Oyster Restoration in the Gulf of Mexico

RECOMMENDATIONS FROM
THE NATURE CONSERVANCY

OCTOBER 2023

The Nature Conservancy

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CONTENTS

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Gulf of Mexico


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Summary

More than 10 years ago, scientists warned that oyster reefs had declined significantly in the Gulf of Mexico (Beck et al., 2011). Since then, the situation has gotten much worse. Despite the concerted efforts of state agencies, increasing restoration of oyster reefs, the growth of the oyster aquaculture industry, important oyster restoration research, and increased funding for improving the overall condition of the Gulf, the extent and condition of oyster reefs have continued to decline in all five Gulf states. With this decline the people of the Gulf region are losing the economic and cultural value of the oyster fishery and the important ecosystem services provided by oysters and oyster reefs. Current restoration and management efforts, while very much in the right direction, are not sufficient to reverse that decline.

Thus, the Gulf states are facing an unprecedented oyster crisis. Additional decisive action is needed to address this problem. There is more funding available to restore oysters than ever before, but unless that funding is allocated and invested strategically, oysters will not recover to a self-sustaining level in the Gulf of Mexico ecosystem. This paper presents The Nature Conservancy's recommendations to address the oyster crisis at a scale and pace that will make a lasting positive difference in the ecological and economic health of the Gulf.

The Nature Conservancy has directly engaged in oyster restoration in the Gulf and elsewhere in the world for more than 20 years. In this paper, we draw on that experience and on the research of others to suggest a shared vision for the future of oysters in the Gulf of Mexico. We propose the following specific actions that we believe can accelerate oyster restoration in the Gulf region:

1. Develop actionable, watershed-based plans with quantifiable goals for returning self-sustaining oyster reefs to whole bays and estuaries. These plans must assess where salinity, water quality, tidal flows and other conditions are suitable for oyster restoration.
2. Employ a wide range of permitting, design and construction strategies, tools, and techniques that reduce the cost and significantly increase the pace and scale of oyster restoration to achieve sustainable fisheries and ecosystem services throughout the Gulf.
3. Apply up-to-date, science-driven data to governance and regulatory management of oyster resources to achieve sustainable harvests and ecosystem services in collaboration with stakeholders and rights holders. This includes advancing management of wild oyster habitat through a combination of unharvested reefs and harvestable reefs to ensure a robust and sustainable oyster population and harvest.
4. Apply new science to oyster restoration.
5. Encourage and support oyster aquaculture as a viable economic option that takes the pressure off wild oyster stocks and provides valuable ecosystem services.
6. Understand and manage freshwater flows into estuaries to maintain natural habitat, including oyster reefs.
7. Retain and recycle oyster shell back onto reefs, when possible to their reef of origin, to maintain reef viability and productivity and seek new sources for oyster substrate.
8. Sustain long-term monitoring of oyster restoration, enhancement, and creation efforts and wild stocks to provide the information needed for effective and ongoing adaptive management of oyster habitat and the oyster fishery.
9. Accelerate oyster restoration by sourcing new funding.

The decline of oysters in the Gulf did not happen overnight, and recovery will take thoughtful and unwavering commitment over many years. A systems approach is required to restore oyster resources while addressing the impacts from human-related activities in watershed lands and waters that affect the health of the Gulf's estuaries.

To support these actions, The Nature Conservancy proposes that Deepwater Horizon Natural Resource Damage Assessment and other Deepwater Horizon–related funding be combined with other federal grant sources to allocate $40–50 million to each Gulf state for stepped-up actions to reverse the oyster decline and make visible and tangible progress toward restoring oysters as a key element in a healthy future Gulf of Mexico. These public funds may be supplemented by private investment in oyster restoration.


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The Oyster Crisis

Oyster harvesting and processing provide significant direct and indirect sources of income to many Gulf of Mexico coastal communities. In addition to supplying oysters for market, oyster reefs provide important ecosystem services that are essential to the health of the Gulf region, including:

- Increasing the resilience of coastal habitats and communities
- Protecting adjacent shorelines
- Providing forage, nursery, and refuge habitat for commercially, recreationally, and ecologically important species of fish, shrimp and crabs and other reef-associated estuarine species
- Improving/maintaining water quality through the filtration that takes place when oysters feed
- Providing larval oyster supplies to adjacent commercial and public harvest areas

The vast numbers of wild oysters historically present in the Gulf of Mexico played a key role in the health of the overall ecosystem; the dramatic decline of oysters, estimated at 50–85% or greater throughout the Gulf, has damaged the stability and productivity of the Gulf's estuaries and harmed coastal economies (Beck et al., 2011).

Despite increased remedial efforts across the Gulf region, that decline has continued, and wild oyster harvests are being further restricted or closed. The loss of oyster resources resulting from impacts associated with the Deepwater Horizon (DWH) spill in 2010 only compounded existing challenges to maintaining long-term, viable oyster populations. These challenges include changes in freshwater flows to the Gulf's estuaries (from droughts, floods, and water use upstream), sedimentation, increasingly frequent and intense storms, low dissolved oxygen levels, oyster diseases, and heavy fishing pressure. Increased fishing pressure is a characteristic of many diminishing fisheries resources as seafood prices rise and can be difficult to manage, despite the good intentions of the managers of oyster stocks.

