The Business of Restoration

Examining the oyster reef restoration industry in the U.S. with recommendations for how conservation organizations can increase efficiencies and decrease costs to scale restoration efforts

Photo credit: Michelle Peters-Snyder

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EXECUTIVE SUMMARY

Oyster reefs provide a plethora of ecosystem services including water filtration, denitrification, provision of aquatic habitat, and shoreline protection, yet they are largely depleted in bays and estuaries along the U.S. coast. Therefore, restoring oyster reefs is increasingly a priority, with work led by all three levels of government in addition to many non-governmental organizations (NGOs). This growing demand for oyster reef restoration has led to the development of an 'oyster reef restoration economy'.

Oyster reef restoration is led predominantly by over one hundred NGOs and state resource agencies; consequently, it is often not treated like a private business that is forced to continually optimize its cost structure and find cheaper methods to achieve desired outcomes. After decades of consistent work, costs for oyster reef restoration remain extremely high, with the national average well over $100,000 per acre. Given oyster reef restoration has become an industry of its own, this report sought to assess it as such by using similar approaches to private sector market studies. Practically, this means quantifying the market size and assessing the industry's practices through a 'business' lens.

In this study, over 68-hours of interviews were conducted with industry experts, including restoration practitioners, engineers, construction companies, hatcheries, and others, primarily from the U.S. Additionally, this study included a review of recent literature, analysis of five oyster reef restoration project datasets, and an examination of detailed budget data from recent individual projects. The insights from this primary and secondary research provided state, organization, and project-level data to build a detailed market assessment and derived many performance improvement ideas aimed at reducing the costs of oyster reef restoration.

This first part of the study focused on conducting a market assessment of oyster reef restoration at a national scale – work that has never been done before. The primary result was an estimate of the market size: oyster reef restoration is a $70-90M industry, directly supporting nearly 1,500 jobs and contributing $210M of economic output. For context, this is roughly one-third of either the oyster wild harvest or oyster aquaculture industries in the U.S. Most of the market ($60-70M) is in-water oyster reef restoration projects (i.e., projects whose intended direct result is increased oyster populations vs. research, planning or surveys). The vast majority (~85%) of the market resides in the mid-Atlantic and the Gulf of Mexico regions; notably, the west coast represents just ~1.5% of oyster reef restoration work. Interviews and market growth factors suggest the oyster reef restoration industry will continue to experience strong growth over the next 5 years, with federal and state funding initiatives and increasing living shoreline prevalence as the top two drivers.

The second part of the effort focused on six 'Cost Reduction Opportunities' and nine 'Advancements Required to Scale'. Predominantly through interviews with industry experts, 175 ideas were collected, then grouped into these 15 key recommendations to reduce the cost of oyster reef restoration.

This report first outlines the 6 opportunities that collectively can reduce the cost of restoration by greater than 50% (i.e., doubling the pace of restoration without any more funding), including: (1) running fewer but larger projects to gain economies of scale, (2) enhancing capabilities through in-sourcing and training, (3) increasing collaboration with existing commercial work, (4) elevating contractor involvement in conception and design stages, (5), sharing designs through the creation of a design database, and (6) continued idea sharing to follow the latest industry best practices. Collectively, these cost reduction opportunities can meaningfully reduce the time required to restore a given area. For example, if $10M per year was dedicated to oyster restoration efforts in Pensacola Bay (FL) to restore oyster habitat to an ecologically meaningful landscape scale of 1,400 acres, it would take nearly 28 years under status quo approaches. If implementing only opportunities #2-6, this is reduced to under 20 years. Finally, by leveraging economies of scale as well, the goal can be reached in under 14 years.

Further, oyster reef restoration is inhibited by multiple factors that make scaling difficult. This report has 9 recommendations for the advancements required for the industry to scale, including: (1) consistent funding for restoration, (2) state-wide oyster restoration planning, permitting, and protection, (3) upfront investment in permitting efficiencies and simplification, (4) alternative and innovative substrate, (5) restoration-earmarked hatchery capacity, (6) integration with commercial fisheries replenishment efforts, (7) multi-year monitoring of restored sites, (8) increased prevalence of, and competition among, contractors, and (9) support for restoration from commercial and recreational fisheries. These will mutually make each project easier for restoration practitioners and catalyze further step-changes in the costs of oyster reef restoration.

To provide a holistic example combining opportunities and advancements, economies of scale (Opportunity #1) could reduce spat-on-shell costs in California's coast from $5 to $1 per unit by batching production – a meaningful reduction. Further, by building restoration-earmarked hatchery capacity (Advancement #5), per unit costs could decrease further to below $0.10 – another striking step-change, ultimately resulting in more restoration accomplished per dollar.

Although this report does not explore the funding side of restoration, it is worth noting the oyster reef restoration industry is exceptionally positioned to benefit from additional funding given the large number of organizations running small-scale projects due to limited budgets. Over one hundred organizations are operating independently, and each have a baseline of fixed costs to cover. Many of the organizations interviewed mentioned that if they received more funding, nearly all of it would go to additional reef construction, rather than supporting those fixed costs. Therefore, oyster reef restoration efforts could achieve outsized incremental benefits with additional funding, especially when compared to other industries that have fewer organizations, each operating at closer to their full capacity.

The vast ecosystem services of oyster reefs make them critical to restore; however, the degree of oyster habitat restoration required is daunting. There have been hundreds of thousands of acres lost across the U.S. coast and restoring oyster reefs to documented historic baselines would take over 1,000 years and tens of billions of dollars at the current pace and efficiency. This study sought to identify opportunities to support efficient industry growth, make the most of limited funding, and restore oyster reefs as fast as possible. The future requires restoration of oyster habitat at unprecedented scales. These recommendations can help oyster reef restoration projects around the U.S. significantly reduce costs to scale and succeed.

INTRODUCTION

Historic oyster reefs are largely depleted in bays and estuaries along the U.S. coast (Zu Ermgassen et al. 2012) due to inadequate management, overfishing, disease, poor water quality from nutrient and sediment runoff from agriculture, deforestation and coastal development, and other factors. An estimated 85% of the world's oyster reefs are already lost and will remain declined unless we can scale up our restoration efforts (Lotze et al. 2006, Beck et al. 2011). However, oyster reefs are known to provide a plethora of ecosystem services including water filtration, denitrification, provision of aquatic habitat, and shoreline protection (Wells 1961, Thayer et al. 1978, Bahr and Lanier 1981, Rothschild et al. 1994, Meyer et al. 1997, Coen et al. 1999, Breitburg et al. 2000, Harding and Mann 2001, Newell et al. 2002, Peterson et al. 2003, Baird et al. 2004, Tolley and Volety 2005, Piehler and Smyth 2011, Zu Ermgassen et al. 2020, Zu Ermgassen et al. 2021). Therefore, restoring oyster reefs is increasingly a priority, with work led by all three levels of government in addition to many non-governmental organizations (NGOs). This growing demand for oyster reef restoration has led to the development of an 'oyster reef restoration economy', albeit somewhat disparate and disconnected with over one hundred organizations overseeing dozens of individual projects in the coastal U.S. states each year.

In this study, over 68-hours of interviews were conducted with oyster reef restoration industry experts, including restoration practitioners, engineers, construction companies, hatcheries, and others primarily from the U.S, in addition to a review of recent literature, analysis of five oyster reef restoration project datasets, and an examination of detailed budget data from over 12 individual projects (Appendix A). The insights from this primary and secondary research provided state, organization, and project-level data to build a detailed market assessment and derived many performance improvement ideas aimed at reducing the costs of oyster reef restoration.

Oyster reef restoration is defined to include activities supporting the creation or enhancement of intertidal and subtidal habitat reef, as well as living shorelines with an oyster reef as the dominant shoreline protection structure. Precise definitions of restoration were left to the discretion of each interviewee; however, care was taken to exclude any projects when the explicit intention was to harvest the oysters once replenished (e.g., state cultch planting for commercial and recreational fishing, aquaculture production).

Oyster reef restoration was assessed as an industry using similar approaches to private sector market studies. Practically, this means assessing the industry solely through a 'business' lens, and explicitly avoiding making any technical recommendations which others in the industry are more adept to make. Therefore, while this report may reference ecosystem service values, discuss substrate types, and other more technical elements, it does not comment on the efficacy of these decisions. This 'business' lens approach involves two main components: [1] conducting a current market assessment and [2] identifying 'business' opportunities to improve performance.

[1] Market assessment includes gaining an understanding of the industry's overall size, measured as annual direct spend, and then evaluating each state/region to assess its industry maturity. This type of work has never been conducted for oyster reef restoration at a national scale.[1]

[2] Identifying performance improvement opportunities had two goals: (i) to make recommendations to increase the efficiency and reduce the costs of each project (i.e., to spend less per acre restored); and (ii) to identify the advancements required (or impediments to remove) to scale the oyster reef restoration economy more effectively. This report will share 15 recommendations across these two performance improvement topics. Overall, the goals of the recommendations in this report are to increase oyster reef restoration per dollar invested.

[1] Work has been done to quantify the broader restoration economy, reaching a figure for marine and estuarine restoration (BenDor et al. 2015), to understand oyster reef restoration projects at a regional scale for the west coast (Ridlon et al. 2021), and for Deepwater Horizon oil spill funded projects (Brooke and Alfasso 2022).

MARKET ASSESSMENT

The goals of a market assessment are to:

- Quantify the market size (i.e., annual dollars spent on oyster reef restoration projects)
- Understand the variation in terms of market size, stakeholders involved, type of projects, and industry maturity by region/state
- Analyze each value chain activity's share of the total market size (i.e., spend on each step of an oyster reef restoration project from planning and permitting to construction and monitoring)

Market size

The oyster reef restoration market size in the United States is estimated to be $70-90M per year. The majority of the market size is comprised by in-water oyster reef restoration projects (i.e., projects whose intended direct result is increased oyster populations vs. research, planning or surveys), with budgets typically covering planning, surveying, permitting, engineering and design, construction, conservation aquaculture[2], and monitoring. This study directly summed the vast majority of the in-water projects; however, an estimate for uncounted small projects and for in-kind, unbudgeted spend was also added. Additionally, an estimate of spend was included for associated projects which do not directly increase oyster populations but are necessary to support the advancement of in-water projects (e.g., state-wide oyster planning; research studies).

