

PROJECT INFORMATION

Project Director's Name*	Randall Hughes
Organization*	Northeastern University
Project Title*	Ecological and social drivers of mangrove expansion and restoration in the future Gulf of Mexico
Reporting Period*	09/01/2020-02/27/2024

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

1. GOALS AND ACCOMPLISHMENTS

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

This project proposed to use a coupled social-ecological systems approach to address four primary objectives regarding mangrove range expansion in the northern Gulf of Mexico (Cedar Key, Florida to Port Aransas, Texas). We are focusing on the black mangrove (*Avicennia germinans*), the most abundant and most cold tolerant of the three mangrove species found in this region. We are examining mangrove traits including presence/absence, relative abundance, canopy height, and aboveground biomass. These traits are directly linked to key ecosystem functions including: aboveground productivity, aboveground carbon storage, belowground carbon storage, wave attenuation, erosion prevention, and provision of habitat. By linking current and projected mangrove distributions to biomass and ecosystem function, this project will represent a significant advance over past efforts. The ultimate goal of the project is to provide coastal managers, decision makers and private landowners with comprehensive information about ecosystem functions associated with existing and future mangroves, as well as the unique local and regional social constraints or catalysts on those mangrove-associated functions. Our interdisciplinary project team, comprised of academic, federal and non-profit scientists will achieve this goal via the following four objectives:

Objective 1: Synthesize existing data on the geographic distribution, traits, ecosystem function, and policy landscape of mangroves in the northern Gulf of Mexico

Objective 2: Analyze attitudes, beliefs, and decision-making of different stakeholders (resource managers, waterfront homeowners) regarding mangrove expansion

Objective 3: Project future mangrove distribution, abundance, and ecosystem function based on changes in temperature

Objective 4: Integrate and communicate ecological and social data via a Mangrove Explorer app on the existing Coastal Resilience decision support tool

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.*

Objective 1 -

Current distribution: In October 2021, we held a virtual workshop that gathered 52 coastal scientists from academic, governmental, and non-governmental organizations across the five states that span the mangrove range limit in eastern North America (i.e., Texas, Louisiana, Mississippi, Alabama, and Florida). Workshop participants were identified and invited based on their active, on-the-ground mangrove research in this region as evidenced by the published literature, providing the necessary expertise to address our objectives. In the workshop, we used expert elicitation techniques to gather data on mangrove presence and absence throughout the region, as well as to collate information on data limitations and tools needed to advance our understanding of mangrove distribution and range dynamics. We then synthesized these results, following up with additional scientists as needed to fill in gaps in geographic coverage or content expertise. All individuals who contributed to our data collection and synthesis efforts were invited to be co-authors on a publication led by Postdoctoral Researcher Dr. Rémi Bardou (Bardou et al. 2023). Dr. Bardou also presented these results at the 2022 GomCon meeting.

Historical analysis: To provide context for the current distribution of mangroves in the northern Gulf, we are examining historical (1900s to present) expansion and contraction of mangroves in four key areas within the northern Gulf of Mexico region: Cedar Key, FL; Apalachicola Bay, FL; Corpus Christi, TX; Galveston, TX . We have identified historical temperature records that can be used along with established equations regarding freezing temperature thresholds for mangrove damage and mortality to understand historical mangrove expansion and contraction. Key personnel Hughes and Osland published a similar analysis for Apalachicola Bay, FL in collaboration with project collaborator Caitlin Snyder at the Apalachicola Bay National Estuarine Research Reserve (Snyder et al. 2021 Estuaries and Coasts). We had difficulty finding records of sufficient duration in the other locations of interest, but the analyses for Cedar Key, Corpus Christi, and Galveston are now nearly complete. We are comparing these environmental records with waterfront homeowner perceptions of mangrove expansion and contraction (from our survey) to evaluate the alignment or lack thereof. This analysis is part of PhD student Kalaina Thorne's dissertation research and will continue despite the grant having now ended.

Policy analysis: An important first step in understanding mangrove management decisions is to identify relevant policies and practices throughout the region. We have identified and compiled mangrove policy and management resources at local, state, and federal scales using a polycentric analytical framework. There are numerous policies that affect mangroves, and these policies vary by state and sometimes by locality. The protection of mangroves is linked to the protection of other wetland species, and each state employs a separate delineation methodology to

identify wetland presence. Most states have a no-net-loss goal for wetlands, which requires that mitigation strategies be employed once a certain acreage of wetland habitat is being removed. Multiple agencies are involved in the oversight and application of these mangrove policies, and authority to administer these policies is often nested; some proceedings authorized by these policies are even administered through joint federal-state programs.