Oyster Reefs in the Gulf Continue to Decline

Despite concerted restoration efforts by state agencies and nonprofit organizations, oyster harvests in the Gulf continue to decline:

- In 2020, the Florida Fish and Wildlife Conservation Commission closed Apalachicola Bay to oyster harvest for five years to enable recovery from the collapse of oyster populations. Traditionally Apalachicola Bay supplied 90% of the oysters harvested in Florida.
- In Alabama oyster harvests were so low in 2016–2018 and oyster stocks so depleted that no harvest was permitted by the state in 2019.
- In Mississippi in 2022, only 457 sacks of oysters were harvested when 10 years before the harvest was in the range of 400,000 sacks.
- In Louisiana, a 2019 study concluded that the size of public oyster reefs was the smallest ever recorded.
- In Texas in 2022, almost all public reefs were closed to harvest early in the season because of depleted stocks, and three bays were closed permanently.

While harvest numbers are an indicator of the overall size and health of the oyster population, they do not fully represent the status of oyster habitat, which also continues to decline.

We Are Not on a Trajectory to Restore Oysters to Their Former Ecological and Economic Importance in the Gulf

Oyster restoration has increased across the Gulf, particularly since the Deepwater Horizon Oil Spill in 2010, and there have been individual successes in the restoration of reefs and the growth of aquaculture. However, the overall population of wild oysters and self-sustaining oyster reefs in the Gulf of Mexico continues to decline. The recovery of oyster populations and habitat is not self-sustaining, is insufficient to enable increased harvests, and is inadequate to recover all the other ecosystem benefits provided by healthy oyster populations. Further, there are scientific concerns that not all oyster restoration projects are successful and that oysters in an estuary must meet a certain threshold of numbers and density to be self-sustaining.

Oysters are not being restored at the pace and scale needed to achieve sustainable fisheries and ecosystem services. TNC and others have been constructing individual reef projects in the hope that these reefs will contribute to reversing oyster decline. Our direct experience and our oyster restoration partnerships tell us that across the Gulf current per acre restoration costs are too high, the sizes of projects are too small, the pace of restoration projects is too slow, and restoration capacity of agencies, nonprofits and contractors is insufficient to result in significantly increased Gulfwide ecological benefits from oysters or to ensure sustainable oyster harvesting. Having both healthy oyster habitat and a prosperous oyster fishery is not an "either/or" scenario.

The Basis for TNC's Recommendations

The Nature Conservancy has had a long-standing commitment to oyster restoration and management in the Gulf and elsewhere in the United States, driven by our recognition of the multiple benefits of oysters and oyster reefs to coastal ecosystems and to the people and communities in coastal areas and beyond. This paper builds on our direct experience and restoration partnerships, our continuing active engagement in oyster restoration in the Gulf, and our review of the research and recommendations of others, including:

- The Strategic Framework for Oyster Restoration Activities following the Deepwater Horizon Oil Spill (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2017)
- Discussions with government officials and staff responsible for oyster management in the Gulf states
- Oyster restoration projects completed by TNC in Galveston Bay, TX; Calcasieu Lake, LA; Bay St. Louis, MS; Pensacola Bay, FL; and our experience with oyster restoration and management throughout the United States and other countries
- TNC's previous report, Oyster Restoration in the Gulf of Mexico Proposals (Bendick et al., 2018)
- The Oyster Fisheries and Habitat Management Plan for the Pensacola Bay System completed by TNC with community and agency partners (Birch et al., 2021)
- Research and project development being conducted by a Rutgers University Team for the Defense Advanced Research Projects Agency (DARPA)
- Participation in a National Fish and Wildlife Foundation Gulf Environmental Benefit Fund workshop on oyster restoration in the summer of 2022
- Participation in the Oyster Restoration Community of Practice sponsored by the Gulf of Mexico Alliance
- Oyster Model Inventory: Identifying Critical Data and Modeling Approaches to Support Restoration of Oyster Reefs in Coastal U.S. Gulf of Mexico Waters (LePeyre et al., 2021)
- The curious case of eastern oyster *Crassostrea virginica* stock status in Apalachicola Bay, Florida (Pine et al., 2015)

- An extensive survey of the oyster reef-building industry conducted by TNC staff in partnership with Bain and Company in 2022 (Hall & DeAngelis, 2022)
- A range of manuals and guides to help the restoration community succeed in reef restoration, including a Monitoring Guide (Baggett et al., 2014), a Manager's Guide (zu Ermgassen et al., 2016), a Restoration Guide (Fitzsimons et al., 2019), and a habitat site suitability model (Geselbracht et al., in press).

This paper offers recommendations from TNC on restoration, management, and recovery of oysters in the Gulf. We do not expect these recommendations to be adopted all at once, nor do we expect that TNC will be the implementer of most of these proposals. They are intended to stimulate discussion and a variety of actions by the many stakeholders involved in oyster restoration, harvest, research, and management. Each of the Gulf states is already engaged in various oyster restoration efforts. This document offers some solutions to the oyster crisis that meet the needs of the Gulf's natural resources, people, and economies. While state governments are primarily responsible for the restoration and management of oysters, local, state and federal agencies can provide financial support and research; nonprofit organizations can provide recommendations, conduct science, execute projects, convene stakeholders, and advocate for restoration policies; academic institutions conduct important research, carry out monitoring, and offer policy recommendations; and private businesses provide restoration expertise, funding and community support. Those whose livelihoods depend on or are augmented by a sustainable oyster fishery and habitat and healthy bay systems must be consulted and included in all oyster restoration decision-making processes.

