3-7.

Raul J. Osorio, Anna Linhoss, Padmanava Dash (2019). Assessment of Marsh Terraces Performance in Coastal Louisiana U.S. using Multi-temporal High-Resolution Imagery. In: Proceedings of the Mississippi Water Resources Conference (MWRC); April 2019; Jackson, MS.

Raul J. Osorio, Anna Linhoss (2018). Assessment of Marsh Terraces Variability in Coastal Louisiana U.S. using Multi-temporal High-Resolution Imagery. In: Young Coastal Scientists and Engineers Conference (YCSEC); November 2018; Merida, Mexico.

Davis, J. B., M. Woodrey, A. Linhoss, R. Moorhead, M. Brasher, A. Skarke, A. Mohamedmehdi, and M. McFarland. The efficacy of marsh terraces for enhancing and restoring Gulf coastal wetlands. Davis Invited speaker for a seminar series, Clemson University campus, January 24, 2019.

Davis, J. B., M. Woodrey, A. Linhoss, R. Moorhead, M. Brasher, A. Skarke, A. Mohamedmehdi, and M. McFarland. The efficacy of marsh terraces for enhancing and restoring Gulf coastal wetlands. Davis Invited speaker, Baruch Institute of Coastal Ecology and Forest Science, Georgetown, South Carolina, January 25, 2019.

McFarland, M. M. Armandei, M. Brasher, J. B. Davis, J. French, A. Linhoss, H. Masood, R. Moorhead, R. O. Morillo, A. Skarke, and M. Woodrey. Efficacy of marsh terraces for enhancing and restoring Gulf Coast wetlands. Invited oral presentation for a special session: 21st Century Waterfowl, Waterbird, and Wetland Science and Conservation in Southeastern United States, 73rd Southeastern Association of Fish & Wildlife Agencies (SEAFWA) Annual Conference, Hilton Head, South Carolina, October 27 - 30, 2019.

Skarke, A. M. Brasher, B. Davis, A. Linhoss, R. Moorhead, M. Woodrey, M. Armandei, J. French, M. McFarland, R. Osorio Morillo, F. Vizcarra. Optimizing Marsh Terrace Design for Wetland Restoration and Avian Habitat Associations. Presentation at the 25th Biennial Conference of the Coastal and Estuarine Research Federation (CERF) conference, Mobile, AL, November 3-7, 2019

McFarland, M (MS student of J. B. Davis). The efficacy of marsh terraces for enhancing and restoring Gulf coastal wetlands. Mock Three Minute Thesis research competition presentation in WFA's QuEST lab (Oct. 16, 2019) among students and faculty to prepare for the larger MSU sanctioned event in Fowlkes Auditorium, November 14-15, 2019.

McFarland, M. (Presenter), Davis, J. B. (Author), Brasher, M. G. (Author), Woodrey, M. (Author), Reynolds, L. (Author), Vizcarra, F. (Author), (December 2, 2020). "Avian Use of Marsh Terraces in Gulf Coastal Wetlands." Oral Presentation. 2020 Bays and Bayous Symposium, Mississippi-Alabama Sea Grant Consortium, Virtual (Coronavirus). Scope: Regional. Refereed: Yes. Invited or accepted: Accepted

McFarland, M. (Author & Presenter), Davis, J. B. (Author), Woodrey, M. (Author), Reynolds, L. (Author), Brasher, M. G. (Author), Vizcarra, F. (Author), (October 27, 2020). "Avian Use of Marsh Terraces in Gulf Coastal Wetlands." Oral Presentation. Southeastern Association of the Fish and Wildlife Agencies 74th meeting, Southeastern Association of the Fish and Wildlife Agencies, Missouri (but virtual; Coronavirus). Scope: Regional. Refereed: Yes. Invited or accepted: Accepted

McFarland, M. (Author & Presenter), Davis, J. B. (Author), Brasher, M. G. (Author), Woodrey, M. (Author), Reynolds, L. (Author), Vizcarra, F. (Author), (August 12, 2020). "•An Evaluation of Avian Use of Marsh Terraces in Gulf Coastal Wetlands." Oral Presentation. North American Ornithological Conference, American Ornithological Society, Puerto Rico (but virtual; Coronavirus). Scope: International. Refereed: Yes. Invited or accepted: Accepted.

McFarland, M. (Author & Presenter), Davis, J. B. (Author), Brasher, M. G. (Author), Reynolds, L. (Author), Vizcarra, F. (Author), (February 20, 2020). "Avian Use of Marsh Terraces in Gulf Coastal Wetlands." Oral Presentation. Mississippi Academy of Sciences 84th Annual Meeting, Mississippi Academy of Sciences, Biloxi, MS. Scope: State. Refereed: Yes. Invited or accepted: Invited

McFarland, M., Davis, J. B., Woodrey, M., Reynolds, L., Brasher, M. G., Vizcarra, F. Avian Use of Marsh Terraces in Gulf Coastal Wetlands of Louisiana. Oral Presentation. 75th Annual Meeting of the Southeastern Association of Fish and Wildlife Agencies, Roanoke, VA. In-person. Regional.

McFarland, M., Davis, J. B., Woodrey, M., Reynolds, L., Brasher, M. G., and Vizcarra, F. (). Avian Use of Marsh Terraces in Gulf Coastal Wetlands. Oral Presentation (but virtual), Society of Wetland Scientists, Washington state, June 8, 2021. National.