In order to supplement our results from the online document collection and review, we consulted with The Nature Conservancy staff with experience in mangrove policy in each Gulf of Mexico state in our study region. These staff members were often representatives from those state's Government Relations teams or state coastal program directors. We structured our conversations with TNC staff using a framework that classifies mangrove policies as ones concerning planting, maintenance, and trimming. Within each of these types of mangrove policies, we discussed the presence or absence of policy explicitly involving or implicating mangroves, as well as the ways in which wetlands more generally may be handled differently from mangrove species in a legal and political context. These conversations provided guidance on how to expand our existing database on mangrove policy, and brought attention to the complexity involved in the practical application of these policies on the ground.

In November 2021, we also convened a workshop of 33 participants, consisting of the project team as well as resource managers and practitioners across the study region. In the workshop, we presented our compilation of mangrove-relevant policies and solicited information regarding any gaps in our analysis at the federal, state, and local levels. We also elicited participant opinions on (1) the factors and motivations driving current mangrove policy; (2) any policies that are barriers to current or future practice, and (3) the policies that would be useful moving forward. Our engagement with stakeholders and coastal managers revealed that perceptions of mangrove range expansion vary greatly and are likely dependent upon the management objectives in a specific area or location. Florida is the only state with explicit state policy protecting mangroves as they expand into new areas. As a result, the management actions taken in mangrove expansion areas in the other Gulf States are not dictated by state policy but are likely driven more by individual managers' opinions and beliefs about mangrove range expansion and/or their specific coastal management objectives. Therefore, there is anticipated variation across the northern Gulf of Mexico in how and when coastal managers will react (or not) to mangrove range expansion into new areas.

Objective 2 -

To investigate how human influences may affect mangrove distribution in the Gulf of Mexico, we developed a survey instrument with an aim to elicit social drivers such as attitudes, beliefs, and perceptions surrounding healthy coastal systems and mangrove expansion.

Data Collection: Four study sites in the northern GOM were targeted: Cedar Key, FL (Levy County), Panama City Beach, FL (Bay County), Galveston, TX (Galveston County), and Corpus Christi, TX (Nueces County). Cedar Key has very few waterfront home parcels, so we expanded our target area into Homosassa, FL (Citrus County) to

achieve the same sample size of waterfront homeowners as in other study areas. Cedar Key and Corpus Christi are located within the current range of established mangroves in this region, while Panama City Beach and Galveston fall within current mangrove expansion hotspots. We were unable to establish a study site in Louisiana because of impacts of COVID-19 and Hurricane Ida in the state during our study period.

A stratified sample of 3200 residential waterfront addresses (800 addresses from each study site) were selected using county public property records. Residents were targeted using a mixed-mode survey in three mailings following a “tailored design method”. Data collection commenced in fall 2021 and was concluded in summer 2022. The survey yielded an adjusted response rate of 20% (N = 530 responses).

Survey Design and Analysis: The instrument captured information in four major categories: demographic characteristics; mental models of healthy coasts; marsh/mangrove perceptions of ecosystem service delivery potential; and shoreline characteristics, fishing behaviors, and attitudes. Demographic information included zip code, age, highest level of education, household income in 2021, gender, race, occupational reliance on coastal resources, and political affiliation. These variables were applied across all studies utilizing survey data.

The proportion of responses from each study site was as follows: 23.8% (n = 126) in Cedar Key / Homosassa, 27.0% (n = 143) in Panama City Beach, 27.9% (n = 148) in Galveston, and 21.3% (n = 113) in Corpus Christi. The majority of respondents were white (85.1%, n = 451), and men represented slightly more than half of the sample (58.1%, n = 308). Respondents were on average 66 ± 1 years old. The highest level of education among respondents was most often a bachelor's degree (35.3%, n = 187) followed by a master's degree (21.9%, n = 116); almost three-quarters of the sample had received at least a bachelor's degree. The most frequently chosen 2020 household income category was more than \$250,000 (22.8%, n = 116). Across all study sites, over 85% of respondents fell into income categories above the median income level for their county.