Achieving Gulfwide success can be accomplished by establishing a shared vision for the future of oysters. This includes sharing management strategies, restoration technologies, planning techniques, monitoring results, data and, importantly, working in collaboration with the harvest and aquaculture industries and other community stakeholders. The Gulf States Marine Fisheries Commission, the Gulf of Mexico Alliance Oyster Community of Practice, national and state estuary programs, National Estuarine Research Reserves, TNC and other nonprofit entities can be useful in this respect.

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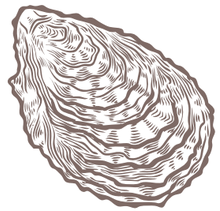
Goal for Oyster Restoration

After discussion with many stakeholders, The Nature Conservancy proposes an overall goal for oyster restoration in the Gulf:



By 2035, restore oyster populations in all five Gulf states to enable a viable oyster fishery to exist with the simultaneous recovery of oysters as a functional, self-sustaining habitat that provides multiple benefits.

Toward achieving this overall goal, The Nature Conservancy believes that it is possible to set acreage and locational oyster restoration goals for specific bays and estuaries based upon the desired levels of ecosystem services, which includes harvest, for those locations. This requires calculating the quantity of oysters and oyster reefs needed in each bay/estuary and designing and implementing restoration and management strategies to achieve this goal. This planning requires an understanding of the physical capability of bays and estuaries to support self-sustaining oyster populations in an era of changing climate.

The above goal encompasses the sub-goals set out in the *Strategic Framework for Oyster Restoration Activities* (2017) produced by the Regionwide Trustee Implementation Group for the Deepwater Horizon Oil Spill:

- **Restore oyster abundance and spawning stock** to support a regional oyster larvae pool sufficient for healthy recruitment levels to subtidal and nearshore oyster reefs.
- **Restore resilience to oyster populations** that are supported by productive larval source reefs and sufficient substrate in larval sink areas to sustain reefs over time.
- **Restore a diversity of oyster reef habitats** that provide ecological functions for estuarine-dependent fish species, vegetated shoreline and marsh habitats, and nearshore benthic communities.

These sub-goals include both maintaining a viable and sustainable harvest of oysters for sale and consumption and the effective, conservation, management, and restoration of oysters to provide ecosystem services.

Strategies to Achieve Oyster Restoration

A long-term objective of oyster restoration and management in the Gulf should be to manage oysters using a shared vision and coordinated approach that delivers the ecosystem functions and services needed to sustain healthy reef habitats and economically sustainable oyster fisheries. What follows are strategies that can aid in achieving this objective:

1. Develop actionable plans with quantifiable goals for oyster restoration and management.
2. Increase the scale and pace of oyster restoration in the Gulf.
3. Manage oyster stocks based on the multiple benefits of oysters.
4. Apply new science to oyster restoration.
5. Encourage oyster aquaculture.
6. Manage freshwater inflows and site restoration to reflect freshwater inflow variations.

7. Retain oyster shell and seek alternative substrate materials.
8. Expand monitoring and adaptive management.
9. Accelerate oyster restoration by sourcing new funding.

These strategies should be considered in an integrated manner to meet the specific needs of a particular geography and the goals of the various stakeholders in those bays and estuaries. Since each of the Gulf states manages its oyster resources independently, the combination of strategies may be different based on those that work best for the physical, social, economic, and environmental needs of each state. A coordinated effort within and across the Gulf states is needed to facilitate sharing of ideas and experiences, research, and the results of restoration projects, and to achieve the 2035 goal of restoring oysters across the region. These strategies are described in more detail in the following pages.

1. Develop actionable plans with quantifiable goals for oyster restoration and management.

Planning is essential to optimize investments in oyster restoration. Three levels of planning activities are needed to accelerate oyster restoration, including to take into account the impacts of climate change:

- Regionwide sharing of restoration information and science.
- State-level planning for restoration and management policies that further the ability of agencies to achieve desired results.
- Specific estuary-level planning for where and how oysters are to be restored and how they are to be managed to establish long-term sustainability.

Gulfwide oyster restoration planning

The Strategic Framework for Oyster Restoration Activities report produced by the Gulf Natural Resource Damage Trustees (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2017) is a sound document that proposes strategies and actions consistent with The Nature Conservancy's assessment of oyster restoration. This document can be a foundation for further oyster restoration planning, but it is not sufficient to solve the oyster crisis.

Identification of a Gulfwide entity, or dedicated collaboration of entities, is needed for rapid and effective sharing of advances in science and ecosystem services–based oyster restoration strategies, techniques, experiences, modeling, monitoring results, and restoration planning. The Gulf of Mexico Alliance Oyster Community of Practice and the Gulf States Marine Fisheries Commission have begun to play this role.

State-level planning

The Gulf states recognize the continuing decline of oyster reefs and are developing plans that share a comprehensive approach to oyster restoration. TNC urges all states to adopt management strategies that advance the goals set out earlier in this paper.

