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Gulf of Mexico Ecosystem Service Logic Models and Socio-Economic Indicators (GEMS)

GEMS PHASE I REPORT: OYSTER REEF RESTORATION

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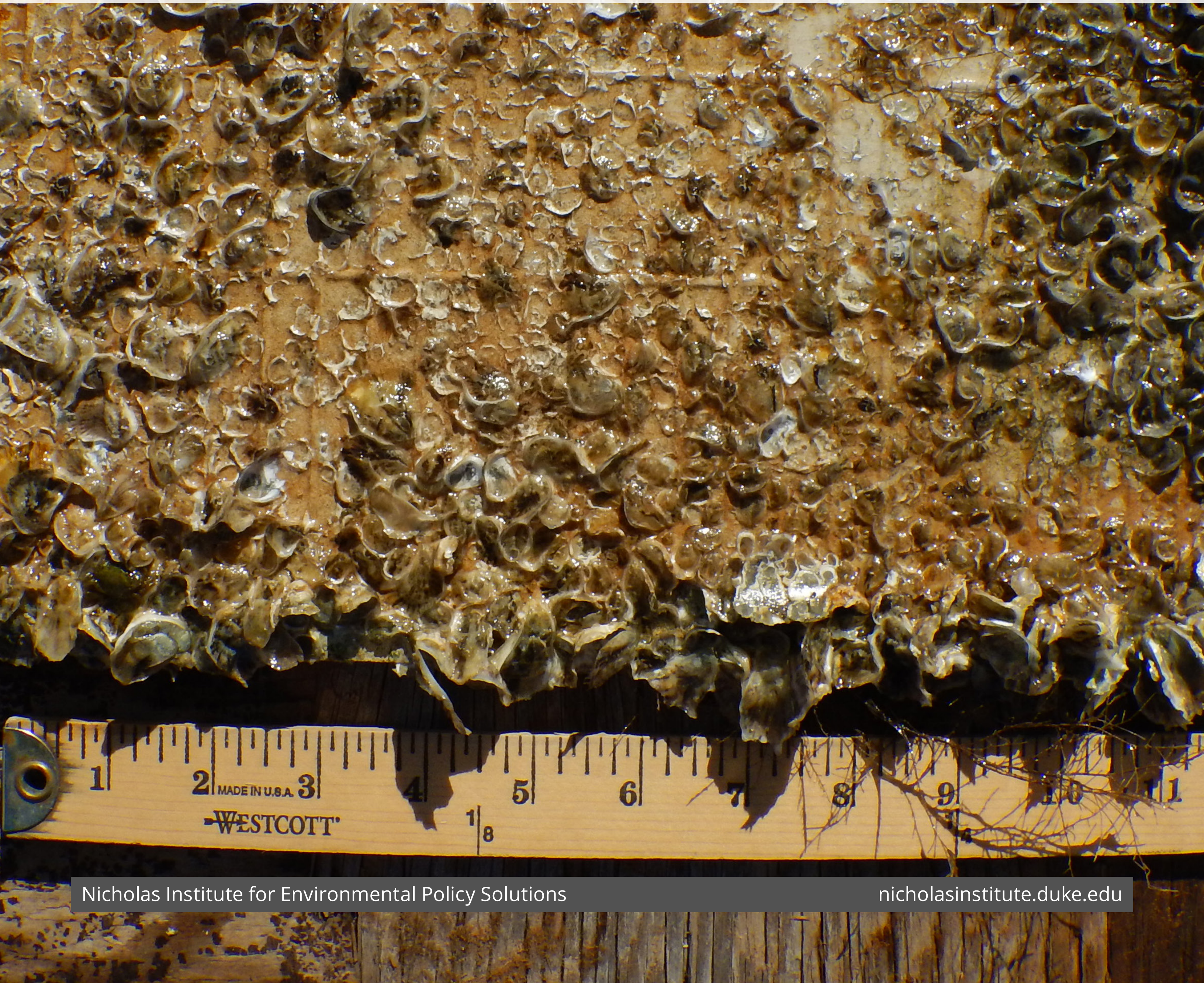

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Project Background

Billions of dollars will be spent on large-scale restoration of Gulf ecosystems over the coming decades, but there is no shared platform to guide assessment and reporting of restoration progress and effectiveness for the broad set of environmental, social, and economic goals shared by the many institutions working in the Gulf. The diversity of these goals—including habitat restoration, water quality improvement, marine resource protection, community resilience, and economic revitalization—means that a variety of metrics are needed to fully evaluate the effectiveness of restoration projects. A set of common models and metrics relevant across projects, programs, and locations can facilitate effective project planning and evaluation. While there are existing efforts to collate and standardize ecological and biophysical metrics for Gulf restoration projects (GOMA Monitoring Community of Practice; NRDA Monitoring and Adaptive Management Manual), there is no current effort to do the same for the social, economic, and human well-being outcomes of restoration. This project aims to do that.

The GEMS (Gulf of Mexico Ecosystem Service Logic Models and Socio-Economic Indicators) project aims to advance standardized metrics of restoration success by developing ecosystem service logic models (ESLMs) with stakeholders from the five Gulf states, relevant federal agencies, and technical experts. ESLMs trace the effects of restoration strategies as they influence ecological and social systems to create outcomes that are important to people. The use of logic models is recommended by the National Academies of Science as best practice for monitoring plan design; these models can provide a practical and transferable approach for measuring success at different scales.

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Numerous strategies for coastal restoration exist (for example, see the numerous project types included in the RESTORE Planning Framework), and there are many places along the Gulf coast where restoration can be implemented. ESLMs are helpful for comparing across restoration strategies and locations to match likely restoration outcomes with stakeholder goals. In addition, evidence that accompanies these models can be used to clarify uncertainties that need to be considered and to identify critical research gaps.

The GEMS team will develop ESLMs and metrics for a wide range of coastal restoration approaches over the course of the project. This report presents the results of the first phase of the GEMS project, which focused on oyster reef restoration.