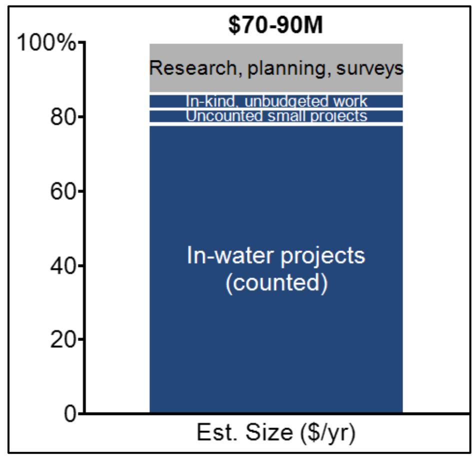

Figure 1: Oyster reef restoration market size (2021)

As shown in Figure 1, the majority of the oyster reef restoration market is in-water projects (i.e., projects with the direct intended result of increased oyster populations by adding substrate and/or oysters). Per Figure 2, in-water spend accounts for $60-70M of the market, with the majority (~85%) in the Mid-Atlantic and the Gulf of Mexico. Notably, the west coast represents just ~1.5% of oyster reef restoration work. Accounting for non-in-water work (i.e., research, planning, surveys, etc.) increases the total estimated market size to $70-90M per year. For context, U.S. commercial oyster landings were $253M/year in 2019, U.S. oyster aquaculture production was $219M/year in 2018, and oyster production globally is a ~$6B industry (National Marine Fisheries Service, 2021).

[2] Conservation aquaculture includes the use of hatcheries to produce larvae and spat-on-shell, as well as any grow-out assistance required to outplant oysters on a restoration site, to aid recruitment of oysters to substrate

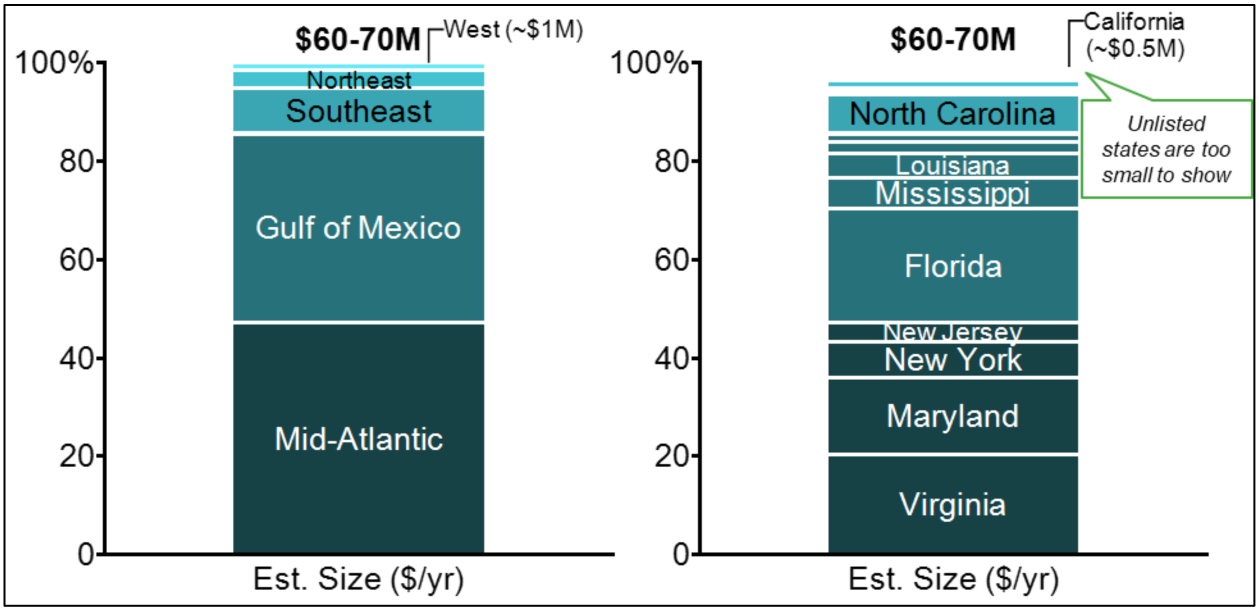

Figure 2: Annual estimated in-water oyster reef restoration spend (2021)

Market size approach

It was presumed that the majority of oyster reef restoration spend was on in-water projects; therefore, the most effort was focused on gathering data on each state's in-water projects over the last 5 years.[3] To this end, several national and regional oyster restoration project datasets were collected and synthesized. These included all NOAA Restoration Center funded projects, all Deepwater Horizon (DWH) oil spill funded projects, and three large, consolidated datasets collected for previous academic research (Bersoza Hernández et al. 2018, Ridlon et al. 2021, DeAngelis unpublished).

Initial expectations were that these datasets would encompass a sufficient portion of recent projects to extrapolate from; however, after speaking with project managers and state agencies to understand their current projects and main funding sources, it was concluded that these datasets would not be representative of today's market, even collectively (see Appendix B for an explanation of each dataset's characteristics and limitations). Therefore, an alterative approach was implemented which involved speaking to the leading organizations sponsoring oyster reef restoration projects in each state (e.g., federal and state government agencies, NGOs, universities) to build the market size from the bottom up. In total, project data was collected through interviews and follow-ups from 39 project sponsors across 19 organizations in 20 of the 21 coastal states.[4]

Oyster reef restoration was defined to include activities supporting the creation or enhancement of intertidal and subtidal habitat reef, including living shorelines with an oyster reef as the dominant shoreline protection structure, within the last 5 years. Precise definitions of restoration were left to the

[3] An ideal market sizing approach involves extrapolating from the last full year of annual data; however, oyster reef restoration project spend is often difficult to separate annually as projects last many years, in addition to recent COVID-19 project delays and disruptions. Therefore, average annual spend (i.e., market size) was estimated by using the last 5 years of data from each source to estimate the spend in 2021.

[4] The final coastal state (Delaware) was not interviewed but was understood to not have undertaken any oyster reef restoration projects in the last 5 years

discretion of each interviewee, in terms of what projects were included in the analysis and which were not; however, care was taken to exclude any projects whose explicit intention was to subsidise or support harvesting the oysters once replenished (e.g., state cultch planting for commercial and recreational fishing, aquaculture production). If a project was included based on the criteria above, there was no further exclusion of projects based on technical approach to restoring the habitat (e.g., type of substrate used, use of spat-on-shell or not, etc.); however, the types of projects, approaches, and techniques were tracked so those variables could still be assessed. For example, restoration projects often vary from state to state, and even project to project (e.g., small-scale spat-on-shell projects that involve few industry partners to large-scale constructed reefs that involve several industry and government partners).

The initial list of interviewees was created by targeting the major organizations sponsoring[5] oyster reef restoration projects in each coastal state, in the past 5 years. Then during interviews, interviewees were asked if there were other significant organizations that should be interviewed in their state in order to ensure that, ultimately, every major organization was accounted for in each state. Prior to each interview, interviewees were asked to share data on the number and types of projects implemented over the past 5 years. During the interview, interviewees were asked about the scale of oyster reef restoration in their state (i.e., number of unique projects, size of projects), the major partners involved (both hired and in-kind), to elaborate on their recent project budgets, and their expectations regarding future growth of the industry.[6]

A more detailed analysis of in-water project spending trends was further analyzed. After select interviews, interviewees were asked to complete a template to capture individual project details for their projects. The intent was to capture highly detailed information on a smaller number of projects with 12 templates completed in total. Information captured on these templates included project timeline, total cost, split of costs by value chain activity, restoration footprint, sources of funding, types and costs of substrate deployed, use of conservation aquaculture, and other descriptive information.

Next, the information and data shared from each interview was triangulated with the five national and regional datasets to refine the figures. Here, the term triangulation is being used to describe the process used to ‘sense check’ figures across many sources to understand and correct any discrepancies. This approach of ‘triangulation’ is often used in commercial due diligence work to assess industries lacking complete data. For example:

- Through multiple interviews of organizations operating in Louisiana, the state’s in-water oyster reef restoration spend was initially estimated to be $2.0M; however, Deepwater Horizon oil spill funded projects alone averaged $2.8M per year from 2015-2019. Therefore, the estimate was raised to $3.0M per year given there are other known projects in Louisiana funded by non-DWH sources.

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[5] Project sponsor refers to the organization officially leading a restoration project, often a government agency or NGO. The project sponsor will choose a site, secure funding, lead the permitting process, and frequently use external funding to contract out the remainder of the project to third parties

[6] Interviewees were asked to comment on their expectations for future growth by answering if they expected more restoration in their region five years from now compared to today, and why

- One dataset suggested that hundreds of acres of oyster reef were restored in Alabama between 2011 and 2016, suggesting a significant current market size[7]; however, initial interviews revealed that no recent in-water oyster reef restoration activity had occurred in Alabama. Therefore, experts from Alabama were re-interviewed to confirm that, in fact, non-harvest focused oyster reef restoration efforts were stopped in recent years, with the exception of living shoreline projects

Once in-water project spend was estimated, 'gross-up factors' were included to determine the total size of the oyster reef restoration market. Gross-up factors account for the additional activities that comprise any industry but are difficult to count individually. Gross-up factors are typically included in market analyses to capture the smaller portions of a market.

Here, three presumed gaps were addressed to gross-up the initial $60-70M in-water figure. First, it was acknowledged that there were likely some smaller projects over the past 5 years, such as small-scale efforts run by individual counties or communities, which were not captured in the data or from interviews. Second, organizations were not always able to quantify their own in-kind contributions to each project; they would share project budgets, with outsourced labour and materials spend, but their own time was often difficult to measure and left unaccounted. Third, associated projects, including planning, project-specific research, and monitoring work was not comprehensively captured in the datasets or interviews. Additionally, many projects use a considerable amount of volunteer labour; however, this was deliberately excluded from the analysis so volunteer time was not included as a gross-up factor. In the table below, the additional value of each presumed gap was estimated, along with the rationale.