Estuary/watershed-based planning

Reversing the decline of oysters requires stakeholders in communities across the Gulf (e.g., oyster industry, businesses, state agencies, local municipalities, universities, nonprofit organizations, and others) to join together to develop and implement oyster restoration plans. Oyster restoration plans must be at appropriate and meaningful scales for implementation and include discussions and trade-off analyses around how much, where and for what purpose restoration is needed and how to manage oyster resources to maximize ecological services, including harvest. This information must also identify those areas of the estuary that are suitable for oyster restoration based on salinity, water quality, tidal flows, vulnerability to sedimentation and other physical factors projected and take into account the impacts of a changing climate.

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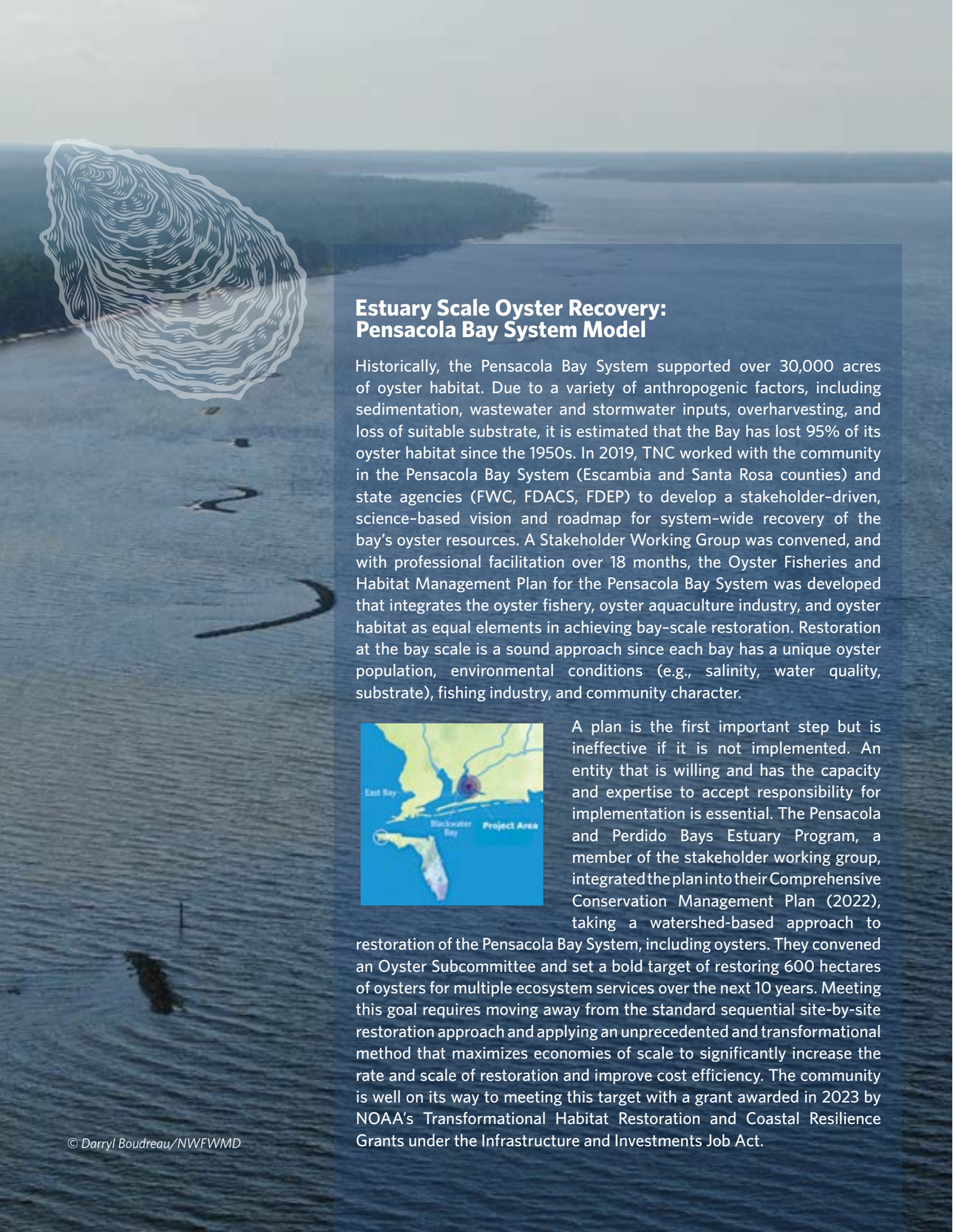
TNC works closely with leading Gulf scientists to develop practical methods for setting oyster restoration and management goals based on desired levels of ecosystem and oyster production results. This means establishing estuary-specific restoration goals for ecosystem services that include harvest and adopting restoration and management actions to achieve those goals.

The appropriate scale to implement these plans will vary depending on the location but will have the following commonalities: 1) uses a scale that is meaningful to the community and resonates with how the community views and uses their ecosystem; 2) is discrete enough to establish realistic goals and objectives; 3) uses a geographic scale that best represents oyster standing stock biomass to facilitate improved oyster harvest and habitat management.