Phase I Process

We selected specific restoration approaches to focus on for each phase of this project to ground our efforts in commonly used, widely applicable restoration project types. With input from the advisory council (Appendix I), oyster reef restoration was selected as the focal restoration approach for the first phase of the GEMS project for several reasons. Oyster harvesting is a significant economic and cultural activity in the Gulf region, and oyster reefs are a key part of healthy coastal ecosystems. Recent widespread declines in oyster populations have spurred substantial investment in oyster reef restoration and oyster population enhancement projects across the Gulf of Mexico.

Our first step was to develop a general oyster reef restoration ESLM based on literature and conversations with restoration experts. We also created restoration technique specific models (see next section for details). Then, a series of local workshops brought together restoration practitioners and stakeholders in five focal estuaries (one in each Gulf coast state; see details below) to discuss what oyster reef restoration looks like in that estuary, identify the outcomes of oyster reef restoration that are most important in the local context, and develop an initial list of socioeconomic metrics that could be used to measure those outcomes. Local workshop participant selection was guided by the advisory council, and a local lead for each focal estuary helped with participant outreach and workshop preparation. Information from the local workshops was used to further refine the oyster reef restoration ESLM and to start a metrics assessment process. Metrics suggested at local workshops were integrated with additional metrics from the literature and standard criteria were applied to identify the most useful metrics. Next, a regional workshop including representatives from the local workshops, experts on oyster reef restoration and socioeconomic indicators, and members of Gulf coast restoration funding organizations focused on testing and refining the proposed metrics. (See Appendix I for lists of workshop participants.)

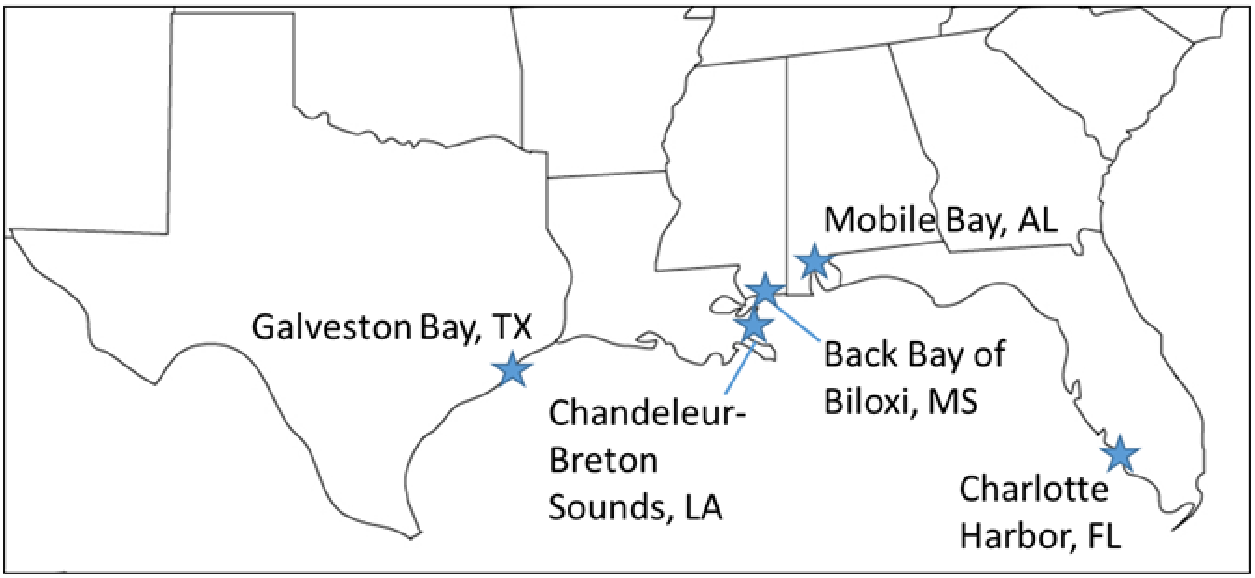
Key outputs from phase I of the GEMS project included in this report are:

- General and technique-specific oyster reef restoration ESLMs
- Estuary-specific results (outcomes, key species, and external factors)
- Socioeconomic metrics for oyster reef restoration in the Gulf of Mexico

Focal Estuaries

Five focal estuaries, one in each Gulf coast state, were selected with input from the advisory council to capture the range of ecological and social conditions as well as data availability found across the region. Estuaries selected included: Galveston Bay, TX; Chandeleur-Breton Sounds, LA; Back Bay of Biloxi, MS; Mobile Bay, AL; and Charlotte Harbor, FL (for more information on these estuaries, see fact sheets used at local workshops). We hosted a workshop in each of these locations to get feedback and insight from oyster restoration researchers and practitioners working in various contexts across the Gulf.

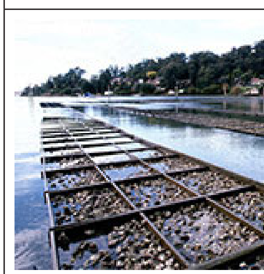
Figure 1. Focal Estuaries



Oyster Reef Restoration Techniques

Oyster reef restoration techniques vary in the process and materials used, environmental conditions required, social and legal contexts, and expected outcomes (shoreline stabilization, oyster harvest, water quality improvement, etc.). Six different oyster reef restoration techniques are widely used across the Gulf of Mexico; techniques used vary by estuary (or locally).