Gross up factor	**Est. add'l size**	**Rationale**
Uncounted, smaller projects	5%	There are some small projects assumed to be missing outright from the data collected, likely led by organizations which have atypical funding sources, or which are new and thus the larger organizations interviewed were not aware of their work
In-kind labour provided by sponsoring organization	5%	This is a conservative estimate to represent in-kind spend (typically salaries) for the organizations sponsoring or leading restoration projects. Appraised based on 12 separate organizations providing estimations of unbudgeted value on top of budgeted project spend
Associated spend (planning, research, monitoring, etc.)	15%	DWH is the only dataset of funded projects that includes both in-water and associated projects, but there are many states engaging in statewide associated work (VA, MD, FL, LA, GA, etc.). For DWH-funded projects with a primary focus on

[7] This data source ended in 2016

		oyster reefs, ~15% of the funding went to planning and research leading to this assumption. Academic research is also significant but difficult to quantify and likely would be additional to this figure (and the market size). Similarly, no accounting for policy-related work (e.g., advocacy, improving restoration policy, etc.) was included.

Overall, while this approach may seem nonrigorous, it resulted in the most efficient understanding of the market given the lack of comprehensive project data. Relying solely on the initial five national and regional datasets would have resulted in an estimate that reflected outdated data (i.e., older than 5 years), was heavily skewed toward federal funding sources, and did not adequately represent substantial state and privately funded work. Further, counting only the most accessible information (i.e., in-water projects) would likely understate the oyster reef restoration market size by 25%+.

Value chain activities share of market size

The overall market size provides a sense of the scale of the oyster restoration industry. Within the market, spend can be classified into the six main project activities. Figure 3 shows the split of a typical project to demonstrate the portion of in-water project spend (i.e., the $60-70M market size figure) that is directed toward each stage. Note, by displaying a 'typical' project, it does not effectively represent any one project. For example, there are many pilot-scale in-water projects; these will likely have higher proportions of planning, permitting, design, and monitoring costs relative to material and construction costs. On the other hand, established large-scale programs may include projects where >80% of the budget is materials and construction. The below figure shows that on average, one-third of oyster reef restoration spend goes to marine construction, with another one-third to materials. Project sponsor staff time is another large spend category, but one which spans many activities, with average spend of 17% of the total cost, with a wide range of 4 to 44%[8]. This would round out the top three groups receiving 'revenue' from the market: marine construction firms (~37%), materials suppliers (~33%), and project sponsors (~17%).

[8] Project sponsor staff time is not shown on the following chart as their time is required at multiple stages

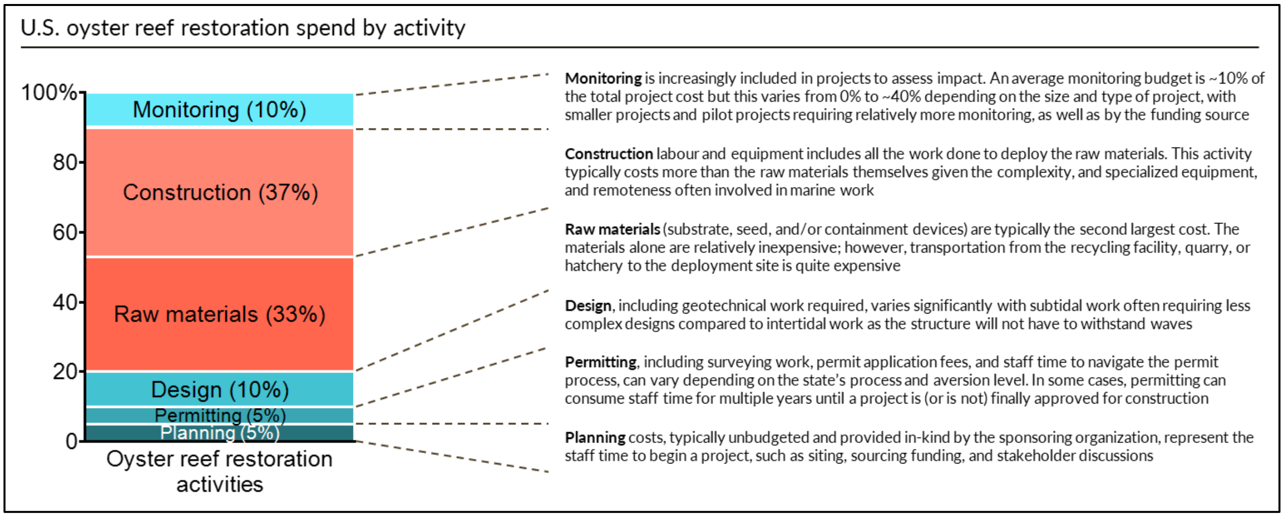

Figure 3: Oyster reef restoration activities

Jobs supported by oyster reef restoration

In addition to the vast ecosystem service benefits of restored oyster reefs, the implementation of restoration projects is an economic activity. While this work itself focused on the market size (i.e., direct annual spend), a review of economic impact studies of restoration by BenDor et al. (2015a,b) can be leveraged to estimate the industry's impact on jobs, indirect output, and induced output.

By taking the midpoint of the estimated oyster reef restoration market size, $80M per year, several conclusions can be drawn regarding the industry's economic contribution and impact. First, if we extrapolate the "job creation efficiency" (18.55 jobs per $1M[9]), an $80M annual investment in oyster reef restoration in the U.S. directly supports approximately 1,484 jobs each year (BenDor et al. 2015a). This rate of jobs per $1M for oyster reef restoration is slightly above the ecological restoration average of 13.3 jobs per $1M; this is likely due to a higher ratio of project dollars spent on labour compared to materials and equipment. Further, employment multipliers cited in BenDor et al. (2015b) suggest that between 742 to 4,155 additional jobs are supported by every restoration job[10]. The quality of these jobs remains unqualified; however, anecdotal evidence suggests that while contractors often utilize temporary labour, other jobs (e.g., government and NGO staff, engineers, etc.) are typically more stable. Next, indirect and induced output measure the impact a community will feel when an oyster reef restoration investment is made. By applying BenDor et al.'s (2015a) input-output model for ecological restoration (i.e., not specific to oyster reef restoration) to oyster reef restoration projects, we can extrapolate that indirect output adds an additional $38.4M (48%) of business-to-business spending and induced output adds an additional $91.2M (114%) of household spending with the labour income. This brings the total economic impact of $80M in annual oyster reef restoration to between 2,226 and 5,639 jobs supported annually and $209.6M in direct, indirect, and induced annual output.

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[9] 18.55 jobs per $1M is the midpoint between two sources referenced in BenDor et al. (2015b) derived from Edwards et al. (2013) estimating 16.6 jobs per $1M (state-based) while Kroeger (2012) estimated 20.5 jobs per $1M (county-based)

[10] Wide range given ecological restoration employment multipliers range across studies between 1.5 to 3.8

Expected market growth

Outlined in BenDor et al. (2015a), there are five broad factors which create demand for restoration:

- Regulatory mechanisms that mandate or incentivize public and private investment to offset development activities (i.e., mitigation)
- Public procurement of restoration through programs with restoration providers
- Regional initiatives enabled through partnerships at different levels of government
- Internal government agency policies
- Private investments by foundations, non-profits, corporations, and institutions

Clearly, these factors are not economic driver-based[11], making it difficult to project their future impact on the oyster reef restoration economy. In essence, each factor is a group's appetite to fund restoration work (e.g., government policy), which is difficult to quantify and project outwards. Further, although the market growth of ecological restoration overall may be easier to project, the portion that reaches oyster reef restoration cannot be assumed given the high number of competing priorities. Therefore, instead each interviewee was asked about their expectations regarding the amount of oyster reef restoration 5 years from now compared to today. Interviewees nearly unanimously expect oyster reef restoration to increase, with the positive, neutral, and negative factors described below (in decreasing order of importance, per category). Overall, oyster reef restoration spend is expected to continue to grow at a moderate pace (i.e., high single digit growth) through a combination of more frequent and larger projects.

Tailwinds to growth (positive factors):

↗ Federal and state funding initiatives: Broadly, there is an expectation for increased federal and state funding of oyster reef restoration. For example, over the last 10 years the NOAA Restoration Center (NOAA RC) has allocated $1M to over $2.5M per year to oyster reef restoration work from its habitat restoration grant funding which ranged from a total budget of $10M to over $20M per year. Moving forward, the Infrastructure Investment and Jobs Act (IIJA) will increase NOAA RC's budget to $90M per year for the next 5 years and it expects to fund more projects across every habitat, marking a potential 4x to 9x increase in funding (NOAA 2022). Taking a historical example, under the American Reinvestment and Recovery Act of 2009, approximately $18M of the $167M available for projects supported oyster reef restoration.

↗ Increased living shoreline prevalence: Shoreline protection is increasingly a priority for many states amid rising sea levels. Historically, grey infrastructure (e.g., bulkheads) has been used to protect shorelines but engineers, contractors, and states are increasingly promoting living shorelines, which are often built to mimic or promote oyster reefs, as an alternative that is cheaper, more effective, and natural. For example, a full-service contractor in North Carolina expects to complete over 55 living shoreline projects this year, up from an average of 3.6 projects per year from 2017 to 2019. Additionally, Georgia has collaborated with multiple groups to pilot living shoreline work in each of the state's nine coastal archetypes to prove its efficacy and promote future public and private investment.

↗ Commercial oyster industry restoring reefs to support larvae supply: Oyster habitat continues to decline, creating spat-limited environments which impact nearby commercial reef productivity. Initial 'brood reef' projects are underway in several states to demonstrate the impact of restoring and

[11] For a typical private sector market study, the industry's growth can be projected by weighting various economic drivers such as population demographics, household spending, or other census-level data. However, none of these drivers would adequately project oyster reef restoration spend since its spend is largely policy driven

protecting adjacent habitat reefs to support recruitment for commercial endeavours. Although the primary goal is to support the fisheries, it nevertheless creates new, protected oyster habitat with support and funding from commercial fishing interests.