The mental model exercise was designed to understand the attributes and connections that respondents perceive to be important within their coastal SES. We followed standard methods set out by Özesmi and Özesmi (2004) for eliciting and transcribing mental models for social-ecological systems research, however our online survey approach is more advanced. Respondents were first prompted to select from a list of fifteen concepts which they perceived to be important for understanding the health of coasts, with an Other option which allowed respondents to manually indicate one concept that they felt was not represented in the provided list of concepts. Concepts were initially developed by the project team using scientific literature and initial interviews, and definitions were made available to respondents to ensure clarity of meaning. Next, respondents chose up to five of their most important concepts for understanding healthy coasts. Respondents then indicated the direction and magnitude of causal relationships between these concepts using a 5-point Likert Scale (Very Beneficial, Somewhat Beneficial, No Effect, Somewhat Harmful, Very Harmful), with a sixth option (I'm not sure) for respondents to indicate lack of knowledge of the

relationship.

These mental models were subjected to various analytical techniques to investigate their structure and demographics. First, non-parametric multivariate analysis was performed to identify demographic drivers of various measures of mental model structure. No demographic variables significantly predicted these structural components, thus in analyses of dynamics the mental models were grouped to represent Gulf of Mexico community knowledge. Next, mental models were subjected to three kinds of anthropogenic shoreline change: (1) habitat loss to sea level rise; (2) tropicalization of nearshore habitats; and (3) shoreline armoring. We identified the three most prominent ecosystem service concepts from these models (which were determined to be Marine Life, Storm Protection, and Water Quality) and quantified the relative change in these ecosystem services under multiple simulations of the three shoreline change scenarios. We found that the majority of shoreline change scenarios presented negative impacts on ecosystem services. Habitat loss to sea level rise caused the most negative trajectories for Marine Life and Water Quality under losses of mangroves and salt marshes; hardened shoreline loss negatively impacted these ecosystem services as well, but to a lesser extent. Storm Protection was equally harmed by losses of all shoreline types. For tropicalization of nearshore habitats (manifested as mangrove expansion in the simulations), gaining mangroves was not able to compensate for losses of salt marshes, and all ecosystem services were negatively impacted. Lastly, for shoreline armoring, increasing the impact of hardened shoreline also had negative impacts for all ecosystem services, but these impacts were least negative for Storm Protection. These results suggest that waterfront resident mental models are useful to understand the impact of anthropogenic shoreline change on ecosystem services, and that the perceptions of these residents discern complex relationships between nearshore habitats and the ecosystem services they provide. PhD student Savannah Swinea presented preliminary results of this aspect of the project at the 2021 American Fisheries Society meeting and the 2023 Coastal and Estuarine Research Federation annual meeting. She has drafted a manuscript of these results for submission to a peer-reviewed journal.

The survey instrument then employed an in-survey experiment to explore differences in the perception of relative performance in marshes and mangroves to deliver 15 ecosystem services, across three treatments: (1) respondents are asked to answer questions with mangrove shrubs (<3 feet) in mind, and photos of mangrove shrubs are displayed; (2) respondents are asked to answer questions with mangrove trees (>3 feet) in mind, and photos of mangrove trees are displayed; or (3) respondents are not exposed to either of the two treatments and proceed directly to the questions. The aim of this experiment is to examine how mangrove traits influence coastal resident perceptions of mangrove ecosystem service delivery. PhD student Kalaina Thorne and Postdoctoral Researcher Dr. Jahson Alemu I presented preliminary results from this section of the survey at the 2022 GomCon meeting. Dr. Alemu I is working on a manuscript of these results for submission for peer review.

Lastly, a specific analysis of the factors influencing perceptions of the comparative ability of mangroves and salt

marshes to support coastal fisheries was conducted. This analysis was important because no studies we encountered had quantified coastal resident perceptions comparing fisheries ecosystem service delivery under present vs. projected habitat scenarios in our region. Predictor variables included the number of years respondents had lived on the waterfront, frequency of recreational fishing activity, years of fishing experience, fishing locations (including from shore, inshore, and/or offshore) in the last year, current shoreline condition, shoreline attitudes (which were represented as a respondent's ideal desired shoreline condition), as well as demographic characteristics. We performed an ordinal logistic regression to evaluate the influence of these predictors on respondent perceptions. PhD student Savannah Swinea has submitted a manuscript describing the findings to the journal *Landscape and Urban Planning* for peer-review.