McFarland, M., Davis, J. B., Woodrey, M., Reynolds, L., Brasher, M., and Vizcarra, F. 2021. An Evaluation of Avian Use of Marsh Terraces In Gulf Coastal Wetlands. Oral presentation (but virtual), State of The Coast, The Coalition to Restore Coastal Louisiana and its partners, New Orleans, LA, June 2, 2021. International.

R. Moorhead, “Remote Sensing and Other High Technologies for Assessing Cumulative Restoration Responses,” Panel Session: The Next Wave: Future Trends in Environmental Data Collection, Synthesis, and Analysis Panel, Bays and Bayous, Mobile, AL, November 28-29, 2018. (https://bbs.baysandbayous.com/en/) (invited)

R. Moorhead, “Remote Sensing and Other High Technologies For Assessing Cumulative Restoration Responses,” Panel Session: Measuring Success Of Multiple Gulf Coast Restoration Programs: Accountability For Long-Term Success, National Conference on Ecosystem Restoration, New Orleans, LA, August 26-30, 2018. (invited)

R. Moorhead, “Habitat Analysis And Marsh Reconstruction Monitoring Using A UAS,” SouthEastern Division of the Association of American Geographers, 72nd Annual Meeting, Starkville, MS, Nov. 19-20, 2017. (invited)

Poster Presentations:

McFarland, M., M. Armandei, M. Brasher, J. B. Davis, J. French, A. Linhoss, R. Moorhead, R. Morillo, A. Skarke, F. Vizcarra, and M. Woodrey. Poster presentation, 8th North American Duck Symposium, Winnipeg, MB, Canada, August 26-30, 2019.

McFarland, M. (Author & Presenter), Davis, J. B. (Author), Woodrey, M. (Author), Reynolds, L. (Author), Brasher, M. G. (Author), Vizcarra, F. (Author), (September 29, 2020). "Avian Use of Marsh Terraces in Gulf Coastal Wetlands." Poster. The 27th Annual Conference of The Wildlife Society, The Wildlife Society, Louisville, Kentucky (but virtual; Coronavirus).

OTHER - REPORTS

Ducks Unlimited, Inc. (2020).
Our research project, The Efficacy of Marsh Terraces for Restoring and Enhancing Gulf Coastal Wetlands, described in this comprehensive international report in 2020. Davis' MS student, Madie McFarland mentioned in the report.

The Wildlife Society, Southeastern Section. (January 2020).
Our marsh terracing research project in coastal Louisiana featured in the newsletter (January 2020 Volume 62, number 1). Madie McFarland is Davis' MS student working on the project.

Ducks Unlimited International Science Report: Highlights of Ducks Unlimited Science in
FY2021. McFarland, M., French, J., Osario, R., Davis, J. B., Skarke, A., Linhoss, A., Brasher, M. (2021). The Efficacy Of Marsh Terraces For Restoring And Enhancing Gulf Coastal Wetlands (vol. FY2021). Ducks Unlimited International Science Report FY2021.

McFarland, M. 2021. In K. Edwards (Ed.), Evaluating the efficacy of marsh terraces for restoring and enhancing Gulf Coastal wetlands in Louisiana. The Wildlife Society, Southeastern Section. 3rd ed., vol. 63, pp. 6-7.

Tweet, through MSU's Faculty Senate: McFarland, M. Evaluation of Marsh Terraces as a Gulf Coastal Wetlands Restoration Technique. Faculty Senate of MSU weekly Tweet from Graduate student Madie McFarland.

Student Spotlight, The Graduate School, Mississippi State University, University, (August 2021).
Madie McFarland, was featured in Mississippi State's, The Graduate School Newsletter, Issue 11, August 2021

Curricula for education and training, GIS applications, Models or simulations, Software packages or digital tools, or other interactive media, and Other *

If you produced any additional documentation to describe information products, please provide a list of this documentation (e.g., model or simulation documentation, software manuals, source code annotation).

N/A

4.2. Beyond depositing information products in a repository, what other activities have you undertaken or will undertake to ensure that others (e.g., researchers, decision makers, and the public) can easily discover and access the listed information products? *

Some blog posts were created for this project:

See: Blog | GRI (msstate.edu)

Unfortunately, we do not have a link to each one. we posted one August 31, 2021 and April 22, 2016 (this one was describing terraces before we won the award).

4.3. Are any of the information products you produced confidential, proprietary, or subject to special license agreements? *

No

5. Project Outcomes

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

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5. PROJECT OUTCOMES

Outcomes refer to the **impact(s), consequence(s), result(s), or effect(s)** that occur from carrying out the activities or outputs of the project. Outcomes may be environmental, behavioral, health-related, or programmatic. Example outcomes include, but are not limited to: increased learning, knowledge, skills, and motivation; policy changes; actions taken by a group as a result of information generated by your project.

5.1. Please describe the outcomes achieved during your project and how they were assessed. For this question, we are interested in learning about the immediate short-term outcomes that have already occurred during or as a result of your project. Do not include long-term outcomes you foresee your work contributing to beyond the end of the project. *

This study was unique in several aspects because we designed it to evaluate potential benefits of terraces (the experimental aspect) while also considering control and refernce sites. We adopted this framework across the avian monitoring and the sediment, wave, and hydrology monitoring aspects of this project. This is perhaps the greatest advance or strength that differentiated our work from previous studies.