- ↗ Rising damage/mitigation funding: Damage/mitigation funds are a frequent source of oyster reef restoration funding as infrastructure projects and unplanned events continue to destroy habitat. This coastal habitat restoration funding pool is likely to increase with the increased dredging of ports to accommodate New Panamax ships (e.g., dredging projects are planned in Coos Bay, OR and NY/NJ Harbour), increased frequency of natural disasters due to climate change, and possible future oil spills and similar events, increasing the potential funding specifically for oyster restoration.
    - Regarding past oil spill damage funding, it is worth noting that the Deepwater Horizon oil spill funding will continue as a major funding source for the Gulf of Mexico through 2031 given over half of the funding remains to be spent. Representatives from each of the three main funding sources were interviewed (i.e., NRDA, RESTORE Council, and NFWF GEBF). NRDA and RESTORE are each allocated just ~6% of their $8.1B and $5.3B respective sums annually through 2031, and they cannot spend ahead of this timeline. Therefore, there remains $7.9B of funding available from NRDA and RESTORE combined from 2022 - 2031. Additionally, although NFWF GEBF is allocating funds at a faster pace, it also has 2-3 more years of allocations[12], with allocated dollars then typically spent over the next 5 years.
- ↗ Coastal towns gaining appetite to support restoration: Historically, oyster restoration work has been funded by federal grants, state agencies, and NGOs raising private dollars. However, coastal towns are increasingly allocating municipal budget to restoring oyster reefs to both enhance their water quality and bolster recreational fishing opportunities.
- ↗ Ecosystem service value attributed to oyster reefs: The ecosystem service value of an oyster reef is continually revised upwards as more sophisticated monitoring techniques are utilized and more factors are included in the economic modeling. This has potential to attract additional funding from public and private interests.
- → 'Nutrient credits' potential: Several groups are exploring potential for oyster reefs to provide 'nutrient credits' to offset other industrial processes such as nitrogen runoff from fertilizer use. This system is envisioned to operate similar to carbon credits for CO_2 pollution, where each credit represents a unit of absorption of nutrients and the sale of these credits will fund future restoration. Although this trend seems promising, it is too early to determine the extent of its impact on oyster reef restoration.

Headwinds to growth (negative factors and risks):

- ↘ Alternative restoration priorities: Oyster reef restoration often competes for the same grant dollars as other forms of ecological restoration. If funds are believed to be more effective at restoring other important habitats, there is potential for decreased oyster reef restoration specific funding.
- ↘ Fluctuating government priorities: While continued government funding is likely, federal and state priorities regarding the environment fluctuate with each election cycle and therefore poses a risk to the industry.

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[12] NFWF GEBF remaining funds vary by Gulf state; Mississippi, Alabama, and Florida all have funding left to allocate while Texas and Louisiana do not have any funding remaining for oysters

One additional note on growth: Oyster reef restoration spend is expected to grow based on the views of the vast majority of industry participants interviewed. However, when analyzing available data, time series spend and acreage data does not show restoration accelerating as described above. This discrepancy is attributed to a data issue rather than a trend, given no single source has comprehensive historical oyster reef restoration data.

Market characteristics

In addition to the market assessment quantifying both spend and acreage, each state was classified according to its 'maturity' to create a broader understanding of the market. Maturity is defined by multiple factors, including market size, efficiency - measured as spend per acre, state involvement in restoration efforts (vs. federal or municipal governments, NGOs), ease of permitting, and investment protection (i.e., protection status of restored reef).

Depicted in Figure 4 below, each of the 21 coastal states are plotted along this maturity index.[13] VA and MD, with their large-scale work in the Chesapeake Bay, are leading the industry followed by NC and FL who both have NGOs working in the space, high state involvement, and are growing quickly amid rising living shoreline interests that heavily involves oyster habitat materials and objectives. On the other end, CT and DE both were not found to have any active oyster reef restoration projects within the past 5 years, despite their strong aquaculture industries. They are then proceeded by the west coast states, with WA leading in this region primarily through the Puget Sound Restoration Fund's established infrastructure (e.g., on-site Olympia oyster hatchery) and relatively large projects.

The higher maturity states likely have the most lessons other states can take to further develop their oyster reef restoration economies. Particularly, high state involvement was noticed to yield cost synergies by sharing resources with public reef replenishment efforts and enabling easier permitting processes which decreases staff time spent on an otherwise arduous and expensive permitting process.

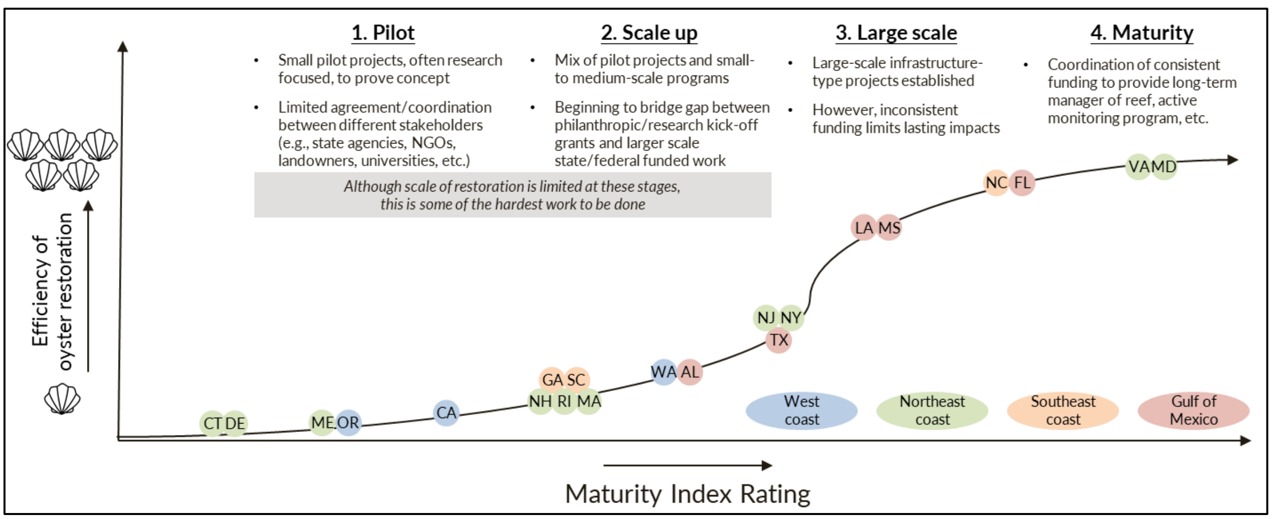

Figure 4: Relative oyster reef restoration maturity by state (illustrative)

[13] The maturity index is a relative scale; all states have room to improve current practices

Market assessment conclusion

In total, the $60-70M of annual in-water spend restores 300-500 acres of oyster reef each year; however, there have been hundreds of thousands of acres lost across the U.S. (Zu Ermgassent et al. 2012). This suggests that restoring to documented historic baselines would take over 1,000 years and tens of billions of dollars.

While this market assessment shows the industry is substantial and growing, it is also clear that there is a lot more work to be done. The next section has 15 recommendations across three time horizons – near, medium, and longer-term – to both reduce costs of oyster reef restoration as well as promote specific advancements to allow the industry to scale more efficiently.

PERFORMANCE IMPROVEMENT

After three decades of consistent work, costs for restoration remain extremely high – averaging well over one hundred thousand dollars per acre, nationally. Therefore, this section explores opportunities to reduce these costs, and recommend advancements to scale future efforts. Importantly, this moment marks a key point in the industry's history; while there is likely more oyster reef restoration occurring than ever before, many project managers expressed frustration over rising fuel, labour, and materials prices, making the case for cost reduction all the more critical.[14]

One factor impacting the industry's efficiency is that it has grown in isolated regional pockets under the purview of over one hundred largely independent organizations. The bright side of this is that many organizations have identified innovative solutions to improve their work, with the lessons from each organization interviewed consolidated into the recommendations below.

The goals of this performance improvement section are to:

- Examine the industry from a 'business' lens to identify opportunities to reduce the cost of oyster reef restoration by improving current processes from funding mechanisms through to design, implementation, and monitoring
- Identify advancements required to allow the industry to scale

Performance improvement approach

This second component of the study involved conducting a series of 68 one-hour interviews, as well as a review of relevant literature. The 39 project managers and sponsors interviewed for market assessment data were also asked a series of performance improvement questions. Additionally, 29 interviews were conducted with academics, government funders and regulators, design and engineering firms, construction firms, materials providers, hatcheries and nurseries, and others (Appendix C and D) to gain insight into the entire value chain of an oyster reef restoration project.

Interviewees were asked to share their best practices and discuss challenges encountered across their projects, before diving into more specific questions around funding, permitting, contractor and vendor selection, outsourcing, etc. While responses varied by specialty, many interviewees expressed common views. In total, 175 ideas were collected, and then grouped into 15 key recommendations: 6 'Cost Reduction Opportunities' and 9 'Advancements Required to Scale'. Once these 15 recommendations were drafted, they were tested in later interviews to confirm their validity and usefulness. The *Cost Reduction Opportunities* are recommendations any single project or organization could take on today to reduce costs. In contrast, the *Advancements Required to Scale* will require a regionally or even nationally coordinated effort, but once accomplished will support the success of every future project.

Potential savings are estimated below for the 6 economies of scale and cost reduction opportunities outlined. For economies of scale (Opportunity #1), savings potential was discussed with project managers,

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[14] To clarify, inflation impacts every industry, but oyster reef restoration is over-exposed to two detrimental trends which raise its price tag: marine work is extremely sensitive to rising fuel prices and expanding infrastructure funding through the IIJA has triggered heightened competition driving prices for materials and equipment sharply upward

engineering and design firms, and contractors for each stage of an oyster reef restoration project. The value was refined through interviews and by leveraging the project budget data collected from 13 individual projects led by 12 separate project managers. For example, contractor bid data provided an estimate for savings in the materials and construction phases; comparing project budgets of various sizes in close proximity indicated planning, permitting and monitoring savings; and finally, practitioners were simply asked to estimate how a given step would scale in cost if it was 5x the size. For the cost reduction opportunities (#2-6), once an idea was suggested in an interview, the interviewee was asked to estimate its savings potential. Then, this idea was brought to other similar interviewees to verify its potential (i.e., if a contractor suggested their earlier involvement would save X%, other contractors were asked to estimate savings from the same idea), and then it was confirmed with interviewed project managers that the idea was broadly applicable. Once sufficient confidence was attained, the savings estimates were synthesized to a reasonable value, as shown in Figure 5 and 6.