Table 1. Oyster Reef Restoration Techniques

	**Structurally simple, subtidal, intensively harvested** This technique consists of placing cultch material (usually oyster shells, relic shells, crushed limestone, or crushed concrete), either loose or contained, so that the resulting structure lies flat along the estuary/ocean floor. This technique has been widely used throughout the Gulf for the primary purpose of providing oysters for harvest. Example project: Louisiana Oyster Cultch Project
	**Structurally complex, subtidal, intensively harvested** Large, durable structures (e.g., oyster balls, precast concrete structures, and limestone structures) are placed in subtidal areas to create substrate to which oysters can attach. The resulting oyster reef has a significant vertical component, provides a more complex structure which oysters (of varying ages) and other aquatic organisms can use for habitat, and is less likely to be buried by sediment or degraded by waves than the simpler structures in the previous technique. Example project: Galveston Bay Sustainable Oyster Reef Restoration
	**Structurally complex, subtidal, not intensively harvested** This technique is identical to the previous one, except that intensive harvesting (dredging or intensive tonging) is not permitted. Example project: Half Moon Reef
	**Structurally complex, intertidal, not intensively harvested** Large, durable structures (e.g., oyster balls, precast concrete structures, rocks, limestone structures) are placed in intertidal areas to create substrate to which oysters can attach. Projects using this technique are often called “living shoreline” projects, as they are intended to protect shorelines from erosion by stabilizing sediment and attenuating waves as they approach the shoreline. Example project: Restoring Living Shorelines and Reefs in Mississippi Estuaries
	**Protection or enhancement of existing oyster reef** These projects focus on the protection of an existing oyster reef from intensive harvest (dredging), with or without reef enhancement (via seeding or placing oysters in existing reef area). Protected reefs could still allow low-impact harvesting methods (tonging or hand collection) that do not threaten the reef structure or long-term viability of the oyster populations. The objective of these projects is to support a sustainable oyster population, allow the reef to develop structurally over a long period, and possibly to create a source of oyster larvae to nearby reefs. Example project: Oyster Reserve Establishment in Mississippi Sound
	**Aquaculture: intertidal or subtidal, intensively harvested** Oyster aquaculture projects of varying methods, including all bottom and off-bottom techniques. These projects encompass both intertidal and subtidal projects, and are considered to be intensively harvested, since the primary goal of oyster farming is harvest and consumption. Example project: Alabama Oyster Aquaculture

Participants in the local workshops identified the techniques used in each focal estuary:

Table 2. Techniques Used in Each Focal Estuary

	Simple subtidal, intensively harvested	Complex subtidal, intensively harvested	Complex subtidal, NOT intensively harvested	Complex intertidal, NOT intensively harvested	Protection and enhancement of existing reef	Oyster aquaculture
Charlotte Harbor, FL			✓	✓	✓	
Back Bay of Biloxi, MS			✓	✓	✓	
Mobile Bay, AL	✓	✓	✓	✓	✓	✓
Galveston Bay, TX	✓	✓	✓	✓	✓	
Chandeleur & Breton Sounds, LA	✓			✓		

Local workshop participants also discussed what drives the use of certain techniques, and prevents the use of other techniques, in each focal estuary. Their discussions are summarized below:

Charlotte Harbor, FL: Because there is currently no oyster harvesting allowed in this estuary due to human health concerns linked to water quality, the techniques that include intensive harvesting, including aquaculture, are not implemented here. In general, projects in this area tend to be small and done in intertidal areas (for protection of adjacent habitat types). There is institutional resistance to subtidal projects because they are more expensive than intertidal ones, and harvest restrictions due to water quality issues limit the benefits of many subtidal projects.

Back Bay of Biloxi, MS: Commercial harvest of any type is prohibited in this estuary by state law, and recreational oyster harvest is not currently allowed due to health concerns, so the restoration techniques involving intensive harvest or aquaculture are not implemented in Back Bay of Biloxi.

Mobile Bay, AL: All six of the techniques are currently used or planned for use in this estuary. Placing simple substrate in subtidal areas with intensive harvest and placing complex substrate in intertidal areas without intensive harvest are the most common. There are some complex substrate, subtidal projects planned. Oyster farming and aquaculture activity is growing in the area and is a source of local pride and identity.

Galveston Bay, TX: All of the restoration techniques except aquaculture are currently implemented in this estuary. Placing simple substrate in intensively harvested subtidal areas is most common and is done in both public oyster areas and on private leases (by the leaseholders). The Galveston Bay Foundation does many intertidal shoreline protection projects aimed at protecting other habitats (e.g., marsh). There are some complex substrate subtidal projects aimed at promoting ecosystem services, but there is always pressure to open projects to harvest. About one-third of the bay is closed to harvest due to water quality issues, and some small, ecologically sensitive areas, such as Christmas Bay, have been recently closed to intensive harvest. While oyster aquaculture is not currently used here, it is being discussed as a potential future option to reduce harvest pressure on oyster reefs.