Remote Sensing Aspect of the Research (after Morillo 2021, Dissertation):

We assessed marsh terrace performance of 20 terrace fields in coastal Louisiana using a remote sensing approach. We measured change in marsh terrace areas over time using NAIP imagery from 2003 until 2017 from five Louisiana coastal parishes. Marsh terrace performance over time showed more predominant deposition than erosion in the 20 terrace fields of study, even in the face of subsidence and sea level rise. Their longevity within a 10–14-year time period effectively achieved one of the terrace restoration goals, which was marsh creation.

We found a relationship between geomorphological area, sediment supply, and adjacent or connecting channels with terrace fields. High density of channels surrounding or adjacent to the terrace fields, and external source of sediment loading are likely important drivers encouraging terrace deposition. However, further analysis is necessary to understand the reasons for differences in terrace functional performance. In the future, these results will be related to environmental factors (sediment type, sediment load, soil strength, salinity, terrace location in relation to wave energy, etc.) and other drivers (wind and wave energy) that might have important influence on the success of this restoration technique. This will help restoration planners select optimal sites and designs for marsh terrace implementation (further discussed in Section 5.2).

Use and Efficacy of a Simulating Waves Nearshore (SWAN) Model to better understand the effect of terraces on wave climate in marsh terrace environment.

The SWAN is a numerical third–generation phase–averaged model, based on the spectrum concept that solves the energy balanced equation to simulate wave conditions in coastal and inland shallow water environments. We used a numerical wave model to understand wave dynamics in two marsh terrace fields during frequent wind conditions in coastal Louisiana. Results from this study demonstrate SWAN's ability to simulate measured waves in marsh terrace fields, compare wave climates in terraced and unterraced fields, and identify the role of marsh terraces at reducing significant wave height. The results also demonstrate the ability of marsh terraces to reduce wind driven waves. Results from the comparison of wave climates in terraced and unterraced fields showed that Hs was reduced by up to 84% in all the terraced scenarios proving the efficacy of this restoration technique.

Overall, the SWAN model simulated wave conditions in marsh terrace fields even in the complex conditions of sheltered environments. The measured and modeled small (0.03–0.14 m) and high–frequency (0.80–1.29 s) waves found in this study are characteristic of other studies in low energy environments. Wave direction ranged between 42–152º in accordance with the most frequent wind directions during the deployment periods.

Model validation indicated that the simulated and observed data at both terrace fields of study were similar, particularly for significant wave height (RMSE: 0.01–0.02 m; R: 0.97 for R2, 0.79 for C2 and 0.42 for C1) and wave direction (RMSE: 8.29–26.03º; R: 0.76 for R2, 0.73 for C2, and 0.59 for C1,), demonstrating that SWAN was appropriate for use in marsh terrace systems. We beileve the accuracy of the simulations was likely affected by model limitations and the instruments' ability to measure small waves in complex systems. Also, model error statistics were very sensitive to change, possibly because of the nature of the narrow range of data measured in the marsh terrace fields.

To improve the accuracy of the simulations, future studies may require the use of a phased decoupled refraction–diffraction approximation, particularly in the shadow zone of the terraces and around their tips. Future studies should also conduct model validation utilizing wind conditions (cold front passages, hurricanes) that are more likely to result in erosive waves based on previous studies. It is important to note that the most frequent wind conditions are not always necessarily the wind conditions that result in marsh erosion. Therefore, utilizing higherwind conditions and greater Hs values as an input in SWAN could potentially strength and improve model validation results.

To our knowledge, this is the first study evaluating real wind wave climates in terrace fields using a numerical wave model such as SWAN. Results indicate that 1) SWAN is appropriate for use in these low energy and geometrically complex marsh terrace systems and 2) marsh terraces are effective at reducing wave energy. Future studies assessing a variety of terrace configurations including different spacing, shape and orientation relative to wave height reduction, are recommended to optimize the use of this restoration technique. Also, more research assessing terrace designs relative to erosional forces are encouraged to determine the effectiveness of terraces at reducing marsh erosion in coastal Louisiana

Overall, the outcomes of Morillo (2021) and associated work are very important given the lack of previous research on the performance of multiple terrace projects over time using remote sensing and numerical modeling. To our knowledge, this is the first study evaluating real wind wave climates in terrace fields, assessing significant wave height reduction by terraces, and evaluating different terrace design factors such as shape and spacing during a variety of wind conditions.