Economies of scale and cost reduction opportunities

This section provides details and examples for the 6 cost reduction opportunities:

1. Run fewer, larger projects to gain economies of scale
2. Enhance capabilities through in-sourcing and training
3. Increase collaboration with commercial work
4. Elevate contractor involvement in conception and design stages
5. Optimize designs and use of engineering firms
6. Idea sharing to following industry best practices

Each opportunity stems from successful examples oyster reef restoration practitioners have used and should be actionable across a broad set of regions and project types. Figure 5 shows the potential per acre savings per stage of a project by engaging in larger projects to gain economies of scale.[15] Figure 6 depicts the five cost reduction opportunities which can be implemented individually or collectively. Together, the two charts show examples of reasonable savings projections demonstrated in past projects, but savings in each stage will likely vary by exact project specifications.

[15] Economies of scale refers to the per unit savings achieved by increasing the scale of a purchase or a task

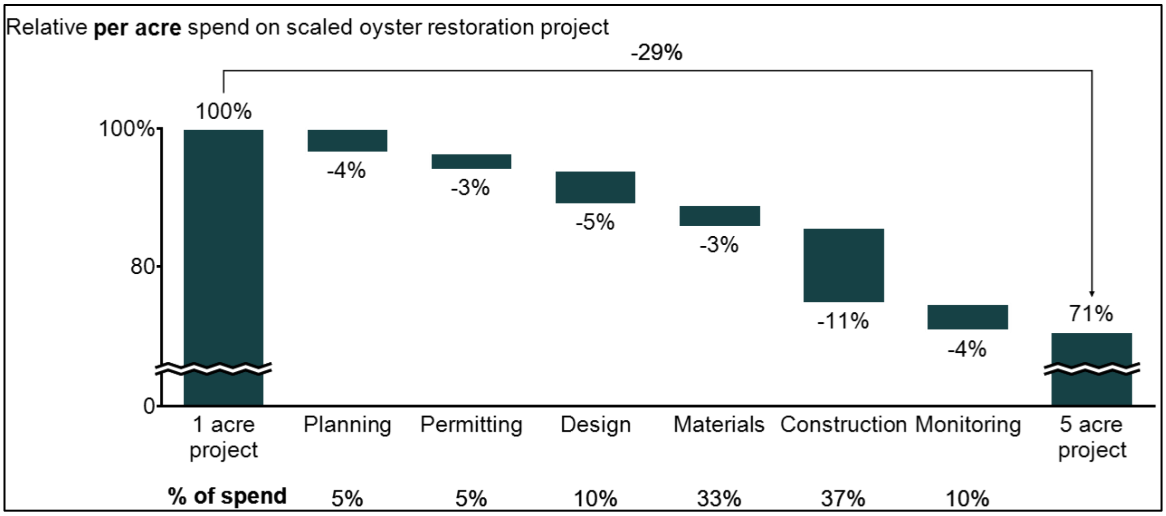

Figure 5: Opportunity #1: Economies of scale savings

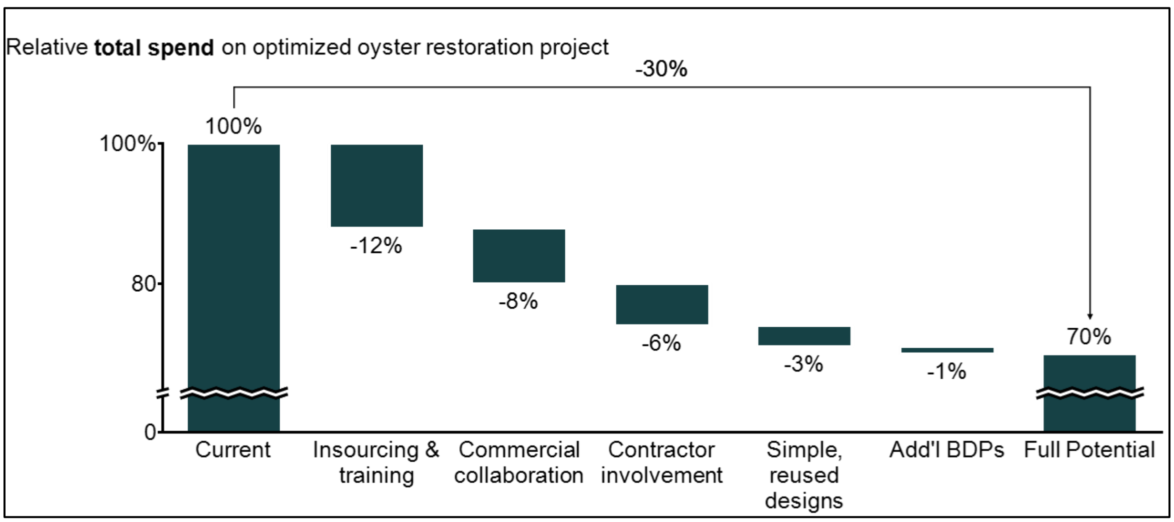

Figure 6: Cost Reduction Opportunities #2-6 savings

Opportunity #1: Run fewer but larger projects to gain economies of scale

Economies of scale refers to savings achieved by scaling – such as the ability to negotiate lower unit prices when purchasing higher volumes or spreading fixed costs over more units. In the case of oyster reef restoration, economies of scale can be gained across the value chain, not only by bulk purchasing materials but also by sharing planning, permitting, design, and other resources across a larger restoration area, or by allowing a contractor to become more efficient with each subsequent reef installation. In Figure 5, if an organization conducted one 5-acre project instead of five 1-acre projects, costs could reasonably be reduced by almost one-third. The following list outlines up each step of the value chain and the potential average savings from economies of scale as estimated by project managers and exemplified through the budget templates they shared.

- **Planning**: Project sponsor staff time and travel is the major cost of planning, but these costs do not scale with the restoration footprint. Whether the project is only a few acres in size, or hundreds of acres, the project sponsor will require a similar amount of time for siting and stakeholder discussions, with sourcing funding likely taking some additional effort.

  - *To restore 5-acres instead of 1-acre, planning costs may only increase from 1x to 1.5x, representing 70% savings per acre (e.g., planning for a 1-acre project may cost $10K, whereas planning for a 5-acre project may only cost $15K, or $3K per acre)*

- **Permitting**: Engineering surveys[16] and project management staff time are the major permitting costs. Engineering surveys will take more time for a larger area but there will still be savings on travel, equipment set-up, and analysis; staff time to manage the permitting process will also require a similar amount of time no matter the restoration area.
  - *For 5x the restoration area, permitting costs may only increase by 2.5x, representing 50% savings per acre*
- **Design and engineering**: Reef designs and further engineering surveys are the major design costs. Engineering surveys will take more time for a larger area but there will still be savings on travel, equipment set-up, and analysis; reef designs can often be replicated across the project area with little added cost.
  - *For 5x the restoration area, design and engineering costs may only increase by 2.5x, representing 50% savings per acre*
- **Materials**: The purchase of shell, concrete, limestone, and/or oysters will see some savings as the most traditional interpretation of economies of scale: larger orders provide more opportunity to negotiate prices and lower transportation costs by using larger vehicles and vessels.
  - *For 5x the restoration area, materials costs may increase by 4.5x, representing 10% savings per acre*
- **Construction**: Contractor labour and equipment, including mobilization and demobilization, are the major costs of construction. Mobilization and demobilization provide the most obvious savings, as people and equipment will only have to be transported to (often remote) sites once. Further, contractors suggest they would benefit from larger projects by gaining experience as the project progresses (i.e., each subsequent reef taking less time to construct than the last, especially for new or difficult designs).
  - For example, contractors bidding on living shoreline work in the Gulf of Mexico charge 70-90% of the cost for the 2nd half mile compared to the 1st half mile of a project (see Appendix E), indicating ~20% economies of scale from the materials[17] and construction phase by just doubling the size of a project
  - *For 5x the restoration area, construction costs may only increase by 3.5x, representing 30% savings per acre*
- **Monitoring**: Staff or contractor[18] field time and travel are the major monitoring costs. Time in-field will scale linearly for a larger area, but there will still be savings on travel, set-up, and analysis.

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[16] Typically, oyster restoration projects often require several forms of surveys and baseline studies to inform the project. These often include geotechnical studies, bathymetry surveys, ecological baseline surveys, water quality studies, etc. which collectively will be referred to here forth as engineering surveys

[17] This example includes the contractor procuring most materials, demonstrating savings potential across both 'Materials' and 'Construction' steps

[18] There are very few monitoring contractors. Engineering firms have teams that do monitoring, but there are few dedicated scientific monitoring companies

- *For 5x the restoration area, monitoring costs may only increase by 3x, representing 40% savings per acre*

Overall, there is a strong economic case to make projects larger: funding can go much further. Tactically, this means organizations should run fewer but much larger projects, explore opportunities to combine budgets with other organizations, and re-approach funders of small projects to make this business case and convince them to fund a larger project. Additionally, once a project is underway, project sponsors could have contractors bid on varying sizes (i.e., contractor submits a bid for a project of 10-acres, 20-acres, and 50-acres), then share these bids to the funder to justify the ask for the additional investment.

It is worth noting that the oyster reef restoration industry seems exceptionally positioned to benefit from economies of scale[19] given the large number of organizations running small-scale projects. Each of over one hundred organizations operates quite independently, and each have a baseline of fixed costs to cover. For example, for many of the organizations interviewed, if they received 50% more funding nearly all of it would go to additional substrate or oyster seed purchased given they already have the physical and intellectual capital in place (e.g., knowledgeable and eager staff, equipment, relationships with contractors, government agencies, etc.) to make use of the funds. Therefore, oyster reef restoration efforts could achieve outsized economies of scale benefits compared to other industries.

Opportunity #2: Enhance capabilities through in-sourcing and training

Most organizations, both state agencies and NGOs, sponsoring oyster reef restoration have biologists and ecologists on staff to lead their restoration projects. While these roles are critical to each project, project management and engineering skillsets are also required to run a successful project. Often, the staff biologist/ecologist will take on some or all the project management, with any remainder outsourced to an engineering firm at significant expense; the engineering work (e.g., engineering surveys, designs, contractor oversight) is nearly always outsourced.

Typically, the reason for outsourcing project management and engineering is two-fold. First, there are separate funding sources for project-specific resources. Restoration projects are typically funded by grants, but to write a grant application the sponsoring organization will internally fund staff time – these costs are seldom recovered by the grant. Then, once a project has grant funding, the project sponsor will contract out project management and engineering on the grant's budget. While this is optimal for any organization running a single smaller project, it is sub-optimal when running larger and/or multiple consecutive projects where the more economical alternative can be to bring project management and engineering in-house.