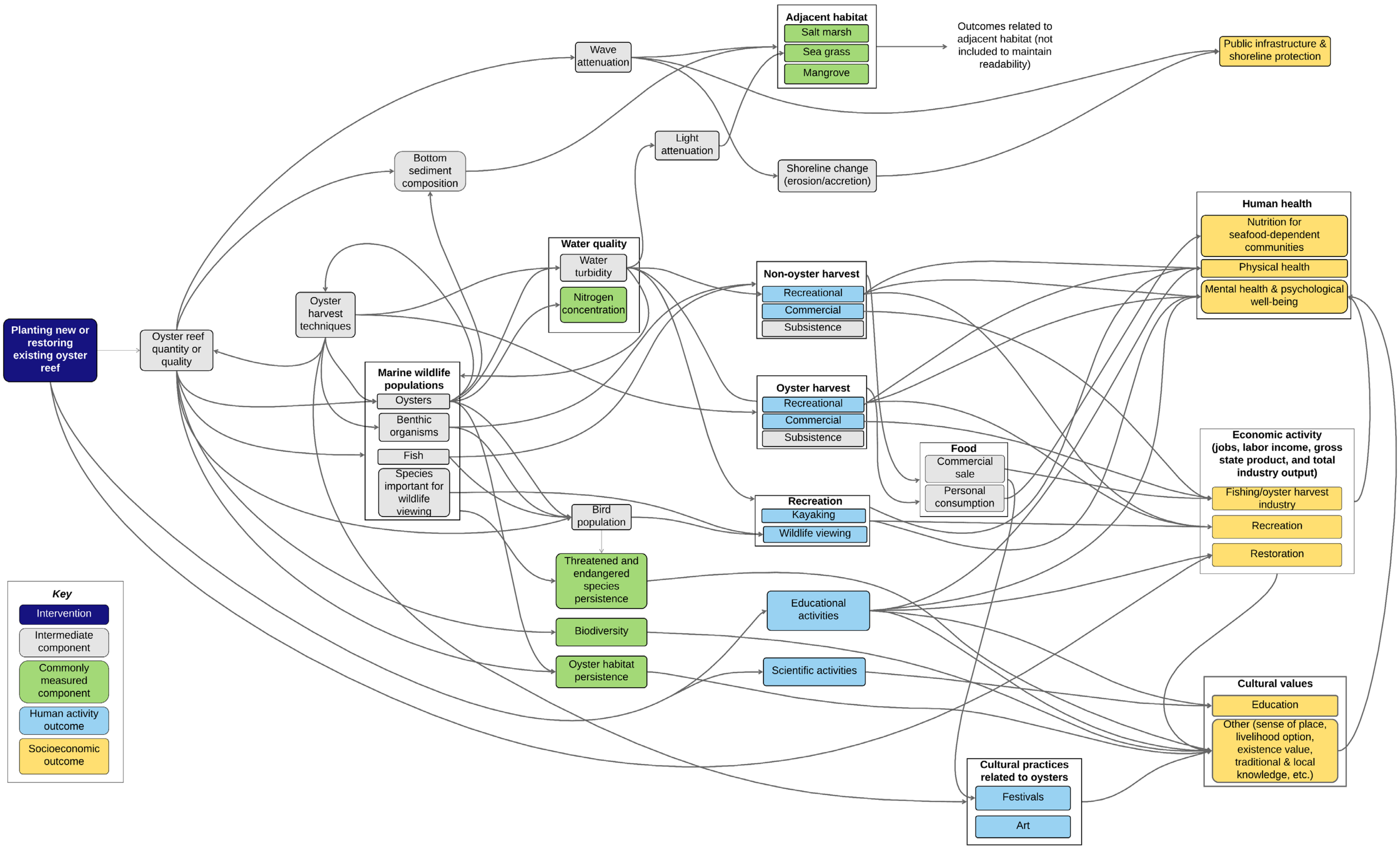
Chandeleur & Breton Sounds, LA: The only oyster restoration techniques used here involve placing simple substrate in intensively harvested subtidal areas and three-dimensional, intertidal "living shoreline" projects. The state uses simple, two-dimensional substrate to provide harvestable oysters, and the intertidal (shoreline or habitat protection) projects are done by organizations like The Nature Conservancy and the Coalition to Restore Coastal Louisiana. There have been a few very small demonstration projects placing complex substrate in subtidal areas, but these are unlikely to be scaled up because there is no large-scale oyster reef restoration of this type included in the Louisiana Coastal Protection and Restoration Authority master plan. There are no protected oyster reefs in this area, and there is currently no aquaculture, although there are ongoing efforts to obtain funding for it.

Oyster Reef Restoration Ecosystem Service Logic Model

The general ESLM was developed through a multistep process with input from oyster restoration experts and local stakeholders as well as through a literature review. Information about each of the links in the model is summarized in an evidence library, a structured way to collect and assess the evidence supporting each relationship represented in the model. The evidence library can be used to highlight gaps in our understanding of how oyster reef restoration affects the biophysical and social systems and guide monitoring efforts to address these uncertainties.

This is a general ESLM for oyster reef restoration. It is not tied to any one of the six restoration techniques; rather, it represents all of the outcomes from those techniques that are dominant—large, tightly linked to oyster reef restoration, and important to the local community. The model shows the cascade of changes that restoration (dark blue box) causes in the biophysical and social systems (gray boxes), leading to effects on commonly measured ecological components (green boxes), human activity outcomes (light blue boxes), and socioeconomic outcomes (yellow boxes). Downloadable pdf and editable versions of the general ESLM, as well as specific versions of the ESLM for each oyster reef restoration technique, are available on the GEMS website.