Skarke, French (MS student) and Team-Erosion/Sediment Transport

Regarding the hydrodynamic, sediment transport, shoreline erosion, and terrace longevity aspects of this project, we used field observations to evaluate the capacity of marsh terraces to reduce the erosive potential of wind driven waves relative to the mechanical strength of soils composing the adjacent marsh platform as well as the terraces themselves. Wave conditions were measured with four acoustic Doppler current profiler (ADCP) instruments deployed at four marsh terrace sites across coastal Louisiana for approximately four months each. These instruments recorded spectral wave height, wave period, wave direction, water level, and water temperature with a sampling frequency of one hour. During these deployments, a proximal sonic anemometer was also deployed on a three-meter mast in the center of each site. The anemometer measured wind direction and velocity with a sampling frequency of one minute. A series of representative submarine sediment samples were collected from numerous terrace and marsh platform locations at each site. The resulting ADCP data were processed to determine the bed shear stress force imparted on the marsh platform and marsh terraces by observed wave conditions. Additionally, the sediment samples were analyzed in a laboratory to determine their shear strength (critical threshold for erosion) and therefore their mechanical resistance to the bed shear stress imparted by wave conditions. Finally, the anemometer data and coincident NOAA National Weather Service observations were used to establish the meteorological conditions (particularly wind directions and velocities) temporally coincident with wave conditions capable of eroding the marsh platform or terraces at each study site. Collectively these results indicate the environmental conditions responsible for a majority of erosive wetland loss in the study areas and suggests terrace design parameters that are most important in mitigating the effects of such conditions.

Results collected between November 2018 and February 2021, which captured the passage of multiple frontal storms as well as Hurricane Barry, indicate that the primary driver of marsh erosion at the study sites is high-energy wind-driven wave events resulting from tropical storms and fronts. Whereas tropical storms winds were observed to have a greater magnitude and duration, frontal winds events were more frequent and exhibited more consistent wind fields. Results suggest that wave energy and sediment erosion resulting from tropical storm passage is roughly equivalent in magnitude to that resulting from frontal passage and that marsh terracing can be an effective means of mitigating wave erosion, depending upon the orientation of constructed terraces relative to the direction of prevailing winds resulting from storm events. Results show that the mean threshold for erosion for marsh platform and terraces (0.194 N/m2 and 0.500 N/m2) were often exceeded during the passage of cold front storms. Therefore, these were the periods of greatest wave erosion and sediment transport potential, based upon soil shear strength, occurred during the passage of strong cold fronts in the fall, winter, and spring. These results indicate that the optimal orientation for terraces, with regard to reducing wave fetch and mitigating resultant erosion, is perpendicular to the two prevailing wind directions associated with cold front passage (Approximately 235°/55° and 270°/90°).

Davis, McFarland (MS student), Brasher, Woodrey--Waterfowl Surveys, Secretive Marsh Bird (SMB)

Aerial Waterfowl Surveys:

We conducted 19 aerial waterfowl surveys during autumn-winters 2018-2019 and 2019-2020. Surveys generally spanned mid-October through mid-March each year. A total of 17 species and 36,903 total waterfowl were identified over the entire survey period in both terraced and control sites. Because geese nor swans were detected, our results only concern ducks.

We counted 9 species and 20,933 (+741.0 SD) dabbling ducks and 8 species and 15,970 (+759.3 SD) of diving ducks pooled across years and terraced and control sites. There were an estimated 131% more dabbling ducks in terraced than control sites (14,606 versus 6,327 dabbling ducks, respectively). For diving ducks, there was an estimated 273% more in terraced versus control sites (12,590 versus 3,380 diving ducks, respectively). We detected more than twice as many ducks (n = 26,813) in the 2018-2019 survey season than the 2019-2020 season (n = 10,090). Mean duck counts pooled across all sites and sample periods was 485.6 + 748.08 with a range of 0–3,908 individuals.

We used GLM with data fitted to a negative binomial distribution and it best explained the relationship between our response and explanatory variables. We detected a marginal difference ($P = 0.056$) in duck counts between treatments, i.e., terraced or control sites. We counted a total of 27,196 (+ 418.03; 73.7%) ducks and 9,707 (+ 91.25; 26.3%) ducks in terraced and control sites, respectively. We found no evidence that duck abundance differed between terrace control sites between years ($P = 0.578$). We did find, however, that duck counts differed between terrace and control sites among months ($P = 0.006$). However, we need to emphasize that some sites (e.g., paired sites 3 and 10) and dates accounted for a substantially greater abundance of ducks than the other sample sites and dates. Duck counts were positively associated with wetland size ($P < 0.001$, rho = 0.188), where larger sites contained a greater number of birds. Duck abundance was not correlated with distance to nearest sanctuary ($P = 0.263$). All paired sites were equally likely to contain the same abundances of waterfowl regardless of distance to nearest state, refuge, or conservation agency-owned land.

Duck counts varied spatially and temporally over both seasons regardless of treatment. Perhaps the gretatest revelation of the aerial survey results is the strong contrast in numbers of ducks between regions. The Chenier region accounted for most ($P < 0.001$) of the ducks (90.7%) compared to the Deltaic region (9.3%). We successfully classified surveyed wetlands relative to salinities and of the 21 paired sites, 16 were brackish, 4 were intermediate, and 1 was saline (Table 2.3). Because of only having one site considered saline, we removed it from further analysis. Duck counts were influenced by wetland type ($P < 0.0001$). We pooled duck abundances across treatments and examined the influence of wetland type. Brackish wetlands contained 88% (3.983 + 0.149) of the ducks compared to intermediate wetlands (12%, 3.318 + 0.299; P = 0.046). We counted a total of 54 ducks in the saline wetland. Upon examining waterfowl abundance in marsh terrace sites and control sites, we did not find a regional (P = 0.059) nor wetland type effect (P = 0.788).