The Oyster Fisheries and Management Plan for Pensacola Bay (Birch et al., 2021), the Oyster Futures stakeholder process in Maryland (OysterFutures Stakeholder Workgroup, 2018), and the Calcasieu Lake Plan developed by TNC's Louisiana Chapter in partnership with local Louisiana stakeholders can serve as models for replicating this approach to oyster restoration.

Additional locations for estuary-based planning should best meet the data and informational needs required to have meaningful uptake by resource managers, restoration practitioners, and industry.



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Estuary Scale Oyster Recovery: Pensacola Bay System Model

Historically, the Pensacola Bay System supported over 30,000 acres of oyster habitat. Due to a variety of anthropogenic factors, including sedimentation, wastewater and stormwater inputs, overharvesting, and loss of suitable substrate, it is estimated that the Bay has lost 95% of its oyster habitat since the 1950s. In 2019, TNC worked with the community in the Pensacola Bay System (Escambia and Santa Rosa counties) and state agencies (FWC, FDACS, FDEP) to develop a stakeholder-driven, science-based vision and roadmap for system-wide recovery of the bay's oyster resources. A Stakeholder Working Group was convened, and with professional facilitation over 18 months, the Oyster Fisheries and Habitat Management Plan for the Pensacola Bay System was developed that integrates the oyster fishery, oyster aquaculture industry, and oyster habitat as equal elements in achieving bay-scale restoration. Restoration at the bay scale is a sound approach since each bay has a unique oyster population, environmental conditions (e.g., salinity, water quality, substrate), fishing industry, and community character.

A plan is the first important step but is ineffective if it is not implemented. An entity that is willing and has the capacity and expertise to accept responsibility for implementation is essential. The Pensacola and Perdido Bays Estuary Program, a member of the stakeholder working group, integrated the plan into their Comprehensive Conservation Management Plan (2022), taking a watershed-based approach to restoration of the Pensacola Bay System, including oysters. They convened an Oyster Subcommittee and set a bold target of restoring 600 hectares of oysters for multiple ecosystem services over the next 10 years. Meeting this goal requires moving away from the standard sequential site-by-site restoration approach and applying an unprecedented and transformational method that maximizes economies of scale to significantly increase the rate and scale of restoration and improve cost efficiency. The community is well on its way to meeting this target with a grant awarded in 2023 by NOAA's Transformational Habitat Restoration and Coastal Resilience Grants under the Infrastructure and Investments Job Act.

In selecting estuary-based planning projects TNC recommends that the following considerations be taken into account:

- Does the community support restoration and recovery of oyster resources and development of a plan?
- Is there an entity trusted by the community and agencies that has the expertise and capacity to facilitate development of a plan?
- Is there an entity trusted by the community and agencies that has the expertise and capacity to implement the plan?
- Is there sufficient funding available to develop a plan?
- Are there regulatory/management issues that are causing conflict and must be addressed?
- Can resource managers, the oyster industry, and community leaders serve as strong partners and voices of support?
- Are there sufficient resources to initiate changes in state policy (e.g., biologists, communications, government relations)?
- Are there trends/shifts in the current oyster management approach in the prospective planning area that will affect the new plan?
- Possible other considerations include existing or planned ecosystem service science, fisheries projects and the presence or absence of existing state, regional or estuary oyster goals.

2. Increase the scale and pace of oyster restoration in the Gulf.

Despite the success of some individual reef projects, oyster reef restoration is not progressing at a pace or scale necessary to restore the ecological or economic benefits of widespread self-sustaining reefs that existed previously in the Gulf. With a few exceptions such as Apalachicola Bay, restoration (i.e. planning, funding, designing, permitting, constructing, and monitoring) is being conducted project-by-project. As a result, restoration is too costly, and the pace of restoration is not adequate to meet the large-scale oyster population goal. To achieve the oyster restoration goals expressed above, the speed and scale of reef construction must be accelerated and the per unit costs of restoration reduced while recognizing the importance of building oyster reefs with strong vertical profiles (Pine et al., 2022; Schulte et al., 2009).

Oyster reef restoration, nationally, is led predominantly by over 100 NGOs and state resource agencies; consequently, it is often not pursued like a private business that must continually optimize its cost structure and find cheaper methods to achieve desired outcomes. Given that oyster reef restoration has become an industry of its own, TNC in partnership with the consulting firm Bain and Company developed a report (Hall & DeAngelis, 2022) to assess how, by using similar approaches to private sector market studies, reef construction can be made more cost effective. This research used state, organization, and project-level data to derive performance improvement ideas to reduce the costs of oyster reef restoration. The study identified seven cost reduction opportunities and nine advancements required to lower the unit cost and increase the scale of restoration. Opportunities like these should be implemented where possible to increase the scale and pace of oyster restoration in the Gulf.

A whole Pensacola Bay oyster restoration project has now been funded for the Pensacola Bay Estuary Program. This is an opportunity to test some of these ideas.

Oyster hatcheries can play a role in restoration but are most useful in supporting an increase in oyster aquaculture. In many places in the Gulf suitable for oyster restoration there is already sufficient spat to populate new substrate, but there are some areas where conditions are right for oyster restoration where populations are so depleted that hatchery-grown spat can help to jump-start the restoration process. Hatcheries should not, however, be considered a single solution to the decline of wild oyster populations.