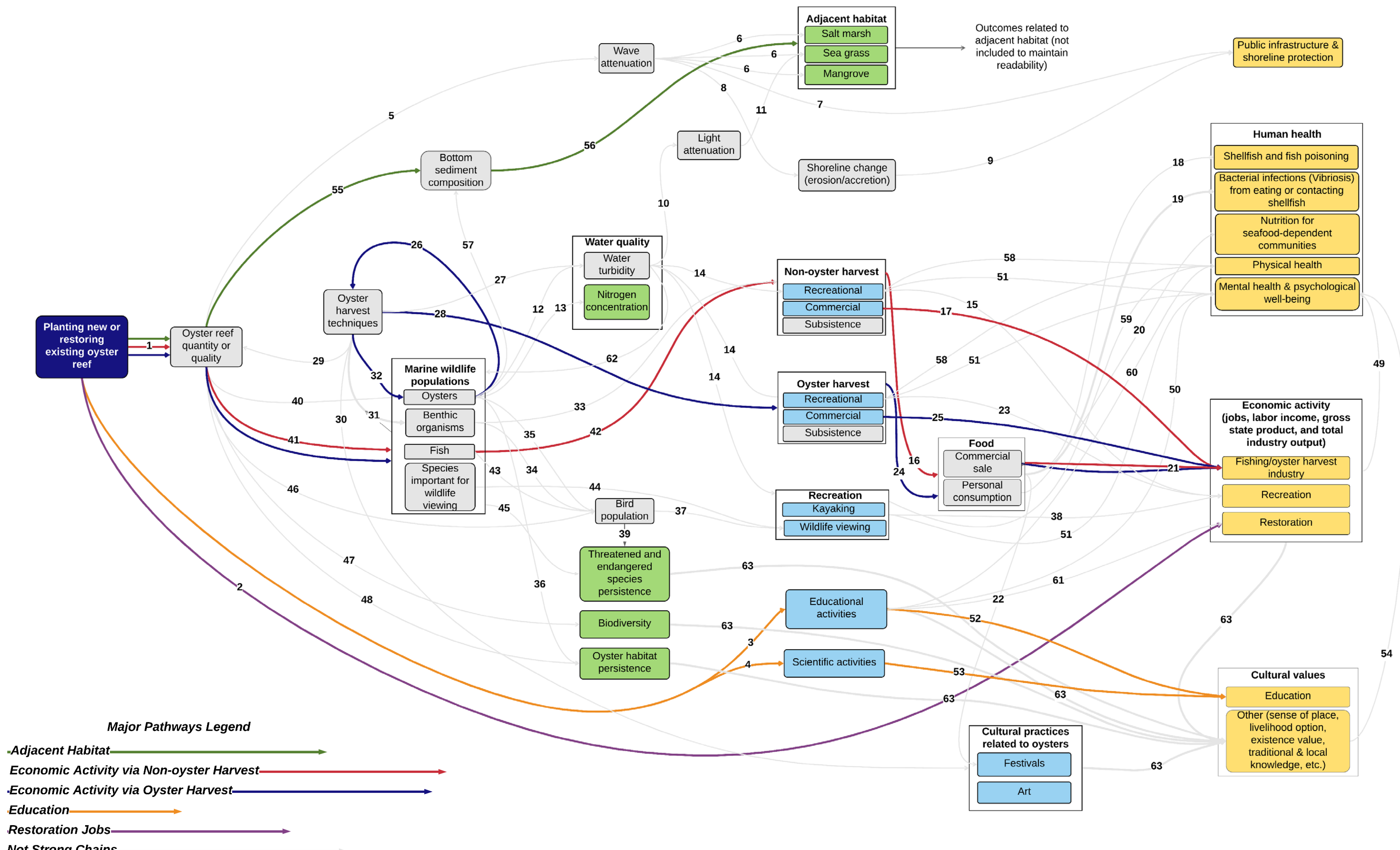
Figure 2. General Ecosystem Service Logic Model for Oyster Reef Restoration



In the ESLM, pathways consist of links that connect the intervention (left) to a socioeconomic outcome (right). Major pathways are those where socioeconomic outcomes are tightly linked to oyster reef restoration (ORR) (i.e. there is a possibility that the outcome would show a noticeable change given an ORR project). Each link in a major pathway has a moderate to high strength of evidence rating, is considered attributable to ORR (or has few "Other Factors"), and is considered significant based on the evidence and stakeholder input. We highlight five major pathways linking the intervention to the following outcomes in Figure 3, below:

- Adjacent habitat (which can have a range of additional outcomes and can be explored through the ESLMs for these other habitats);
- Economic activity in the fishing and oyster harvest industry through oyster harvest (Note: this pathway includes a feedback loop between intermediate outcomes "Oyster population" and "Oyster harvest techniques." Higher oyster populations in an area can result in increased harvest limits (or new areas open to harvest) and greater use of oyster harvest techniques. Oyster harvest in turn decreases oyster populations and generates economic activity through oyster sales.);
- Economic activity in the fishing and oyster harvest industry though non-oyster (fish, other shellfish, etc.) harvest;
- Economic activity through the restoration industry; and
- Education

Figure 3. Major Pathways Linking Oyster Reef Restoration to Socioeconomic Outcomes



Estuary-Specific Oyster Reef Restoration ESLMs

During the local workshops, the general oyster reef restoration ESLM was specified for each focal estuary by identifying which outcomes are important in the estuary, developing lists of key species for certain wildlife-related outcomes, and discussing estuary-specific external and social factors that can change restoration outcomes.

Dominant Outcomes by Oyster Reef Restoration Technique and Focal Estuary

The outcomes of a particular oyster reef restoration technique can vary by location due to differences in environmental and social contexts. Local workshop participants identified dominant outcomes for each relevant technique in their focal estuary. Dominant outcomes are tightly linked to oyster reef restoration (the expected change in the outcome is likely to be large and strongly driven by oyster reef restoration) and important to the community (the expected change in the outcome matters to many people or to groups of special concern). The following tables show the dominant outcomes for each oyster reef restoration technique used at each focal estuary.

Figures 4a-f. Oyster Reef Restoration Techniques

Figure 4a.

Technique 1: Simple subtidal, intensively harvested projects

	Chandeleur & Breton Sounds	Mobile Bay	Galveston Bay
Biodiversity	✓		
Recreational non-oyster harvest	✓		✓
Commercial non-oyster harvest	✓		✓
Commercial oyster harvest	✓	✓	✓
Nutrition for seafood-dependent communities	✓	✓	
Educational opportunities related to oyster reefs	✓		
Scientific opportunities related to oyster reefs	✓	✓	
Cultural practices related to oyster reefs	✓	✓	
Jobs in the fish/oyster harvest industry	✓	✓	✓

Figure 4b.

Technique 2: Complex subtidal, intensively harvested projects

	Mobile Bay	Galveston Bay
Biodiversity	✓	
Recreational non-oyster harvest	✓	✓
Commercial non-oyster harvest	✓	✓
Commercial oyster harvest	✓	✓
Scientific opportunities related to oyster reefs	✓	
Cultural practices related to oyster reefs	✓	
Jobs in the fish/oyster harvest industry	✓	✓

Figure 4c.