Relative to our original hypothesis, presence or absence of marsh terraces was an influence on ducks detected on aerial surveys. Nearly three-quarters of all ducks spied on aerial surveys were amid terraced wetland sites. These results coincide with other assessments of avian abundance and density in marsh terraced sites of coastal Louisiana.

As expected, most ducks were detected in intermediate and brackish wetlands versus those wetlands having greater salinities. Ducks were more abundant in Chenier versus Deltaic regions. Both of these effects of wetland classification and geographic area occurred regardless of a site being terraced or not. Lastly, distance to nearest sanctuary did not influence waterfowl presence or abundance in paired sites. However, my analysis revealed a correlation between site area and duck abundance.

Future studies should assess avian use of wintering waterfowl in marsh terraces, addressing site-specific factors associated with habitat complexity, resource availability, and disturbance. My study emphasizes the need for future analyses to consider site specific characteristics and interactions between local and landscape level effects.

Secretive Marsh Bird (SMB) surveys:

We monitored SMBs in 17 sites (21%) that met our criteria for surveying SMBs. Over the two spring and summer field seasons, 2019 and 2021, we detected 12 species and 4,301 individuals of SMBs. On average, we detected more individuals in reference sites (n = 58.73+22.87) than in marsh terrace sites (n = 30.86+12.72) across both sampling seasons. We detected more individuals in spring-summer 2019 (n = 2,311) than in the spring-summer 2021 (n = 1,990). We detected all 12 species in both marsh terrace and reference sites, except for American Coot (Fulica americana), which was only detected in reference sites.

We continnue to conduct rigorous analyses of the SMB data at the time of this reporting. We are using an N-Mixture model containing the p-count function from the unmarked package in Program R (V 4.1.1) to estimate an index of species abundances between marsh terrace and reference sites. This analysis has taken more time tha noriginally anticipated and our goals is to have the full set of analyses and outputs by April 2022.

Monitoring Submerged Aquatic Vegetation (SAV) Abundance:

This aspect of the project was beneficial to the entire team. SAV is an important component of marsh ecology and may influence numerous variables including avian and other species (e.g., crabs, shrimp, fish) use and abundance, slowing water velocity, and helping slow or thwart soil erosion. We successfully monitored SAV in the Delta (Galliano, LA) and Chenier regions. However, we had to be extremely adaptive because major hurricanes literally annihilated parts of our study areas, and the storms also forced us to collect SAV beyond our originally planned temporal sampling periods. Nonetheless, results of the SAV surveys follow:

SAV Project Objective: The purpose of this aspect of the project was to 1) determine effects of marsh terracing on SAV abundance in southern Louisiana and 2) the usefulness of UAS collected RGB imagery compared to boat based methods for sampling SAV in terraced and non-terraced sites.

Galliano Methods: Paired terrace and non-terraced sites near Galliano, LA were sampled via boat based rake sampling and UAS collected imagery in August of 2019 and again in October of 2020. Presence or absence of SAV on rake or UAS collected data was recorded at 30 points in each site.

We used a Cochran-Mantel-Haenszel (CMH) test to determine 1) if SAV percent frequency differed among site pairs at each sampling event or 2) if SAV percent frequency differed within terrace types (terraced vs. non-terraced) over time. If differences were detected, a Fishers Exact test was used to further separate treatment means. We used a Spearman’s test to determine if UAS collected and Rake collected data were correlated for each CMH analysis; correlation strength was defined as 0 to 0.1 = no correlation, 0.1 to 0.4 = weak correlation, 0.4 to 0.6 = moderate correlation, 0.6 to 0.9 = strong correlation, and 0.9 to 1.0 = perfect correlation (Dancy and Reidy 2004). All tests were conducted at the alpha=0.05 significance level in the statistical package R (R Core Team 2022).

Chenier Methods (SW Louisiana): Paired terrace and non-terraced sites across southwestern Louisiana were sampled via boat based rake sampling and UAS collected imagery in August of 2019, again in August of 2021, and a third time in October of 2021. Data collection and statistical analysis was the same as that used for data collected near Galliano, LA.

Galliano Results (SE Louisiana, Delta): There was no difference in SAV percent frequency between site pairs in 2019 (UAS $p=0.3695$; Rake $p=0.4795$) or 2020 (UAS $p=0.0941$; Rake $p=0.4433$; Table 1); in other words, terracing did not appear to affect SAV presence at either sample date. SAV presence increased in some terraced (UAS $p=0.0003$; Rake $p<0.0001$) and non-terraced sites (UAS $p=0.0004$; Rake $p=0.0006$) over time (Table 2). UAS and rake datasets had a strong positive correlation for each CMH analysis ($p<0.0001$ for each).

Chenier Results: An increase in SAV presence between terraced and non-terraced sites was detected by rake sampling ($p=0.0377$) but not by UAS imagery in 2019 ($p=0.5063$) but SAV presence between terraced and non-terraced sites did not differ in August or October of 2021. Neither UAS imagery ($p=0.6245$) or rake sampling (p=0.2455) detected a difference in SAV abundance of terraced sites between 2019 and August 2021. However, SAV presence declined in non-terraced sites over the same time frame (UAS p=0.0009; Rake p=0.0129). No difference in SAV abundance was detected in terraced or non-terraced sites between 2019 and October 2021. UAS and rake datasets had a perfect positive correlation for each CMH analysis (p<0.0001 for each).