Further, oyster reef restoration is inhibited by multiple factors that make scaling difficult. The Hall & DeAngelis (2022) study has nine recommendations for the advancements required for the industry to scale:

1. Consistent funding for restoration such as through state legislative action.
2. State-wide oyster restoration planning, permitting, and protection.
3. Upfront investment in permitting efficiencies and simplification.
4. Alternative and innovative substrate, including the potential coordinated use of scrap concrete from infrastructure projects, can reduce substrate transportation and purchase costs.
5. Restoration-earmarked hatchery capacity when needed.
6. Integration with commercial fisheries replenishment efforts. This point suggests focused efforts to link the building of spawning source reefs with harvestable reefs such as through pairing or coordinating long-term reef design and construction.
7. Multi-year monitoring of restored sites.
8. Increased prevalence of, and competition among, contractors.
9. Support for restoration from commercial and recreational fisheries.

These will mutually make each project easier for restoration practitioners and catalyze step-changes in the costs of oyster reef restoration.

3. Manage oyster stocks based on the multiple benefits of oysters.

A significant challenge to oyster restoration in the Gulf (and elsewhere in the country) is how to manage oyster stocks in ways that:

- Accomplish restoration at the scale identified for recovery in bay systems.
- Consider the need to manage oyster stocks at levels sufficient to sustain the oyster population and habitat while supporting the livelihoods of oyster fishers.
- Maintain the production of other estuarine and marine species to support the livelihoods of non-oyster fishers.

Oyster stocks have diminished across the Gulf as a result of multiple causes, and harvesting pressure has increased on the remaining reefs. This has caused wild stocks to be further depleted and at many locations they are no longer self-sustaining.

Rebuilding stocks will necessitate stricter harvest limitations, which may be a hardship for harvesters. The Gulf states are seeking their own solutions to this problem, and several options are possible:

- Establishing a network of oyster reef spawning reserves where harvesting is prohibited or limited. Spawning reserves can be paired with harvestable reefs that are carefully managed to ensure a sustainable stock of oysters.
- Evaluating the use of harvesting gear types to ensure that gears and methods used do not impact reefs such that they require frequent cultch placement or become susceptible to prolonged higher salinities (by being reduced in height or buried by sediment).

New Ways of Increasing the Efficiency and Reducing the Unit Cost of Oyster Restoration

The seven opportunities that collectively can reduce the cost of restoration by greater than 50% (i.e., doubling the pace of restoration without any more funding), are:

1. Implement fewer, but larger, projects to gain economies of scale. Ideally this would mean planning, designing, engineering, permitting, and contracting for construction of multiple reef sites across a whole estuary using the same team or a few teams working simultaneously and cooperating with each other.
2. Enhance capabilities through in-sourcing and training. When doing large-scale or connected projects over the long term, it may be cost effective to hire in-house staff to do project design and management.
3. Increase collaboration with existing commercial marine work such as clutching to improve routine oyster harvests and coastal construction. This might also include employment of oyster fishers in reef building.
4. Increase involvement of contractors in conception and design stages.
5. Share designs through the creation of a design database.
6. Create a cultch materials database.
7. Continue sharing ideas to follow the latest industry best practices.

These cost reduction opportunities can meaningfully reduce the time required to restore a given area.

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- Developing regular and more comprehensive monitoring of harvested reefs with an eye toward adaptive management, long term viability and determining rotational harvesting schedules.
- Permitting additional bottom and water column leasing to enhance production.
- Creating a broader portfolio of income-generating opportunities that retain a sense of place to watermen and women, support working waterfronts, and expand the stewardship for the resource (e.g., using restoration funding to pay oyster harvesters for restoration work as an alternative to harvesting as stocks rebuild by involving harvesters in cultching and relaying efforts and other activities that maintain and grow oyster resources).
- Creating dedicated shell retention and recycling programs in each state (for each harvested estuary) to reduce substrate deficits and, thus, to reduce the need to mine rock in other states for cultch material.

In each case, management measures should be developed cooperatively with industry interests to ensure fairness and practicality. This should be part of the oyster planning process described above—that is, when establishing oyster restoration goals for each estuary, the management measures should be identified as critical tools to attain those goals.

4. Apply new science to oyster restoration.

The proposals explained above can accelerate oyster restoration, but we should also take advantage of new science that can fill data gaps and discover new restoration techniques needed to inform oyster recovery and ecosystem-based oyster management. While there are not likely to be individual science breakthroughs that solve the oyster crisis, the following areas of research may inform and accelerate restoration:

- Improve methods of measuring ecosystem services to inform management objectives.
- Research the effectiveness of "spawning reserve reefs" and estuarine protected areas in providing spat to populate surrounding areas of a bay, including methods to encourage oyster recruitment.
- Find methods to increase hatchery production as one means to meet restoration needs in larval-limited areas to kick start oyster colonization.
- Investigate less expensive and more effective environmentally neutral substrates to take restoration to scale, including local sources.
- Investigate new methods of predator control.

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- And, in an important new area of research, investigate the implications of positive density-dependent mortality (depensation) and develop modeling tools that may help to estimate the possible existence of, and avoid reaching, any critical lower thresholds in Gulf oyster populations below which mortality may increase with declining abundance (Johnson et al., 2022). In plain language, oyster restoration may need to reach a critical mass of oysters to be self-sustaining.
- Confirm the importance of oyster reef design, including reefs with vertical profiles, to the success of restoration.