Technique 3: Complex subtidal, NOT intensively harvested projects

	Charlotte Harbor	Back Bay of Biloxi	Mobile Bay	Galveston Bay
Threatened & endangered species persistence	✓			
Biodiversity	✓	✓	✓	✓
Oyster habitat persistence	✓	✓	✓	✓
Damage to private commercial infrastructure		✓		
Damage to residential property		✓		
Recreational non-oyster harvest	✓	✓	✓	✓
Commercial non-oyster harvest	✓		✓	✓
Recreational oyster harvest	✓			
Commercial oyster harvest				✓
Nutrition for seafood-dependent communities	✓	✓	✓	✓
Kayaking			✓	
Wildlife viewing	✓			
Educational opportunities related to oyster reefs		✓	✓	
Scientific opportunities related to oyster reefs	✓	✓	✓	
Cultural practices related to oyster reefs		✓	✓	
Jobs in the fish/oyster harvest industry	✓			
Jobs in recreation	✓	✓	✓	
Jobs in education & scientific research		✓		
Jobs in oyster reef restoration		✓		

Figure 4d.

Technique 4: Complex intertidal, NOT intensively harvested projects

	Charlotte Harbor	Back Bay of Biloxi	Mobile Bay	Galveston Bay	Chandeleur & Breton Sounds
Adjacent habitat: Salt marsh*	✓	✓	✓	✓	✓
Adjacent habitat: Sea grass*	✓	✓	✓	✓	✓
Adjacent habitat: Mangrove*	✓			✓	✓
Threatened & endangered species persistence	✓				
Biodiversity	✓	✓	✓	✓	✓
Oyster habitat persistence	✓	✓	✓	✓	✓
Damage to public infrastructure			✓		
Damage to private commercial infrastructure		✓	✓		
Damage to residential property		✓	✓		
Recreational non-oyster harvest	✓	✓	✓	✓	✓
Commercial non-oyster harvest	✓		✓	✓	
Recreational oyster harvest	✓				
Commercial oyster harvest				✓	
Nutrition for seafood-dependent communities	✓	✓	✓		
Kayaking			✓		
Wildlife viewing	✓	✓	✓		
Educational opportunities related to oyster reefs	✓	✓	✓		✓
Scientific opportunities related to oyster reefs	✓		✓	✓	✓
Cultural practices related to oyster reefs		✓	✓		✓
Jobs in recreation	✓	✓	✓	✓	
Jobs in education & scientific research		✓	✓	✓	
Jobs in oyster reef restoration		✓			✓

*The adjacent habitat outcomes were not included in the dominant outcomes assessment, but often came up in discussion because many intertidal oyster reef restoration projects are done for the purpose of benefiting adjacent habitats. Therefore, these outcomes are included in the lists of dominant ecological outcomes for relevant focal estuaries.

Figure 5e.

Technique 5: Protection or enhancement of existing oyster reefs

	Charlotte Harbor	Back Bay of Biloxi	Mobile Bay	Galveston Bay
Threatened & endangered species persistence	✓			
Biodiversity	✓	✓	✓	✓
Oyster habitat persistence	✓	✓	✓	✓
Damage to public infrastructure			✓	
Damage to private commercial infrastructure		✓	✓	
Damage to residential property		✓	✓	
Recreational non-oyster harvest	✓	✓	✓	✓
Commercial non-oyster harvest	✓		✓	✓
Recreational oyster harvest	✓			
Commercial oyster harvest				✓
Nutrition for seafood-dependent communities	✓	✓	✓	
Kayaking	✓			
Wildlife viewing	✓	✓	✓	
Educational opportunities related to oyster reefs	✓	✓	✓	
Scientific opportunities related to oyster reefs	✓		✓	✓
Cultural practices related to oyster reefs		✓	✓	
Jobs in the fish/oyster harvest industry		✓		
Jobs in recreation	✓	✓	✓	✓
Jobs in education & scientific research		✓	✓	✓

Figure 5f.

Technique 6: Oyster aquaculture

	Mobile Bay
Recreational non-oyster harvest	✓
Commercial non-oyster harvest	✓
Commercial oyster harvest	✓
Nutrition for seafood-dependent communities	✓
Kayaking	✓
Wildlife viewing	✓
Educational opportunities related to oyster reefs	✓
Scientific opportunities related to oyster reefs	✓
Cultural practices related to oyster reefs	✓
Jobs in the fish/oyster harvest industry	✓
Jobs in recreation	✓

Important Wildlife Species by Outcome and Focal Estuary

Several outcomes of oyster reef restoration, such as recreational fishing, depend on individual wildlife species, and the most important species for particular outcomes vary across the Gulf of Mexico. Participants at the local workshops prioritized the top three species for each outcome:

Table 3. Top Three Species for Each Outcome

Outcome	Charlotte Harbor	Back Bay of Biloxi	Mobile Bay	Chandeleur & Breton Sounds	Galveston Bay
Harvest – Commercial	Blue crab, mullet, shrimp	Blue crab, brown shrimp, white shrimp	Blue crab, brown shrimp, mullet	Menhaden, blue crab, white shrimp	Shrimp, blue crab, stone crab
Harvest – Recreational	Snook, Tarpon, Red drum	Speckled sea trout, blue crab, red drum	Speckled trout, red drum, flounder	Red drum, speckled sea trout, blue crab	Spotted sea trout, flounder, red drum
Harvest – Subsistence	Mangrove snapper, sheepshead, mullet	potted sea trout, blue crab, sheepshead	Blue crab, white trout, mullet	Blue crab, red drum, croaker/ speckled seatrout (tie)	Croaker, blue crab, trout Wildlife viewing
Wildlife viewing	Dolphin, roseate spoonbill, white pelican/manatee (tie)	American oyster catcher, alligator, osprey	Dolphin, alligator, blue heron/brown pelican/bald eagle/osprey (tie)	Dolphin, alligator, bald eagle/other wading birds (tie)	Brown pelican, great blue heron, American oystercatcher/great white egret/plover (tie)
Threatened & endangered	American oystercatcher, smalltooth sawfish*	Gulf sturgeon, West Indian manatee, oyster	Gulf sturgeon, bald eagle, West Indian manatee	Sea turtles, pelicans, Gulf sturgeon	American oystercatcher, bottlenose dolphin, green sea turtle / loggerhead turtle (tie)

*This list of species is from discussions at the Charlotte Harbor local workshop, not from the formal prioritization process used for the other species lists in this table.