Discussion: Rake and UAS datasets did not always align regarding which sites had altered SAV presence which is likely due to the small sample area of the plant rake (<1 m2) compared to the UAS image (>100 m2) or the ability of the rake to collect benthic SAV that is undetectable in UAS imagery due to water turbidity (i.e., SAV that has not reached the water surface). However, UAS and rake datasets had strong or perfect positive correlations, likely due to minimal or no SAV presence in sampled sites at any time.

General Conclusions: There was minimal evidence suggesting SAV presence was influenced by the presence or absence of marsh terraces or sampling year in coastal Louisiana. Additionally, results varied regarding the agreement of UAS and rake based methods for determining SAV abundance within individual sites suggesting that UAS surveys with RGB imagery may not be suitable for detection of SAV. However, turbidity, plant growth stage (topped out vs. benthic), plant abundance, and spatial scale of sampling methods (>100 m2 vs. ~1 m2) may have led to confounding results within individual sites as there was strong or perfect correlation between UAS and rake datasets across sites.

5.2. We're interested in hearing not just the results of your project but what are their implications for or contributions to:

- **offshore energy system safety,**
- **environmental protection and stewardship, and/or**
- **health and community resilience**

Please describe what you consider to be the most remarkable accomplishment or finding of your project. What can others learn from your accomplishment and finding? How do you see it fitting in with your greater field of study or community of practice? *

This study incorporated the Simulating Waves Nearshore (SWAN) to better understand the effect of terraces on wave climate in marsh terrace environment. SWAN is a numerical third–generation phase–averaged model based on the spectrum concept that solves the energy balanced equation to simulate wave conditions in coastal and inland shallow water environments.

According to previous studies, the rate of subsidence and sea level rise in a 14-year period could reach 70-140 mm and 168 ± 8 mm, respectively. We found that marsh terraces effectively achieved marsh creation within a 14-year span, achieving one of the primary goals for the implementation of this restoration technique. We also found that the high density of channels surrounding or adjacent to the terrace fields of study were potential drivers encouraging terrace deposition by potentially supplying sediment loading.

We believe our results have important recommendations for engineers and restoration agencies charged with constructing marsh terraces: 1) Terracing projects should be built in ponds surrounding or connected to channels to increase sediment supply entering the sites. We conclude that a high density of channels surrounding or adjacent to the terrace fields, and an external source of sediment loading are likely important drivers encouraging terrace deposition. Moreover, river diversion projects along with marsh terraces might promote marsh deposition in the terrace sites; 2) Terraces should be built perpendicular to the most frequent and strong winds which are also responsible for producing the most erosive waves in the area; and 3) Based on Hs reduction and construction costs, the most optimal terrace shape is the chevron terrace shape oriented perpendicular to the most frequent wind direction occurring in the area. Chevron designs generally have less gaps between terraces compared to linear and square shapes. Therefore, chevron designs produce more elongated and wider shadow zones with lower Hs compared to linear and square shapes. However, the square shape might also be optimal at reducing Hs in areas where winds are coming from different directions, interrupting fetch from four different sides.

Although terraces are typically enjoyed by hunters and fishers because of the potential benefits of marsh creation to various species of wildlife and fish, terraces may become an integral measure to combat sea level rise and protect local Gulf coastal communities. We hope our results help restoration agencies implement terrace designs more effectively to address wetland erosion in the Gulf of Mexico, and perhaps elsewhere in the U.S. facing similar environmental problems.

Regarding the hydrodynamic, sediment transport, shoreline erosion, and terrace longevity aspects of this project, we foresee a number of implications for environmental protection and stewardship. Specifically, this work prescribes design approaches that will optimize the effectiveness of marsh terraces for preventing wetland erosion. A review of existing marsh terrace projects suggest that the orientation of many terraces is suboptimal. Accordingly, future efforts to design marsh terrace projects should consider the orientation of cold front associated winds and the prescribed orientation for marsh terraces determined in this project. Future efforts to design marsh terrace projects in other regions should consider the source of winds that result in the most erosive waves for that region and develop terrace orientations that most effectively interrupt fetch in the direction of those winds.

6. Communication

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

Note to Grantees: In Section 6, we seek input from you to help us evaluate the Gulf Research Program’s funding strategy. <u>This section will not be made available to the public.</u>

6. Information to Inform GRP Evaluations

6.1. Sharing the difficulties you encountered helps us learn from your experience. Describe any challenges you encountered in your project and how you addressed or overcame them. Challenges are inherent to conducting any complex project. These may include (but are not limited to): unexpected staffing changes, changes in the community you are working in, appearance of a new technology or dataset in the field you are working in, challenges accessing a field site, policy or regulatory changes that affect the issue you are addressing, low recruitment rates, delays in setting up services, or other problems in implementing and conducting your project. *

We had two primary challenges during this study: 1) A global pandemic, and 2) 2 massive hurricanes that made landfall in the Chenier of SW Louisiana, one of our prime study areas, in fall 2020. The pandemic just temporarily slowed us, as we had to abandon field work in 2020. However, we completed our tasks in spring-summer 2021.