5. Encourage oyster aquaculture.

Oyster aquaculture can be an important component of a comprehensive oyster restoration strategy. Aquaculture of oysters can provide some of the services derived from natural/reconstructed oyster reefs and, importantly, can supplement the production of wild oysters for the seafood market and provide jobs and income for some of those who have been involved in the oyster fishery and those establishing a new business.

Techniques for growing oyster larvae and attaching them to cultch material are well developed. Oyster industry representatives believe that using this "spat-on-shell" technique will help carry commercial harvesting through periods of naturally low production, help to increase overall production levels, and serve as a supplementary source of income for people in the oyster industry.

In addition to spat-on-shell, there are also a number of "off-bottom" culture techniques (e.g., growing oysters in cages suspended over the bay bottom). These forms of oyster aquaculture are expanding throughout the Gulf.

In locations where oyster aquaculture is feasible, the oyster aquaculture industry, regulatory agencies and other affected stakeholders could consider adopting a standardized lease siting approach that equally considers and integrates environmental, economic, and social needs. The approach could identify optimal aquaculture locations that avoid environmental and social impacts while also maximizing ecosystem benefits and economic profitability. Aquaculture projects could be sited in areas with active oyster restoration activities so that larvae produced (if using diploid oysters) would augment restoration (recognizing that there are some technical issues involving the kinds of oysters that are grown that may limit this benefit). An integrated, collaborative approach to siting aquaculture and restoration activities around the Gulf could help meet commercial production needs regionally and ameliorate temporary local declines in oyster populations that occur during extended periods of drought or flood, or through anthropogenically mediated events like dredging activities or oil spills. Hatcheries can be used to fill orders for both grow-out of oysters for consumption and to produce seed stock used in restoration projects not intended for harvest.

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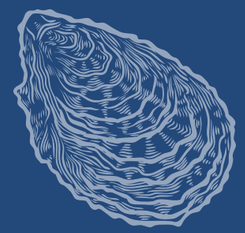
Oyster Shell Recycling and Substrate Alternatives

The Mississippi Chapter of TNC is leading an effort to develop an oyster shell recycling program in Mississippi, called Save Our Shells. Save Our Shells is paid for by an award from the Mississippi Department of Environmental Quality in partnership with the Gulf Coast Ecosystem Restoration (RESTORE) Council. A preliminary feasibility study estimates that annually, approximately 3.1 million customers consume 5.1 million oysters at 51 restaurants along the Mississippi coast. This amounts to an estimated 1.6 million pounds of oyster shell at a volume of about 1,200 cubic yards that is available from Mississippi coast restaurants for recycling. TNC is targeting the collection of a portion of this material with the expectation to deliver shell to activities that benefit oyster restoration and stewardship. Pilot collection activities are planned to begin in 2023 and results will be documented and compared with the initial feasibility study.



But recycling shells is not enough to meet substrate demands for ecological recovery. Shell is so unavailable that most oyster restoration work (both for harvest and unharvested reefs) is done with lime rock or other materials. Much of this rock originates in and is transported from states that do not border the Gulf of Mexico. Regardless of the source, this is not a sustainable, long-term restoration solution. The Bipartisan Infrastructure Legislation, the Inflation Reduction Act, and other federal programs may provide innovative solutions for the use of appropriate materials that include demolished bridge pilings, seawalls (often with live oysters on them), and other suitable substrate that will be available over the next decade or more and would otherwise end up in overburdened landfills. The use of these materials requires coordination among restoration project managers, demolition companies and agency regulators at all levels of government to ensure that contaminated materials are not used that might create an environmental problem in future years. While getting there may be complex, reuse of materials could result in solutions to achieving restoration at the scale needed for recovery of oysters.

6. Manage freshwater inflows and site restoration to reflect freshwater inflow variations.

The best restoration and recovery efforts can be undone by profound changes in freshwater supply to the estuaries where oysters historically, and now currently, exist. Both too much and too little freshwater can disrupt or destroy oyster populations. Projects that seek to restore and maintain the dynamic flow regimes that maintain coastal habitats and processes should be viewed as integral to the restoration and recovery of oyster resources in the Gulf of Mexico. Because oysters are critically tied to freshwater flow regimes, actions that result in changed management of river flows upstream should consider downstream uses, including oyster restoration. Without this linkage, oyster restoration projects can be put in jeopardy of failure by decisions made far upstream. Examples where regional cooperation on freshwater flows would benefit oysters include the Apalachicola Chattahoochee Flint (ACF) Basin and parts of Mississippi Sound affected by the Bonnet Carré Spillway during times of exceptionally high flows in the Mississippi River.

The essential relationship between existing and future salinity should be an integral factor in the siting of oyster restoration projects. Salinity modeling can establish optimum zones for restoration including areas that can hedge against oyster loss from high and low salinity events. In a project called OysterFlows, TNC is developing those modeling techniques for estuaries in Louisiana and Mississippi, but the techniques should also be applicable elsewhere.