Second, there is a lack of consistent funding to hire additional skillsets on staff (see also 'Advancement #1: Consistent restoration funding'). In-sourcing project managers and engineers would mean the sponsoring organization must hire these roles permanently, then try to recover their salaries by charging them out to grant-funded projects. This results in the sponsoring organizing bearing the risk of not recovering the salaries for these two roles, but this risk comes with many benefits. Namely, projects save the margin that an engineering firm will charge on top of their services. For example, Ducks Unlimited is an analogous NGO which made the decision to have engineers on staff and they estimate achieving savings of 25-50% compared to outsourcing the same work. In addition to these more measurable savings,

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[19] Compared to over ten other industries assessed by the author previously

there are substantial process efficiency gains. Both Ducks Unlimited and Florida Fish and Wildlife Conservation Commission suggest on-staff engineering support can help to vet proposed projects and foresee expenses. For instance, by involving an engineer when siting a project, the organization can better predict if a specific location or design will be prohibitively expensive before a grant and/or permit locks in the specifications (also see 'Opportunity #5: Optimize designs and use of engineering firms').

If the outright hiring of additional staff is too difficult, there are alternatives to work with engineering firms in advance and train staff in project management. First, some engineering firms have an internal budget for contributing time to proposals and could support pre-grant work through this means. For example, by engaging in a master service agreement (MSA) with an engineering firm, they are more willing to support the proposal phase as the contract will often be sole sourced to the engineering firm after.[20] Second, providing consistent training in project management could be an effective first step. Oyster reef restoration projects are increasingly similar to other large construction projects, where savings can be found through negotiating contracts, managing timelines, and handling contractors and suppliers efficiently. These are often not core skills of biologists or ecologists, but they certainly can be learned. Investing in training resources for staff can yield outsized impacts, especially on multimillion-dollar projects.

Although each of these recommendations involves investment by the sponsoring organization, the financial risk of not recovering the investment can be reduced by first investing in regions with more consistent funding, and the risk should generally be reduced given the projected growth of the oyster reef restoration industry broadly. For example, if operating in any of the medium to high maturity states (see 'Market Characteristics' section), the savings of these approaches should outweigh the financial risks.

Opportunity #3: Increase collaboration with commercial work

Commercial collaboration is another very tactical, but sometimes overlooked cost reduction opportunity that could lead to savings. Commercial collaboration refers to leveraging shared resources, which can be achieved in a variety of ways. For example, an obvious opportunity is collaborating with state-led wild reef cultching because it requires many of the same resources as restoration. Increasing collaboration with oyster fisheries enhancement work can provide two opportunities to reduce costs.[21]First, resources can be shared between restoration efforts and commercial fisheries replenishment work (e.g., cultch planting). This model will only be applicable in select states that have wild reefs and practice cultch planting for fisheries harvest. Second, in situations where state agencies can lead restoration work, it frequently streamlines often complicated permitting processes. Virginia leverages both of these approaches and has the lowest demonstrated restoration cost per acre of all projects reviewed.

For example, the Virginia Marine Resources Commission (VMRC) leads much of the oyster restoration work in the state, both within and outside of the Chesapeake Bay, and it plans nearby restoration projects immediately before or after commercial replenishment work to maintain use of the same equipment and contractors to reduce mobilization and demobilization costs. In addition to substrate deployment,

[20] A quality-based selection process to solicit professional services (engineering, architecture, consulting) through an IDIQ or MSA is accepted by the OMB Circular rules on purchasing, although it often takes re-educating those involved
[21] Examples include TX, LA, MS, AL, FL, SC, NC, VA, MD, DE

replenishment and restoration efforts could purchase substrate together, increasing their bargaining power to lower prices as well as lower transportation costs.

There are other ways to leverage and collaborate with commercial efforts even in places where states are not cultching, such as involving commercial labour or sharing other common resources from nearby projects. Finally, interviewees suggested that when states partner on projects, often by taking the lead on permitting, efficiencies are gained. This does not mean states must take the work on independently or allocate their own budgets to restoration work, project managers simply found it helpful to have state agencies as implementation partners.

Opportunity #4: Elevate contractor involvement in conception and design stages

Similar to the second opportunity of in-sourcing engineering and project management skillsets, there is material benefit to be gained by involving construction contractors earlier in each project. Looking to the for-profit world, not only can the vertically integrated companies often achieve higher margins, but also they will make decisions optimal for the full system. Ideally, this would mean all parties involved in oyster restoration (e.g., biologists, project managers, engineers, construction contractors, materials suppliers) would be employed by the same entity and therefore have aligned incentives. However, while end-to-end vertical integration is not a feasible solution, oyster reef restoration projects would benefit from earlier construction contractor involvement.

We interviewed three construction contractors, each of which noted their lack of early involvement led to additional costs. Construction contractors suggested that if involved earlier, they could anticipate and reduce high-cost decisions related to design and implementation, generating 5% to 25% of savings while maintaining restoration outcomes. For example, a given design may be unnecessarily complicated to construct or take additional time to verify certain design parameters are met. Currently in a typical project, construction firms are only engaged once permits are approved, funding is secured through explicit grants, and designs are finalized. This is often the process because projects are funded by phase, with later phase work not guaranteed, making it impractical to bring in construction contractors earlier – but this is not optimal.

Tactically, this could mean bringing a representative from one or more construction contractors to early permitting and design discussions. If consistently working with the same people, this may be simple to negotiate – those interviewed suggested they would happily support this stage 'pro bono'. Otherwise, project sponsors could hire construction contractors on a per-hour basis to consult on design ideas. While this is an additional cost for early-phase work, the potential savings gained from reducing spend on materials and construction would suggest this is a worthwhile cost.

It should be noted that this recommendation could bring one complication depending on the funding source. For government agencies or specific grants, engaging a construction contractor may add inquiries surrounding fair bidding practices (i.e., giving preferential treatment to one firm before opening bidding to all), in which case a third-party construction expert should be hired. Overall, given the specialized equipment and labour, and an insufficient volume of restoration work, it is not recommended to in-source construction, but there is significant benefit from earlier construction firm involvement, even if that comes at an added initial cost.

Opportunity #5: Share designs through the creation of a design database

Reducing the cost of design and engineering work presents another cost reduction opportunity. Creating a design database represents an opportunity to share designs across the oyster reef restoration community. The design database would hold the summary and backup file for all designs and allow future projects to reference each as an example and leverage as a significant head start when refining designs for other locations. Further, the design database would support engineering firms to reduce time spent by compiling potential designs and providing a set of alternatives for alternatives analysis. [22] If a national organization were to in-source engineering work, one project the engineer(s) could take on is maintaining this design database for the oyster reef restoration community broadly. Further, overseeing the database inputs would help to create concepts quicker for internal work.

Overall, this does not represent a massive opportunity, given the relatively small cost of design and engineering work, and that engineering surveys still must be done on each site, but it will save costs directly, as well as provide simple design examples to reduce construction costs, in addition to speeding up the design stage of future projects.

Opportunity #6: Promote continued idea sharing to follow industry best practices

The final cost reduction opportunity is to facilitate idea sharing among oyster reef restoration practitioners. A common theme in many interviews was the continuation of pilot projects, testing certain substrates or techniques, without a definitive plan to scale up the project to achieve meaningful restoration outcomes. Further, some pilots are conducted by neighbouring organizations simultaneously, often an avoidable expense. With enhanced idea and outcome sharing, there would be less need for continual pilots, and more funds could be directed to larger scale work.

Although it was not a focus of interviews, interviewees provided many of their best practices one could follow prescriptively. The list below has a few examples of best practice ideas heard through interviews and are the types of ideas that may be applicable more broadly. Typically, project and best practice communication is almost entirely focused on ecological outcomes. While this is critical, the restoration community should also include communication around best practices such as the examples listed below. With regular regional and national conferences, more ideas of this type could be shared, resulting in less repetition of pilots and fewer costly errors.

- Designs
    - Many project designs, according to project managers and construction contractors, are "over-engineered", with unnecessarily specific requirements for the construction contractor. Interviewees suggested designs often do not have to be complex, specific, or novel to be effective. Therefore, the use of both simple and reusable designs is encouraged. Simple designs will reduce design, engineering, and construction time, and flexible designs will allow contractors to use their best judgement to reduce costs. Reusable designs will further reduce costs of future design and engineering efforts.

[22] Alternatives analysis is a common requirement of engineering and design firms in a project scope and requires outlining the reasoning of why other alternative designs were not selected

    - Designs should incorporate as few material types as possible (e.g., only one size and type of rock) to save the contractor the time required to switch between multiple types of material during deployment
- Material procurement
    - Project sponsors should consider purchasing some materials on their own (compared to having the contractor procure it) to achieve better prices either through stronger incentives to negotiate and/or volume discounts if sponsoring multiple projects through different contractors
- Deployment
    - Advise construction contractors new to oyster reef restoration on best deployment practices (e.g., lower substrate below the surface of the water before releasing or it will spread out thinly before reaching the bottom)
    - Seek out restoration locations where one can be less discriminate where the substrate lands (e.g., away from a channel) to save the contractor time
- Coordination
    - Coordinate travel to site with all parties (e.g., contractors, project managers, sponsors, media) to save costs on transportation (i.e., sharing vehicles and boats to remote sites)
- Contract bidding
    - Standardize bid forms to compare contractor bids 'apples to apples' to avoid unaccounted costs and select the true optimal vendor

Consolidated value of cost reduction opportunities: Real-world examples in FL and CA

Collectively, these cost reduction opportunities can all be applied to Pensacola Bay, Florida to meaningfully reduce the time required to restore a given area by reducing costs by ~60%.[23] For example, a concerted restoration effort in Pensacola Bay (Figure 7) is to restore oyster habitat to an ecologically meaningful landscape scale of 1,400 acres. If $10M per year was dedicated to oyster restoration efforts, it would take nearly 28 years to reach the goal under status quo approaches. If implementing only opportunities #2-6, this is reduced to under 20 years. Finally, by leveraging economies of scale as well, the goal can be reached in just over 13 years.