Perceptions of the relative performance of marshes vs. mangroves for fisheries ecosystem services were significantly different for state of residence, current shoreline condition and shoreline attitudes, recreational fishing activity, and household income. Respondents from Galveston, TX and Corpus Christi, TX had significant mangrove preference in comparison to Cedar Key / Homosassa, FL respondents. Residential-scale shoreline condition and attitudes both played a role in the significant divergence of perceptions for supporting coastal fisheries. Respondents with a marsh present on their shoreline rated the relative performance of mangroves higher for supporting coastal fisheries than respondents without a marsh on their shoreline. In contrast, respondents who expressed that their ideal shoreline would hypothetically include a marsh rated the relative performance of marshes higher for supporting coastal fisheries than respondents who did not desire a marsh on their shoreline. In addition, frequent recreational fishing conferred preference for mangrove habitats over marshes. Lastly, with respect to demographics, household income achieved significance in the model because respondents in multiple higher income categories preferred marshes in comparison to respondents in the lowest income level (less than \$25k).

Geographic, environmental, attitudinal, behavioral, and demographic factors influenced respondent perceptions of supporting ecosystem services delivered by marshes and mangroves. This research made a valuable contribution in building evidence that ecosystem service assessments deserve a social valuation technique and that outcomes should be evaluated under the characteristics of the relevant beneficiaries of those services. This study showed that perceptions of coastal habitats for delivering ecosystem services were driven not by demographics, but by the geographic context, environmental attitudes, and resource use of our respondents. This means that if residents' shoreline management decisions are presumed based on readily apparent characteristics such as shoreline condition and demographics, concealed factors such as shoreline attitudes and fishing behaviors will not receive adequate attention. As places at the land-sea interface undergo rapid social-ecological change, it is important to establish a reference point of place-based perceptions of residents regarding coastal habitats for their roles in ecosystem service delivery. In order to design informed and stakeholder-driven strategies for climate resilience, we must consider the social forces that act to shape our coastal ecosystems and societies. PhD student Savannah Swinea presented preliminary results of this aspect of the project at the 2021 Coastal and Estuarine Research

Federation annual meeting, the 2022 Gulf Estuarine Research Society Biennial Conference, and the 2022 Gulf of Mexico Conference (GoMCon) meeting. A manuscript of these results was also prepared by PhD Student Savannah Swinea and is currently under review at a peer-reviewed journal.

Survey Follow-Up: Two follow-up surveys were conducted: one in spring 2023 (N = 62 responses) and one in spring 2024 (N = 43 total responses). These follow-ups utilized contact information provided by our initial survey respondents. These additional surveys provided longitudinal data necessary to quantify rates of change for shoreline condition and habitat perceptions. The specific goals of the follow-up surveys were to identify rates of change for shoreline type, condition, and attitudes.

Approximately 97% of respondents reported that neither their shoreline type had not changed since responding to the initial survey. Of the two respondents who reported a change in their shoreline type, one indicated a transition between two hardened shoreline types, and one indicated a transition from a hybrid to a hardened shoreline type. The proportion of respondents who reported a change in their shoreline condition was approximately 20%. Among qualitative descriptions of these changes, the majority of respondents indicated that erosion had changed their shoreline condition. We also evaluated how the ideal desired shoreline type changed between the initial and follow-up surveys. The only shoreline type that gained preference among respondents was a bulkhead or vertical wall; all other shoreline types had a smaller proportion of respondents indicating that they desired those shorelines on their property. These results make a preliminary step towards quantifying rates of change for shorelines and the attitudes of waterfront residents. It will be critical to quantify how shorelines and the resulting perceptions of waterfront residents are changing in response to actual and projected shoreline changes.

Objective 3 -

We have developed projections of mangrove distribution, abundance, and ecosystem function based on current and future climate scenarios. We used established relationships developed in previous studies for mangrove presence and abundance (Osland et al., 2013), as well as mangrove height, above-ground biomass, and productivity (Feher et al., 2017). We obtained recent climate data (1981-2010) and future climate data (2071-2100) from the AdaptWest database (Wang et al., 2016), for the following two climatic variables: Extreme Minimum Temperature (EMT) and the Mean Annual Precipitation (MAP). EMT represents the absolute coldest temperature recorded during the 30-year period, which is relevant because extreme minimum temperatures govern the distribution and structure of mangroves in this region (Feher et al. 2017, Gabler et al. 2017, Osland et al. 2019). MAP was incorporated because the western side of our study area spans a precipitation gradient that interacts with temperature to affect coastal wetlands. Decreased precipitation and freshwater inputs in that region can lead to hypersaline conditions that influence plant community structure and function (Osland et al. 2014, Gabler et al. 2017, Osland et al. 2019). The recent climate data (i.e., EMT and MAP) were based on data produced by the