External Drivers and Factors

Local workshop participants identified external drivers—processes, events, or policies that can change restoration outcomes. These drivers are outside the control of the project.

- Climate and climate change
- Extreme weather events

- Oil spills and other disasters
- Boat/barge activity
- Land use
- Water management, including freshwater releases and diversions
- Freshwater inflows
- Sediment diversions
- Navigational dredging activity
- Harvest policy and compliance, including harvest closures, overharvesting, and poaching activity (see below for details)
- Restoration policy, including permitting requirements and funding constraints (see below for details)

Considering these drivers, participants identified and then prioritized the mechanisms through which each of these drivers influence the outcomes of oyster restoration projects in the focal estuary. First, we discussed the biophysical mechanisms (which we call external biophysical factors):

Table 4. External Biophysical Factors

	Charlotte Harbor	Back Bay of Biloxi	Mobile Bay	Galveston Bay	Chandeleur & Breton Sounds
Salinity	✓✓	✓✓	✓✓	✓✓	✓✓
Sedimentation	✓✓	✓✓	✓✓	✓✓	✓✓
Physical habitat destruction	✓	✓	✓	✓✓	✓✓
Pollution (including nutrients)	✓✓	✓	✓		✓
Predation	✓		✓✓		
Currents		✓✓			
Ocean acidification		✓	✓		✓
Temperature		✓			✓
Hypoxia			✓		✓
Oyster disease		✓			
Wave energy			✓		
Subsidence of reef complex					✓

Factors marked with a check received at least one vote during the prioritization exercise. Factors marked with two checks were among the top three identified as influential to oyster restoration project success during the prioritization exercise. Factors with no checks are not necessarily unimportant; participants often noted that factors interact with each other and are difficult to consider individually.

Participants also identified the social, behavioral, and economic mechanisms that were important in each estuary. These mechanisms can determine the type and extent of oyster restoration projects in a certain area, where these projects are located, access, and what outcomes the projects will have.

- Permitting requirements increase the cost of project implementation and can constrain project location (e.g., avoiding sensitive habitats or navigational channels).
- There is often institutional resistance to placing restoration projects in non-harvestable areas, either due to health concerns (if areas are closed to harvest due to water quality issues) or because of public pressure to increase the number of oysters available for harvest.
- Funding constraints can also influence the type and location of projects. For example, funding from the Louisiana state oyster program can only be used to create harvestable reefs.
- Overharvesting can limit restored reefs' long-term success and sustainability; the intensity of harvesting is partly determined by natural resource management policies, but poaching and theft are also common in some areas.
- The availability and cost of materials (especially natural oyster shell cultch) influences which materials are used in restoration projects.

Socioeconomic Metrics for Oyster Reef Restoration

Metrics to monitor and report on socioeconomic outcomes of oyster reef restoration were developed for the Gulf of Mexico in phase I of the GEMS project.

Local workshop participants brainstormed an initial list of metrics for socioeconomic outcomes of oyster reef restoration relevant to their communities, and the list was expanded through conversations with additional stakeholders and literature review. The metrics list was refined at a regional workshop in spring 2019 and finalized with feedback from the advisory council in fall 2019.

The final list of metrics is organized into a matrix based on scale (project scale or county to regional scale) and by tier (1 or 2). Scale refers to the scope of the data collection. Project scale metrics could feasibly be measured and reported by individual projects; regional or county scale metrics would likely need to be modeled for a suite of projects by a third party. Tier refers to the ease of data collection; tier 1 metrics are relatively low-effort and easy to measure, while tier 2 metrics would require additional effort and expertise for data collection. Metrics are also flagged by the outcome category (yellow boxes) corresponding to outcomes in the oyster reef restoration ESLM.

We considered metrics related to human health and resilience but did not include any in the final metrics list due to data availability and attribution issues. More information about these categories is included at the end of this document.

More information about each recommended metric follows the metrics matrix.

Table 5. Metrics Matrix

	Tier 1		Tier 2	
Project scale	Economic Activity	Aquaculture **jobs** (FTE, reported every 2 yr) Restoration **jobs** (FTE, reported every 2 yr) Restoration **expenditures** (reported every 2 yr)	Economic Activity	Recreational fishing **jobs** supported (number of guides visiting restored reefs, reported annually) Additional recreational fishing **expenditures** due to oyster reef project (number of recreational trips * average expenditure, reported annually)
Project scale	Public Infrastructure Protection	Miles of **public infrastructure with reduced erosion** from oyster restoration	Cultural Values	Number of people with **additional knowledge of oyster reefs** (surveyed by project) **Cultural value** to be selected through project team engagement with community and monitored via appropriate pre- and post-restoration data collection.
County to regional scale	Economic Activity	Economic activity from commercial harvest of oyster reef-associated species: **jobs, labor income, gross state product, and total industry output** (modeled, reported annually) Economic activity from commercial oyster harvest: **jobs, labor income, gross state product, and total industry output** (modeled, reported annually) Economic activity from restoration spending: **jobs, labor income, gross state product, and total industry output** (modeled, reported annually)	Cultural Values	Number of people with **additional knowledge of oyster reefs** (broader-scale survey)
County to regional scale			Economic Activity	Economic activity from recreational fishing: **jobs, labor income, gross state product, and total industry output** (modeled, reported annually)

A pdf version of the metrics matrix can be downloaded here.

Tier 1, Project Scale Metrics

Aquaculture jobs: The number of jobs directly supported by an oyster aquaculture project during operation (jobs supported through design and construction would be included in the "restoration jobs" metric below). This metric is only relevant for oyster aquaculture projects and should be known by the organization implementing the project. This metric is reported as full-time employee equivalents every two years.