The hurricanes were a different challenge. Although these storms provided us with "natural experiment" type of scenario, it completely challenged the submerged aquatic vegetation (SAV) sampling. Basically, SAV was few and far bewteen after the storms in 2021. We do report on some of those data herein but we did not collect the samples or estimate abundance as initially anticipated.

6.2. We like to hear about what you learned from your work and how you feel it affects future work or the work of others. Think back on your project strategies, methods, and activities, what worked and what did not? Is there anything you would do differently in the future? If so, tell us what and why. *

Results and experiences form this interdisciplinary study provided much needed information on how to maximize the contribution of marsh terraces towards achieving multiple objectives, including the identification of situations and landscape contexts in which marsh terracing likely is not the most effective restoration technique to employ. For example, the effectiveness of marsh terracing at encouraging marsh accretion and expansion is highly dependent on the environmental conditions in the surround marsh landscape, notably the availability of a reliable sediment supply into the location where marsh terraces would be constructed. We consider this to be one of the more profound findings, such that it in those situations where sediment sources are lacking, coastal restoration specialists will be encouraged to either couple the introduction of sediment supply with a terracing project or else seek an alternative technique to achieve marsh restoration. In fact, the integration of marsh terracing and freshwater/sediment diversions along the mainstem of the Mississippi River is already occurring, partly in recognition of the findings from this and other research.

We also found that parametrizing benthic habitat including the presence or absence of submerged aquatic vegetation was highly challenging in marsh environments. Ultimately, we concluded that unmanned aerial vehicle (UAV) surveys paired with in situ ground truth sampling is more effective than acoustic surveys in these environments. We developed effective protocols for UAS sampling in marsh settings and think this methodology has great potential for investigation and monitoring of marsh conditions.

With regard to study design and implementation, the success of our study would not have been possible without the close cooperation of state, federal, NGO, and private partners, and we believe the engagement of this diverse group will continue to pay dividends as study findings are summarized and disseminated to the coastal restoration community. Largely through the capable work of our graduate students, we maintained great relationships with each of our collaborating landowners and agencies, and we expect this sense of joint ownership of the project to also translate into joint ownership and implementation of the findings.

6.3. What are the next steps for this work, either for you and your project team or other researchers? Has this project led to other opportunities to work in this area? *

Future studies should use remote sensing to quantify shoreline erosion, terrace longevity and its variability in marsh environments. Such results could then be related with design and environmental factors to identify the primary factors that influence terrace longevity and shoreline erosion. More work is needed on model validation using wind conditions from cold front passages and hurricanes. Storm conditions are more likely to result in erosive waves, thus using higher wind conditions and greater Hs values as an input in SWAN could potentially strength and improve model validation results.

Finally, future research should also develop a hydrodynamic model focused on sediment transport and flow dynamics assessing different terrace designs. The results of the hydrodynamic model will help to identify environmental factors such as sediment type, sediment load, soil strength and submerged aquatic vegetation (SAV) affecting marsh terrace performance relative to geological processes and the attenuation of wave energy.

Regarding the hydrodynamic, sediment transport, shoreline erosion, and terrace longevity aspects of this project, future work by our group will focus on further optimizing terrace design for wind conditions including consideration of optimal spacing of terraces relative to prevailing fetch conditions. Ultimately, we would like to produce a technical brief with practical and actionable design considerations for distribution to engineers responsible for designing marsh terrace projects.

6.4. Have you developed new collaborations or partnerships (formal or informal) as a result of this work? If yes, please describe the new collaborations or partnerships. *

Perhaps the greatest aspect of the project is the strengthened collaborations with Ducks Unlimited by most of the partners (other than Davis, who already had an established history). We were able to help Ducks Unlimited with delineation of marsh before / after for another project that they were developing

The reseach team was especially grateful to Dr. Mike Brasher! MIke is a great collaborator and had so much insight into the working lands for this project given his 10-year+ tenure in south Louisiana.

We are indebted to major private landowner/corporations during this project. We could not have conducted this project without their support. Specifically, the Miami Corp., Conoco-Phillipps, and the Vermilion and the Apache Corps. Their lands and people support were vital to our work. Ducks Unlimited already had previous solid collaborations with them but we strengthened those relationships through this project.

6.5. What, if any, positive changes in policy or practice do you foresee as a result of your work? *

Perhaps one of the greatest strengths of this study is that some reconciliation of the efficacy of terraces has been resolved. It has literally been since the early 1990's that the functionality of terrace projects were mostly "Guesswork" per the beneficial design and layout. Although our study on marsh terrace design is not final, we have made great gains into identifying design and functionality. Aspects of this work prescribe specific design and implementation practices for optimizing the efficacy of marsh terraces in reducing wetland erosion. We encourage all practitioners to consider these recommendations when designing, constructing, and managing marsh terrace projects.

6.6. If you could make one recommendation to the Gulf Research Program for how best to build on the work you conducted in this project, what would it be? *

Collectively, the results of this project indicate that marsh terracing can be an effective wetland restoration technique. We suggest that NAS continues to fund research focused on marsh terracing, including research that considers how costal management policy can best incorporate and utilize marsh terracing as wetland preservation tool in the northern Gulf of Mexico as well as introduce it in other regions, where wetland erosion is a concern.

Basiclly, we recommend that the GRP continue to support for marsh terrace research, or other closely related activities that work to enhance/restore coastal wetlands.