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[23] Pensacola Bay is a typical example where economies of scale and all the cost reduction opportunities apply

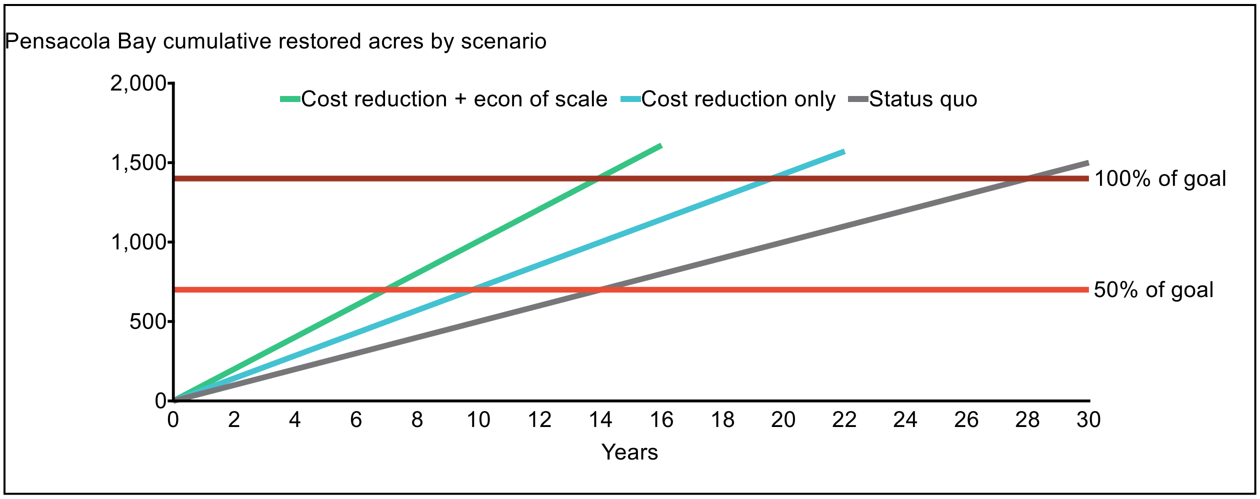

Figure 7: Pensacola Bay Opportunity

Similarly, a concerted restoration effort in Humboldt Bay, CA (Figure 8) may set goals to restore to 50% of documented historic reef area. For Humboldt Bay, commercial collaboration (Opportunity #3) would not apply given there is no oyster fisheries enhancement work on the west coast, and this scenario assumes no other ongoing commercial projects that can be leveraged. This leaves the remaining 4 cost reduction opportunities as well as economies of scale to generate ~50% savings vs. status quo approaches. If $1M per year was dedicated to oyster restoration efforts, it would take nearly 18 years to restore half the bay's historic reef under status quo approaches. If implementing only opportunities #2-6, this is reduced to under 14 years. Finally, by leveraging economies of scale as well, the goal can be reached in just 7 years.

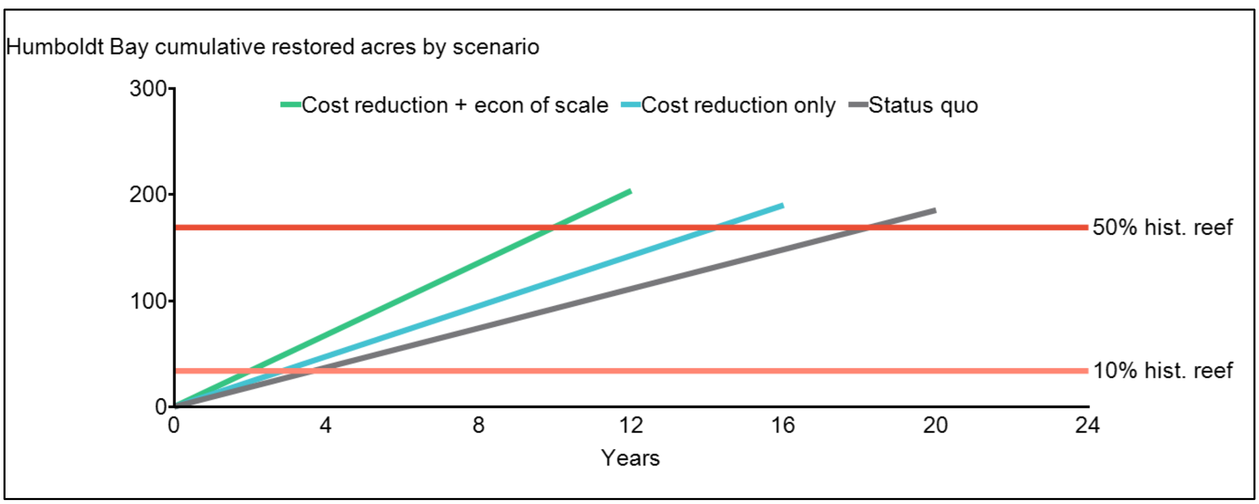

Figure 8: Humboldt Bay Opportunity

Advancements required to scale

The *Cost Reduction Opportunities* outlined above have the potential to double the rate of oyster reef restoration and are recommendations any single project or organization could adopt to reduce costs. However, given the drastic decline of oyster habitat from historic levels (Beck et al. 2011; zu Ermgassen et al. 2012), and current rate of restoration, there is a significant 'uphill battle' faced by the restoration industry. Therefore, further advancements that will allow the industry to efficiently scale are also necessary. In contrast cost reduction opportunities, the *Advancements Required to Scale* will require a regionally or even nationally coordinated effort, but once accomplished will support the success of every future project

This section outlines 9 advancements required for the industry to scale:

1. Consistent funding for restoration
2. State-wide oyster restoration planning, permitting and protection
3. Upfront investment in permitting efficiencies and simplification
4. Alternative and innovative substrate
5. Restoration-earmarked hatchery capacity
6. Integration with commercial fisheries replenishment efforts
7. Multi-year monitoring of restored sites
8. Increased prevalence of, and competition among, contractors
9. Support for restoration from commercial and recreational fisheries

Many of the following recommendations follow exemplar organizations or states that have overcome each specific barrier, and their approach is outlined for others to follow. Unlike the previous section where opportunities were sorted by estimated savings potential, these advancements required to scale are in no particular order as importance will vary based on the current state, project type, etc. Individual organizations should consider each recommendation as a checkbox – if one is achieved, simply look further down the list. To be effective, organizations within the broader oyster reef restoration community must spearhead the undertaking of each advancement to create the desired change broadly.

Advancement #1: Consistent funding for restoration

Oyster reef restoration, likely along with many other restoration priorities, would benefit from more consistent funding. The majority of funding derives from grants, and while these may be relatively consistent sources across all types of restoration, and even within oyster reef restoration nationally, individual regions and organizations do not receive dollars consistently. The lack of consistent funding for organizations causes an unwillingness to invest for the longer term, instead making less economical decisions such as continually hiring short-term staff and making one-time purchases.

As mentioned under 'Cost Reduction Opportunities', the ability for project sponsors to hire engineers, project managers, and other staff full-time for the construction phase has great potential to save costs overall, but hinges on organizations' funding to conduct restoration long-term (e.g., greater than 5 years) which requires confident expectations of future funding. Additionally, contractors hire temporary staff and rent equipment because they also cannot anticipate future work, driving up their own costs and therefore the price they charge. One-time material purchases are also more expensive, compared to locking in annual contracts or having the ability to pre-purchase scarce commodities such as oyster shell. For example, Puget Sound Restoration Fund in Washington State had an opportunity to pre-purchase oyster shell to support multi-year actions at a set, discounted price but was unable to commit to this contract and obtain the discount given a lack of consistent funding, ultimately driving their costs upward.

The lack of consistency also impedes work that is required beyond construction such as baseline assessments and surveys that lay the groundwork for future restoration construction. In addition, some projects may lose their funding after a pilot phase, resulting in few measurable outcomes to base future full-scale projects on. The organization may then only receive funding again a number of years later, and this second round of funding will likely have to go to yet another pilot project to re-test efficacy in a quickly changing nearshore environment.

As noted earlier, there is a unique opportunity for the Gulf of Mexico to leverage the next 10-15 years of consistent Deepwater Horizon oil spill funding to make longer term decisions and reduce costs of oyster reef restoration. However, this is the only region that currently has the luxury of more predictable funding, and even this funding source may not continue allocating funds to oyster reef restoration without a concerted effort to do so. Other regions, including the Chesapeake Bay, are hopeful for long-term future funding but depend more on the current political environment, making organizations timid to invest in longer-term physical or intellectual capital.[24]

Advancement #2: State-wide oyster restoration planning, permitting, and protection

In several states, obtaining a permit to implement restoration is extremely complex, time-consuming, and expensive. Each time a project is proposed, the state evaluates the permit application from scratch instead of against a specific framework or plan. Through interviews, many examples were encountered where permitting took many years, such as The Nature Conservancy Rhode Island working for 3 years to obtain a permit for just a $10m^2$ pilot project, or the Port of San Diego working for 7 years to permit a living shoreline. These long lead times for permitting can have downstream impacts on the project's ability to meet grant requirements, compromising the project. For example, rising costs while awaiting permits may result in the grant dollars not going as far as expected, resulting in the grant requirements not being met, requiring further work to re-confirm funding.

State-wide oyster planning represents a significant opportunity to simplify and streamline restoration processes as well as encourage additional restoration to meet any state set targets. State-wide oyster planning includes (among many other things) collectively designating sites for restoration, then prioritizing and executing on restoration goals. By making the effort upfront to designate specific sites for restoration, significant efficiencies can be gained.[25] One major benefit would be that required regulatory procedures (e.g., select[26] site reviews to avoid impacts to sensitive habitats), spatial planning, benthic surveys, habitat suitability analysis, and several other tasks can be approached at a system-wide level (e.g., entire bay or estuary). Communities can prioritize restoration sites, whereby organizations could simply approach the state and confirm they will take on restoring a predesignated site, instead of proposing to restore an unevaluated location. For example, in Chesapeake Bay a master plan for native oyster restoration was created in 2012. This master plan designated specific sites for restoration and as a result, restoration organizations experience far fewer permitting delays.