Restoration jobs: The number of jobs directly supported by the restoration project. This includes project design, construction, and monitoring. The organization implementing the project should have this information. This metric is reported as full-time employee equivalents every two years.

Restoration expenditures: The total amount of money spent on the restoration project. This metric is reported every two years and can be taken directly from the project budget.

Miles of public infrastructure with reduced erosion from oyster restoration: The total length, in miles, of public roads or other infrastructure (e.g., railroads) that experiences decreased erosion rates due to the oyster restoration project. Infrastructure experiencing decreased erosion rates can be identified in two ways. The first is by designating all infrastructure within a set distance of the project to be protected by the project, according to the expert judgment of the project designer. The second is for the project to use aerial imagery to measure the erosion rate in the surrounding the area before the project is installed and after the project is completed, and to identify areas where the erosion rate decreased from pre-project rates. Any infrastructure in these areas is considered to be protected by the project.

Tier 1, County to Regional Scale Metrics

All tier 1 county to regional scale metrics would likely be modeled by a third party using available county- or state-level data. The modeling approach is technically referred to as "input-output" but is commonly known as economic impact analysis (EIA). EIA measures the change in economic activity (e.g., jobs, income, taxes, etc.) given the implementation of a project, such as oyster reef restoration. Below are direct economic activities, associated with oyster reef restoration, that lead to broader impacts that can be modeled (with EIA).

Economic activity from commercial harvest of oyster reef-associated species: jobs, labor income, gross state product, and total industry output would be modeled annually based on NOAA commercial harvest data and state data (e.g., Florida commercial fisheries) for relevant species.

Economic activity from commercial oyster harvest: jobs, labor income, gross state product, and total industry output would be modeled annually based on NOAA commercial oyster harvest data and relevant state data (e.g., Florida commercial oyster harvest).

Economic activity from restoration spending: jobs, labor income, gross state product, and total industry output would be modeled annually based on the money spent on restoration projects in the county or state.

Tier 2, Project Scale Metrics

Recreational fishing jobs supported: This metric would be reported annually as the number of fishing guides visiting the restored reef, based on a survey of local fishing guides conducted by the restoration project.

Additional recreational fishing expenditures due to oyster reef project: This metric would be reported annually as the additional recreational fishing expenditures due to the project, calculated as the number of recreational fishing trips to the project site (as observed as part of structured monitoring) multiplied by the average trip expenditure (from the National Survey of Fishing, Hunting, and Wildlife-associated Recreation)

Number of people with additional knowledge of oyster reefs: This metric would be assessed by the project through pre- and post-engagement surveys with volunteers, students, or other visitors to the project site. It would be reported once at the conclusion of the project. Surveys should include questions about the cultural importance of oysters, local uses of oysters, and oyster reefs' contributions to a healthy estuarine system in order to assess how visitors' oyster-related knowledge contributes to their sense of place and understanding of the community's ties to oysters.

Cultural value: Because cultural value is locally specific, this is not one recommended metric, but a method by which projects can include a relevant cultural value in their monitoring program. During project planning, the project team should engage with the local community to identify at least one cultural value that may be influenced by the restoration project. Based on the selected cultural value, the project team will conduct appropriate pre- and post-restoration data to assess the project's influence on that cultural value.

Tier 2, County to Regional Scale Metrics

Economic activity from recreational fishing: jobs, labor income, gross state product, and total industry output would be modeled annually at a county to regional level. Angler surveys would be conducted to account for the difference in activity associated with a restoration project, which would then be used as input into the economic impact analysis (see Texas Half Moon Reef example).

Number of people with additional knowledge of oyster reefs: This metric would be measured through a broader (county, state, or regional) survey administered by a third party to assess the influence of oyster reef restoration projects in the area on residents' knowledge of oyster reefs, beyond those people who directly interact with the projects through volunteering or educational activities. The survey would be initially administered prior to any extensive oyster reef restoration activity, and then repeated after several oyster reef restoration projects are completed. The survey should include questions about the cultural importance of oysters, local uses of oysters, and oyster reefs' contributions to a healthy estuarine system in order to assess how residents' oyster-related knowledge contributes to their sense of place and understanding of the community's ties to oysters.

Notes on Health and Resilience Metrics

One socioeconomic outcome in the logic model, human health, does not have any related metrics in the final list. While we considered health-related metrics such as additional nutrition for subsistence fishers provided by wild-caught seafood, reduced stress from physical activity during oyster restoration, and whether oyster restoration increased the number of protein sources regularly consumed by a community, we concluded that, with existing data, there is no way to attribute measures of health gathered at the state level or in national surveys to oyster reef restoration. Health changes would be intensive to measure locally, and even local measurements would be difficult to attribute specifically to oyster reef restoration. Therefore, health metrics are not on the final list.

We also considered several metrics related to resilience, including diversity of job options, income sources, and diet diversity. However, data for these metrics are not generally available, and they may not be relevant indicators of resilience in a developed country context. One metric included in the final list, public infrastructure protection, is relevant to the resilience of communities in the Gulf of Mexico.

Next Steps

Phase II of the GEMS project is currently underway. Based on feedback from the advisory council and regional workshop participants, the project focus is expanding from one restoration approach in phase I (oyster reef restoration) to include many additional types of habitat restoration (salt marsh, seagrass, mangrove, beach and dune, and living shorelines), as well as recreational access enhancement (through installing infrastructure such as boat ramps and boardwalks) and water quality interventions (including gray and green infrastructure for stormwater and wastewater management and restoring hydrologic connectivity). Results and products from phase II, including ESLMs and socioeconomic metrics for the new interventions, will be added to the GEMS website as they are completed.

APPENDIX I: GEMS PARTICIPANTS AND ADVISORS

Local Workshop Participants

Florida

Andrea Graves, TNC Blowing Rocks Preserve

Stephen Geiger, Florida Fish and Wildlife Conservation Commission

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