7. Communication and Dissemination

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

Note to Grantees: In Section 7, we ask you to help us communicate the importance, progress, and accomplishments of your work. Information provided in this section will be used by the Gulf Research Program to highlight its funded projects in print and electronic informational and promotional materials. The intended audience for the information provided in this section is different and should be thought of as a general audience. When you return to the dashboard, you may upload images that represent and illustrate the work of your project.

7.1. Please describe the most exciting or surprising thing you have learned while working on this project in a way that is understandable by a general audience. *

One of the most exciting and rewarding aspect of this study for many of us was its interdisciplinary nature, which brought multiple unique perspectives to the research design and implementation discussions. These interactions also led to new professional and personal relationships which enabled expanded dissemination of our collective findings and amplified the visibility of both this technique and the research.

This was most certainly a project in which we all believed we were doing something really important (or even critical) for such an imperiled system. We all typically believe our science is relevant in some capacity, but this project had special meaning because of the "race" against time and need for determining techniques or approaches that lend themselves to preserving/enhacing our vital coastal systems.

7.2. Do you have any stories that capture the impact of this project? (optional)

If so, please share one or two. Examples of what we are interested in include stories of people/communities that the project has helped; lives that have changed; work that led to policy change, such as legislation or regulation; and research breakthroughs.

Generally, we believe our work will shed more light on terrace systems and their ability to slow marsh loss and help enhance or restore these systems in certain site-specific locations of coastal Louisiana. The important site-specific features and terrace designs that we studied/discovered should provide confidence to planners and engineers developing future terrace projects.

7.3. Have any communications, outreach, or dissemination activities occurred in relation to your project?*

Please describe:

- Any press releases issued (other than that issued by the National Academies of Sciences, Engineering, and Medicine) about the project.
- Any media coverage or news stories about the project.
- Any social media accounts, websites, listservs, or other communication vehicles used to communicate information about this project. Please include relevant web addresses if available.

• In May 2021, project investigators (PIs and students) coordinated a special session at the State of the Coast conference to highlight recent progress in understanding the ecological and restoration benefits of constructed marsh terraces. Three of the 4 presentations in this session were delivered by the 3 students supported on this project (see below).

• The research team will convene a stakeholder meeting during fall-winter 2022 to share and discuss research findings with scientists, conservation planners, and coastal restoration professionals. We intend to hold the meeting in-person at a centralized location in coastal Louisiana (e.g., Lafayette).

• Ducks Unlimited will lead the development of a document that synthesizes the findings from this and other recent research to communicate our current understanding of the benefits of marsh terracing and serve as a guidebook for its implementation. We anticipate having this document available for distribution at our stakeholder meeting.

Name Session Introduction
Michael Brasher Ducks Unlimited, Inc. mbrasher@ducks.org

Speaker 1 Assessment of marsh terraces performance in coastal Louisiana using multi-temporal high resolution imagery Raul Osario (student), Miss. St Univ, Agricultural and Biological Engineering; ro264@msstate.edu

Speaker 2 Sedimentary effectiveness of marsh terracing as a restoration technique in coastal marshes in southeastern Louisiana; Marie Mathews (student), Tulane Univ., Dept of Earth and Environmental Sciences; mmathews1@tulane.edu

Speaker 3 The effect of tropical storm and frontal passage on marsh terrace efficacy in coastal Louisiana Joseph French (student), Miss St. Univ., Dept of Geosciences jef385@student.exchange.msstate.edu

Speaker 4 Avian use of marsh terraces in coastal Louisiana Madelyn McFarland (student), Miss. St. Univ., Dept of Wildl., Fish., & Aquaculture; mbm391@msstate.edu

Perhpas one of the greatest "awards" for Madie McFarland given her experiences on this project and familiarity with coastal birds came when she was appointed by Dr. Kristine Evans (MSU, Wildlife, Fisheries & Aquaculture) to serve as the East Gulf Coastal Plain Waterbird Plan Coordinator, East Gulf Coastal Plain Joint Venture, Regional, (2020 - December 2021). Madie successfully led this initiative that coordinates coastal bird monitoring initiatives among state, federal, and private interest groups.

Other accolades that garnered attention:

Graduate student Madie McFarland was invited by the Mississippi Academy of Sciences to compete in a special symposium sponsored by Mississippi INBRE for top graduate student presentation at the conference.

Graduate student Madie McFarland was the recipient of Thomas Plein scholarship ($3,000) in 2020.

Madie was Featured Graduate Research Assistant (GRA), Forest and Wildlife Research Center, University, (August 2021). Madie McFarland was nominated for the Graduate Research Assistant spotlight article for the 2021 FWRC Annual Report (to be published 2022).

Madie McFarland won the 2021 SWS Best Student Oral Presentation Award ($500). She presented her paper virtually at the annual SWS meeting in Spokane, Washington.

Madie won the Wildlife Section Student Travel Award, Society of Wetland Scientists (SWS), National, (January 2021). She won the 2021 student travel award to attend the SWS' annual meeting in Spokane, Washington. Although awarded, the meeting ended up being virtual with the Coronavirus.

Madie won the James C. Kennedy Waterfowl and Wetlands Conservation Scholarship, College of Forest Resources, Mississippi State University, College, (April 2021).

This project also advertised here:
https://www.gri.msstate.edu/research/marsh/