PRISM Climate Group (Oregon State University; prism.oregonstate.edu) using the PRISM (Parameter-elevation Relationship on Independent Slopes Model) interpolation method (Daly et al. 2008). The future climate data were based on downscaled data from the Coupled Model Intercomparison Project Phase 6 (CMIP6) database, which corresponds to the 6th IPCC (Intergovernmental Panel on Climate Change (IPCC), 2023). The ensemble mean projections are average projections from eight CMIP6 models, which tend to be the most representative for projecting climate warming (Hausfather et al., 2022; Tokarska et al., 2020). We obtained future projected climate data for EMT and MAP for the period 2071-2100 under two Shared Socio-economic Pathways (SSPs): the SSP2-4.5 and SSP5-8.5 scenarios, which correspond to intermediate and high greenhouse gas emissions scenarios, respectively. Our analyses indicate that mangrove presence and relative abundance will dramatically increase in the northern Gulf of Mexico and the southeast Atlantic coast of the United States, particularly under the high emissions scenario. Because of the higher stature of mangroves relative to salt marsh vegetation, this expansion will cause transformative change in coastal wetland vegetation height and aboveground biomass in many areas. However, along the arid southern Texas coast, low precipitation and high salinities are expected to constrain mangrove expansion and growth. A manuscript of these results is currently in revision at Journal of Biogeography and a USGS Data Release has been developed (Bardou et al. 2023)

Objective 4 - Integrate and communicate ecological and social data via a Mangrove Explorer app on the existing Coastal Resilience decision support tool

We have developed the Mangrove Explorer Mapping Tool to communicate the key data products to a diverse audience of Gulf of Mexico and Southeastern US coastal managers, residents, and stakeholders. The Mangrove Explorer is a free, public facing mapping tool that allows individuals to easily explore the multiple datasets developed throughout the project.

The tool features the following key project outputs:

New, gridded mangrove distribution data set

Change map that conveys the potential change in the probability of mangrove presence by 2100 at the county/parish scale to communicate the anticipated change visually with one image

Projections of mangrove distribution, abundance, and ecosystem function that can be explored by the user selecting various current and future climate scenarios

A selection of simplified outputs that characterize some of the policy and social science findings of the study

The goal of the Mangrove Explorer tool is to make these findings more accessible and easily understandable to raise awareness of the significant change that is anticipated in the northern Gulf of Mexico and the Southeastern US coastlines with respect to mangrove range expansion. TNC and the project partners are planning a public outreach and communications campaign to expand the reach of the Mangrove Explorer Tool to additional coastal

managers and stakeholders in Summer of 2024. This campaign will be coordinated with the publication of the manuscript detailing the team's efforts to model and create the data featured in the tool (currently in revision as noted above). In addition, TNC is developing a companion Story Map that will help users unfamiliar with the concept of mangrove expansion in the northern Gulf of Mexico to better understand the project and the possible implications of the findings. The Story Map (in its final review period) was not a grant deliverable but will be published when the manuscript is accepted and the Mangrove Explorer communications campaign is launched by TNC.

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.

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*

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	1
Undergraduate students	3
Graduate students	10
Postdoctoral scholars	2
Citizen Scientists	0
Other Trainees	0

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. *

The approved Data Management Plan was carried out effectively. Ecological data were compiled from existing resources and electronic files were backed up to one remote location. Ecological and metadata will be published on the Knowledge Network for Biocomplexity (KNB) within one year of the project end date.

Social data were collected under established IRB protocols. Human subjects data were stored on project personnel computers with appropriate encryption were backed up to secure servers. Human subjects data will be published on OpenICPSR as well as GRIIDC within one year of the project end date. All project data (ecological and social) will be maintained on Northeastern University's digital repository service.

For information products, The Coastal Resilience Network decision support systems are maintained by The Nature Conservancy (TNC) using Amazon Web Services. Information relating to the Coastal Resilience Network framework and web application associated with our project were stored electronically following FGDC standards. The data and web services hosted online will be updated for up to six months after the project end date by TNC staff to ensure accuracy. Funds have been allocated to cover Amazon Cloud storage fees in order to maintain the public accessibility of this tool.

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.