7. Retain oyster shell and seek alternative substrate materials.

Oyster shells are an important resource for rebuilding natural reefs and for some forms of oyster aquaculture, yet shells from restaurants and other users continue to be discarded, landfilled, or shipped elsewhere. Successful shell recycling projects exist in communities around the Gulf. These require a continuing source of funding, a lead entity, volunteers, restaurants willing to participate, and a shell storage location. Shell recycling is a proven tool for rebuilding oyster stocks and should be adopted more comprehensively across the Gulf. Additionally, states could require harvesters to return a percentage of shells back to the harvested reefs. Low oyster stocks and the commoditization of shell are both impediments to retaining shell, but it is possible for states to set goals and institutionalize (and fund) programs which can steadily increase the shell available to rebuild reefs and renourish them to a baseline height and density.

8. Expand monitoring and active management.

Oyster restoration and habitat management are not an exact science. They take place in a dynamic environment where rainfall patterns and events, storms, oyster diseases, harvesting pressures and other human activities can have a profound impact on success. Given this, oyster restoration and management, and tracking the overall health of oysters in the Gulf, must be accompanied by well-designed long-term monitoring to record success and failure and to determine the timing and causes of problems in order to adapt practices and designs to address those problems. There are numerous documents detailing science-based monitoring protocols that can serve as guidelines for oyster restoration projects (Baggett et al., 2014; Fish and Wildlife Research Institute, 2021; La Peyre et al., 2021).

Restoration budgets should include funds for pre- and post-monitoring. It's important for oyster restoration practitioners and scientists around the Gulf to share data to develop best restoration practices to help gauge the overall health of Gulf oyster populations. Long-term (five or more years) scientific monitoring is critical to determining the relative success of reef restoration projects. Monitoring can include the biological success (or lack of it) of the reef, measuring the ecosystem service impacts, and evaluating the social and economic impacts of reef construction. For example, monitoring the performance of these projects is revealing that, generally, reef structures slow the rates of erosion along adjacent shorelines, sediment settles and builds behind these reefs, and many reef-associated species are found in samples around the reef structures not long after they are deployed. A study by The Nature Conservancy and Texas Sea Grant (Shepard et al., 2016) illustrates the economic impact to communities from the recreational fishing opportunity provided by the successful creation and protection of a large, subtidal reef in Matagorda Bay. Overall, monitoring of factors such as whether, where and to what extent natural recruitment is taking place in the Gulf is needed to inform restoration and management from the project to the ecosystem level.

OysterFlows

OysterFlows is a science-based web tool that uses models (hydrologic, coastal, oyster-physiology, oyster mortality), monitoring data, and data visualization to assess current and future upstream flows and their effects on oyster health. This tool is meant to assess and communicate how upstream water use, water-management decisions, and climate change are likely to affect naturally occurring and restored eastern oyster reefs in Gulf of Mexico bays. It will provide decision makers and restoration practitioners with critical information to protect existing oyster resources and guide investment in future oyster restoration projects. OysterFlows will provide this information for 1) Sabine and Calcaieu Lakes/River Basins in Louisiana; 2) Mississippi Sound, which receives inflows from the Pearl, Wolf and Jourdan River Basins and openings of the Bonnet Carré floodway during Mississippi River floods; and 3) Pascagoula Bay/River Basin. OysterFlows will be freely available on both the Freshwater (freshwaternetwork.org) and Coastal Resilience (coastalresilience.org) Networks.

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9. Accelerate oyster restoration by sourcing new funding.

There remains unspent more than $100 million in Natural Resource Damage funding for oyster restoration from the Deepwater Horizon Spill settlement. Additional coastal restoration funds are now available from the Bipartisan Infrastructure Law and the Inflation Reduction Act approved by Congress. The amount of money now potentially available for oyster restoration in the Gulf is unprecedented, and planning for the expenditure of these funds is critical to the success of oyster restoration.

We recommend that a combination of Natural Resource Damage and other funds from the Deepwater Horizon Oil Spill, the Bipartisan Infrastructure Law, the Inflation Reduction Act, and other funding, IRA, and other funding sources should be used to provide $40–50 million to each of the five Gulf states to:

1. Select one or more estuarine areas in each state for a concentrated effort on oyster restoration.
2. Complete a stakeholder and science-based oyster restoration and management plan for that estuary (or estuaries) using the most current applied science to guide the planning.
3. Implement that plan through the coordinated design, permitting and construction methods described in this document.
4. Manage the restored resource to achieve estuary goals.
5. Monitor the results to determine replicability to other estuaries within the state and beyond.
6. Enable participation in Gulfwide sharing of oyster restoration strategies and techniques such as through the Gulf of Mexico Alliance and the Gulf of Mexico Marine Fisheries Commission.

Given the multiple ecosystem and harvest services provided by oysters, such an investment will produce long-term benefits that would far exceed its cost.

Conclusion

Oyster populations have been lost from 85% of their global range. While there have been dramatic losses in the Gulf of Mexico, the region still leads the nation in commercial production of oysters and has the water quality conditions required to recover oyster resources in many locations. Gulf states have an opportunity to craft and implement thoughtful, integrated restoration, recovery and management plans that can maintain the traditional use and cultural ties to oyster harvesting and also recover and maintain oysters as a habitat important for their multiple ecosystem benefits. Plans and projects that achieve these integrated components would put the Gulf of Mexico at the forefront of oyster resource recovery worldwide.

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