We hosted 2 participatory workshops as part of this project:

(1) We held a virtual workshop in October 2021 that gathered 52 coastal scientists from academic, governmental, and non-governmental organizations across the five states that span the mangrove range limit in eastern North America (i.e., Texas, Louisiana, Mississippi, Alabama, and Florida). Workshop participants were identified and invited based on their active, on-the-ground mangrove research in this region as evidenced by the published literature, providing the necessary expertise to address our objectives. In the workshop, we used expert elicitation techniques to gather data on mangrove presence and absence throughout the region, as well as to collate information on data limitations and tools needed to advance our understanding of mangrove distribution and range dynamics.

(2) In November 2021, we also convened a workshop of 33 participants, consisting of the project team as well as resource managers and practitioners across the study region. In the workshop, we presented our compilation of mangrove-relevant policies and solicited information regarding any gaps in our analysis at the federal, state, and local levels. We also elicited participant opinions on (1) the factors and motivations driving current mangrove policy; (2) any policies that are barriers to current or future practice, and (3) the policies that would be useful moving forward. The input from this workshop is informing the next steps of our policy analysis which will be a policy review paper focused on understanding how policy and action varies in areas of core historic mangrove range versus areas of mangrove range expansion.

We also consulted with The Nature Conservancy staff and other coastal managers with experience in mangrove policy in each Gulf of Mexico state in our study region. We structured our conversations using a framework that classifies mangrove policies as ones concerning planting, maintenance, and trimming. Within each of these types of mangrove policies, we discussed the presence or absence of policy explicitly involving or implicating mangroves, as well as the ways in which wetlands more generally may be handled differently from mangrove species in a legal and political context.

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. *

We have 3 data sets. The first resulted from our expert elicitation workshop and forms the basis of the analyses presented in Bardou et al. 2023 on mangrove presence/absence in the northern Gulf of Mexico. The second incorporates temperature and precipitation forecasts to project mangrove presence, relative abundance, and ecosystem properties based on multiple climate scenarios. The third includes data from our waterfront homeowner survey on perceptions of fisheries services provided by marshes and mangroves.

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? *

We have spread the word regarding our project data through conference presentations, manuscripts submitted for publication, and through informal interactions with our extensive network of colleagues facilitated by this project. We have also included data citations within all papers and presentations to promote access to the underlying data. Finally, we are presenting our data in an accessible manner through the Mangrove Explorer tool and accompanying StoryMap.

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

Yes

3.4a (yes). Were these sensitive, confidential, and/or proprietary data products described in the data management plan of the approved project plan? *

Yes

3.4b (yes). If your plans for managing restricted access to and re-use of confidential data have changed since the approval of the project plan, briefly describe the new plans and procedures. *

The social and human subjects data collected in this project contained confidential information. The data synthesized and produced by the project were conducted under the auspices of and disseminated following the guidance of Northeastern University's Institutional Review Board (Human Subjects Assurance: FWA00004630) and in partnership with each respective Co-PI's Institutions. Co-PI Scyphers currently has active IRB protocols for collecting human subject data in coastal communities (Protocols #12-05-17, #12-07-25, #12-11-25). All survey data were de-identified and anonymous survey responses were stored separately from identifiable information. All human subjects data were scrubbed of identifiers before being made publicly available on OpenICPSR and GRIIDC. These practices are consistent with our approved project plan.

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.

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*

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
2. Websites or data portals
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.

Swinea, S.H., Hughes, A.R., Osland, M.J., Shepard, C.C., Thorne, K.B., Alemu I, J.B. Bardou, R., and Scyphers, S.B. In review. Marshes to mangroves: Resident attitudes and perceptions indicate perceived trade-offs in ecosystem services.

Osland, M.J., Hughes, A.R., Armitage, A.R., Scyphers, S.B., Cebrian, J., Swinea*, S.H., Shepard, C.C., Allen, M.S., Feher, L.C., Nelson, J.A., O'Brien, C.L., Sanspree, C.R., Smee, D.L., Snyder, C.M., Stetter, A.P., Stevens, P.W., Swanson, K.M., Williams, L.H., Brush, J.M., Marchionno*, J., and Bardou*, R., 2022, The impacts of mangrove range expansion on wetland ecosystem services in the southeastern United States: current understanding, knowledge gaps, and emerging research needs. *Global Change Biology*, v. 28, p. 3163-3187.

<https://dx.doi.org/10.1111/gcb.16111>.

Bardou, R., Osland, M.J., Scyphers, S., Shepard, C., Aerni, K.E., Alemu*, J.B., Crimian, R., Day, R.H., Enwright, N.M., Feher, L.C., Gibbs, S.L., O'Donnel, K.O., Swinea*, S.H., Thorne*, K., Truskey, S., Armitage, A.R., Baker, R., Breithaupt, J.L., Cavanaugh, K.C., Cebrian, J., Cummins, K., Devlin, D.J., Doty, J., Dunton, K.H., Ellis, W.L., Feller, I.C., Gabler, C.A., Kang*, Y., Kaplan, D.A., Kennedy, J.P., Krauss, K.W., Lamont, M.M., Liu, K.B., Martinez*, M., Matheny, A.M., McClenachan, G.M., McKee, K.L., Mendelssohn, I.A., Michot, T.C., Miller, C.M., Moon, J.A., Moyer, R.P., Nelson, J., O'Conner, R., Pahl, J.W., Pitchford, J.L., Proffitt, C.E., Quirk, T., Radabaugh, K.R., Sheffel, W.A., Smee, D.L., Snyder, C.M., Sparks, E., Swanson, K.M., Vervaeke, W.C., Weaver, C.A., Willis, J., Yando, E.S., Yao, Q., and Hughes, A.R., 2023, Rapidly changing range limits in a warming world: critical data limitations and knowledge gaps for advancing understanding of mangrove range dynamics. *Estuaries and Coasts*, v. 4, p. 1123-1140. <https://dx.doi.org/10.1007/s12237-023-01209-7>

Bardou, R., Osland, M.J., Alemu I, J.B., Feher, L.C., Harlan, D., Scyphers, S., Shepard, C., Swinea, S.H., Thorne*, K., and Hughes, A.R., In review, Projected changes in mangrove distribution and vegetation structure under climate change in the southeastern United States. Submitted to *Journal of Biogeography*.

Alemu I, J.B., S.H. Swinea, K.A. Thorne, M.J. Osland, R. Bardou, A.R. Hughes, C.C. Shepard, S.B. Scyphers. In prep. Waterfront property owners' awareness of wetland ecosystem services related to coastal resilience.

Websites or data portals *

Please provide a list of project websites and data portals (including the website URL).

Mangrove Explorer Mapping Tool. 2024. <https://maps.coastalresilience.org/mangrove-explorer/>

How long beyond the grant period will you maintain the project website/data portal and its contents? Please describe plans to archive the website/data portal and its contents after regular maintenance concludes.*

The Nature Conservancy is committed to maintaining and updating the Mangrove Explorer Too and the data and web services hosted online will be updated for up to six months after the project end date by TNC staff to ensure accuracy. Funds have been allocated to cover Amazon Cloud storage fees in order to maintain the public accessibility of this tool for a minimum period of two years or longer if additional funding is secured. The components of the Mangrove Explorer are mostly derived from published datasets and manuscripts and are linked to the original resources. It is anticipated that these data products will serve as the archive of the original data products displayed on the Mangrove Explorer Tool.

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).

Swinea, S.H. 2024. Replication materials for: "Marshes to mangroves: Resident attitudes and perceptions indicate perceived trade-offs in ecosystem services". Github. <https://github.com/shswinea/MangMarshFish>.

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? *

We have spread the word regarding our project data through conference presentations, manuscripts submitted for publication, and through informal interactions with our extensive network of colleagues facilitated by this project. We have also included data citations within all papers and presentations to promote access to the underlying data. Finally, we are presenting our data in an accessible manner through the Mangrove Explorer tool and accompanying StoryMap.

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*

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. *

Our participatory workshops led to knowledge sharing and relationship building among scientists, managers, and practitioners in the Gulf of Mexico and beyond. We also generated an updated map of mangrove distribution in the poorly documented range expansion area of the northern Gulf.

Our mixed-mode survey produced parcel-level social data to predict current landowner attitudes and behaviors related to mangrove migration.

Our policy review identified current gaps in mangrove protection.

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? *

The most remarkable finding of our project is the scale and scope of change that is projected to occur to coastal wetlands as a result of warming-induced mangrove expansion. This change is extensive, and it is not clear that coastal managers or waterfront residents have sufficient knowledge of this change to inform their decisions about shoreline usage and management. There is also substantial geographic variation in perceptions of mangrove expansion across the northern Gulf of Mexico that need to be considered when making management and restoration decisions.

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. This section will not be made available to the public.

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. *

Survey data collection in Objective 2 was initially scheduled for doorstep delivery by members of the project team in five focal locations. Doorstep delivery is useful because it allows the researchers to validate addresses on the ground which can produce a higher survey response rate. Survey delivery was changed to mailing in response to surging COVID-19 cases across the Gulf of Mexico in fall 2021 in order to protect members of the project team from potential contamination.

Covid19 and visa-related delays delayed the hiring of postdoctoral researcher Dr. Rémi Bardou who led the broad-scale data synthesis for Objective 1 and the projections for Objective 3. He was finally able to start in Fall 2021. Covid19 restrictions also caused us to postpone our year 1 stakeholder workshops into year 2, and to shift them to a remote setup. Covid19 restrictions also caused us to postpone our year 1 in-person annual project meeting into year 2, but we held remote meetings every 2-4 weeks to maintain progress on the project. Finally, these delays and switches from in person to remote workshops and meetings impacted our spending of grant funds.

PhD Student Kalaina Thorne has pursued a few sources to collect the temperature data for the historical analysis outlined in Objective 1. NOAA's Climate Data Online was initially pursued to gather station based temperature data across an extensive historical period (early 1900s), however gaps in data for some stations in the Corpus Christi, TX region have shifted the focus to other data sources. Other datasets that have been explored include NOAA's 20th Century Reanalysis and Climate Forecast System Reanalysis. Oregon State University's PRISM dataset is currently being explored to gather data for the historical temperature analysis.

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. *

Having a hybrid project team structure with monthly virtual meetings allowed us to have continuous updates and feedback on the progress of the objectives, while the in person meetings were great for focused deep work sessions.

Our survey approach involved focusing on four regions within and outside of the current range of mangroves, and this provided key insights on differences in resident perceptions at this spatial scale. However, it was difficult to integrate these data with the gulf-wide scale of our mangrove projections. After several extensive team meetings largely focused on this integration, we believe our resulting web tools do a nice job of conveying the combined value of both sources of information. It is difficult to say what we could have done differently, given the major reason for the four region approach was in response to: 1) a team decision not to survey Louisiana in the immediate aftermath of Hurricane Laura, and 2) pilot interviews and surveys in Alabama and the Panhandle of Florida showing a very low public awareness of mangroves (largely due to their limited presence in these areas).

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? *

There are a number of key next steps building from this study. Now that we have a better understanding of how the wetland mosaic is changing under climate change, we can explore how these changes are likely to influence the benefits that humans derive from them as ecosystem services. Further, we can begin to estimate the likely impacts of these changes on the wellbeing of coastal human populations, as well as their options for adaptation. Answering these questions enables us to move beyond a simple understanding of the benefits of coastal wetlands, to a better understanding of how different wetland types are linked (through perception) to ecosystem services changes to the mangrove traits, and wetland-specific perceptions of function in a warming world, likely to translate (or not) into impacts on coastal human communities in the northern Gulf of Mexico. Additionally, it leads to more provocative questions such as to what degree will the replacement of salt marsh by mangrove directly translate to a downturn (or not) in economic activity and value, and at what scale? Further, how can an economic understanding of the impacts of mangrove range expansion in the Gulf help us to better manage marshes and other ecosystems, especially when much of this loss in ecosystem service is inevitable?

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. *

We have strengthened the relationships among the original project team and expanded them to include additional personnel at each of our institutions.

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

Our work highlights the scale and scope of change that will occur as salt marshes transition to mangroves in the northern Gulf of Mexico, which will help to inform decisions regarding which species to include in restoration efforts.

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? *

Our work is a critical step in projecting and understanding the effects of climate-induced mangrove expansion into salt marsh ecosystems in the northern Gulf. Additional funding is needed for this team to incorporate information about sea level rise impacts into these projections. Although valuable, the projections we have generated could be misleading without considering wetland losses and shifts due to sea level rise. Sea level rise was not an original component of the project, but with additional funding we could incorporate it into our work.

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. *

The most surprising finding of our project is the scale and scope of change that is projected to occur to salt marshes as a result of warming-induced mangrove expansion: every county in the northern Gulf of Mexico is expected to have mangroves present by the end of this century! This mangrove expansion will result in dramatic changes in coastal vegetation height and plant biomass. Given differences in how waterfront homeowners perceive the benefits of mangroves vs marshes, there will be substantial variation in how this change is viewed, and what policies will be supported as a result, across the northern Gulf.

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.

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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.

The project team has shared the project outputs internally to TNC staff with additional outreach anticipated in summer 2024.

<https://www.usgs.gov/centers/wetland-and-aquatic-research-center/news/rapidly-changing-range-limits-a-warming-world>

<https://utmsi.utexas.edu/blog/entry/movin-on-up>