After examining recent projects, there are some states (i.e., particularly those where commercial harvest is still active) where doing restoration but protecting the restored reefs from harvest is not feasible through regulatory means. Therefore, restoration practitioners are designing reefs based on an additional objective: to increase the difficulty to harvest those reefs. However, this represents a significant added

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[24] On June 28, 2022 the House Appropriations Committee approved continued Chesapeake Bay oyster restoration investment through 2023 by a 32-24 vote; however, funding in 2024 and onwards remains uncertain

[25] Assuming state resource agencies, regulatory officials, and project sponsors and partners are all aligned

[26] Select procedures in select states must be performed within a certain number of months of the project (e.g., seagrass surveys are valid for 6 months in Florida), and therefore cannot be conducted at scale in advance.

expense and efficiencies can be gained if projects are protected regardless of how they are built to avoid these otherwise unnecessary costs and considerations.

There are multiple benefits to state-wide oyster planning. First, as alluded to above, permitting latencies are significantly reduced, resulting in fewer wasted resources from both the state regulators and the restoration organizations. Second, once a substantial area has been designated, preliminary environmental and engineering surveys could be conducted all at once, savings costs compared to mobilizing these resources for each individual project. Then, with range-wide data, detailed cost/benefit analyses could prioritize the best near-term investment decisions. Third, the relative ease of restoration in a state with a state-wide plan compared to one without would mean more investment would be directed there; restoration organizations may choose to focus efforts where restoration is easiest, drawing out-of-state dollars in the form of federal grants and private donations to local, often rural communities. And finally, state-wide oyster planning that further sets restoration goals at the bay/estuary scale is the best and most practical way to approach restoration to achieve the economies of scale outlined previously in this document.

Advancement #3: Upfront investment in permitting efficiencies and simplification

The permitting process typically requires approximately 5% of a project's funding, but often lasts multiple years. Organizations involved in restoration (e.g., funders, project sponsors, regulatory agencies) would benefit by investing the time and associated costs to work together to develop a permitting process for restoring natural habitats that is simpler and more efficient. While this would involve initial investments, not tied to any single restoration project, it would yield considerable savings in the long run. By simplifying the permitting process there can be tangible costs savings resulting in more dollars directed to substrate and oyster seed, as well as intangible benefits such as increased ease of restoration for various stakeholders. Permitting a restoration site should generally not be held to the same standard as permitting a structure which is deliberately damaging the environment to provide another benefit (e.g., building a bridge over an estuary). Currently, the U.S. Army Corps of Engineers (USACE) is working on a separate permit application for natural and nature-based features (NNBFs) that will hopefully have less stringent requirements from USACE's side. However, the USACE permit is often just one of several permits required per oyster reef restoration project in a given state. These types of models and approaches should be considered at each level of the regulatory process.

Additionally, for living shoreline work, there should be a separate and less arduous process for oyster reef living shorelines compared to grey infrastructure shorelines such as bulkheads. This would encourage living shorelines by making them even cheaper and easier to implement. One approach several states have taken is to make a living shoreline the default shoreline protection structure, requiring landowners desiring grey infrastructure to prove a living shoreline will not work – a significant barrier.

Advancement #4: Alternative and innovative substrate

Oyster shell is often the preferred substrate for most oyster reef restoration projects; however, oyster shell is increasingly expensive or simply unavailable. The most common sources for oyster shell are collecting recycled shell from the commercial operations (e.g., restaurants, shucking houses), mining fossilized shell deposits, and dredging shell from deeper waters where oysters cannot grow anymore. None of these methods are perfect and each come with varying degrees of complications; particularly the latter two sources have other significant environmental concerns). Competition for oyster shell is also increasing, with aquaculturists crushing it into micro-cultch to serve the half shell market, as well as some non-oyster related purposes.[27]

For the seed-limited portion of the oyster restoration industry to scale, oyster shell supply must increase because shell is still the most biologically and logistically optimal substrate for hatcheries to set oyster larvae on to create spat-on-shell. Therefore, oyster shell cannot continue to be the preferred substrate for all projects if the goal is large-scale, cost-effective national restoration. Specifically, it is recommended for substrate-only projects to consider alternative substrates discussed below. Beyond this, oyster restoration would greatly benefit from increased regulations or incentives for shucking houses and restaurants to return shell to hatcheries for spat-on-shell.

Concrete, limestone, and surf clam shell frequently replace oyster shell (Goelz et al. 2020). Concrete and limestone are typically used in larger, more complex, and often sub-tidal projects, while surf clam shell is most often used in small to medium sized projects. For concrete specifically, it can either be newly mixed and formed, or recycled as old infrastructure is demolished. Multiple interviews suggested the exciting potential to use recycled materials as substrate for oyster reef restoration projects, such as taking the rubble concrete as bridges are destroyed then rebuilt[28]. Being able to take the rubble, crush it, sort it to discard contaminants (e.g., hydrocarbons, steel, etc.), and then transport it to a restoration site could greatly reduce the cost of restoration projects. For example, there is one company that will dismantle bridges from barges, crush and prep the concrete on the barge, then push the barge to the next site (such as the site of an oyster reef project). Aligning planned projects with bridge demolition projects could increase efficiency significantly. However, two primary issues face this idea before it could be implemented at scale. First, the true ability (i.e., ease, effectiveness, cost) to remove unwanted materials from the rubble before it goes into the water as substrate is not yet understood. Second, coordinating with governments to align what infrastructure is destined for demolition with oyster restoration projects ready for implementation would take considerable effort. While the latter could be overcome, the former issue is a real barrier; some states have already advised against repurposing concrete from road projects due to embedded hydrocarbons. However, if a project requires new concrete, there are still some opportunities to make it more sustainable. For example, a portion of the Half Moon Bay reef in Texas was built with unused concrete from a nearby concrete plant by accepting the leftover concrete a concrete truck dumps when it returns to the facility. Another source of recycled materials is repurposing all the rock that will be dredged to deepen ports in the coming years. The USACE has plans to dredge many large ports in the next decade and even has a mandate of 70% ‘beneficial use’ of dredged material by 2030. While the USACE has built oyster reefs with dredged material in the past, it has limited monitoring data, so its effectiveness remains unknown.

For restoration practitioners and projects who are committed to using native oyster shell, other cheaper and more accessible substrates could be used for the bottom layer(s) of the reef. For example, recycled or new concrete and other materials could be used as the bottom layer, elevating the preferred substrate

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[27] Oyster shell competition includes uses in landscaping and chicken feed, with these customers often having higher willingness to pay than non-profit oyster reef restoration organizations

[28] With the IIJA, there are many large-scale infrastructure rebuilds planned that will result in potential access to rubble materials

(oyster shell) from the bottom to avoid it sinking or being covered by sediment, and to aid recruitment on the oyster shell by raising it higher in the water column.

Additionally, other products are designed for the restoration market with multiple companies exploring further substitutes. While this report does not suggest any particular substrate is best, several materials and companies with promising products are highlighted next. Other products typically used and recommended for intertidal work include Flexamat[29], Oyster Castles[30], Oyster Catcher[31], and QuickReef[32]. No innovative subtidal substrate was identified through interviews, representing a potential innovation opportunity.

Generally, interviews suggested that while oyster shell is a limiting factor, there are sufficient alternatives including the potential for using recycled materials and adequate appetite from private companies to innovate in this space. The final factor in substrate selection should be location. In the detailed project budgets collected, transportation costs were often greater than or equal to the cost of the substrate itself. Overall, the total cost of a given substrate should be considered before purchase, and it may be optimal to choose a substrate that requires additional considerations (e.g., more difficult deployment, heightened design requirements) if its total cost is cheaper.

Advancement #5: Restoration-earmarked hatchery capacity

When bays and estuaries have depleted oyster stocks, conservation aquaculture (e.g., spat-on-shell deployment) is required; however, typically hatcheries have more demand for larvae and spat-on-shell than they can supply. Further, this problem will likely only grow as aquaculture's prominence continues to rise. As hatcheries become more vital, the private market is likely to step up in search of potential profits to ease the supply-demand imbalance, leading to private hatcheries adequately supporting the commercial industry. These existing and new private hatcheries would also be able to supply restoration efforts – hatcheries interviewed said there is nothing inherently different required to serve a restoration customer – but they will not necessarily prioritize restoration over profits. This specific nuance around restoration projects not receiving formal prioritization will result in restoration projects paying high prices or otherwise having limited access to spat-on-shell. Some private hatcheries noted they would be reluctant to take on a restoration if that customer could not commit to frequent business as this would displace loyal commercial customers in a competitive industry (i.e., a further issue derived from a lack of consistent funding). Therefore, to move to large-scale projects, restoration-earmarked hatchery capacity must be a priority.

Horn Point Oyster Hatchery in Maryland is an example of strong restoration hatchery support that has led to remarkable results. Horn Point produces upwards of 500M spat-on-shell each year for restoration and aims to sell 30% of its production commercially. For the upcoming Manokin River project, Horn Point will produce 2.1B spat-on-shell for a total estimated cost of just $8.4M – equivalent to 250 spat-on-shell per dollar. In contrast, projects in other regions paid between 15x and 250x this amount, receiving 1-15 spat-

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[29] Flexamat is made by Motz Enterprisesm, Inc.
[30] Oyster Castles are made by Allied Concrete
[31] Oyster Catcher is made by Sandbar Oyster Company
[32] QuickReef is co-invented by Mary-Margaret McKinney who uses it on many shoreline projects under Restoration Systems (RS Shorelines)

on-shell per dollar, from other hatcheries. Achieving this incredibly low per-unit costs for restoration is only possible with restoration earmarked hatchery capacity.

Advancement #6: Integration with commercial fisheries replenishment efforts

While a similar idea was used as a primary example under 'Cost Reduction Opportunities' as an opportunity for individual project sponsors to explore, the integration of restoration efforts with state commercial fisheries replenishment efforts should be explored at a broader scale as well. First, resources should be shared between restoration and commercial fisheries replenishment work to reduce costs of substrate purchase and transportation, contractor mobilization and demobilization, monitoring, etc. This high degree of planning integration could also be enabled through 'Advancement #2: State-wide oyster restoration planning'. Second, restoring adjacent sanctuary reef as 'brood reefs' is being explored by several organizations as larvae levels are declining on public reefs, making natural recruitment more unreliable. If fisheries replenishment efforts can be bolstered through adjacent restoration, all parties would benefit. Therefore, research should continue to explore the benefits that brood reefs could have on public reefs, and make these benefits clear to harvesters, restoration practitioners, and state resource managers, such that better synergies between efforts are more sought after.

Advancement #7: Multi-year monitoring of restored sites

Many funding sources do not provide capital for more than a couple years to monitor the restored oyster reefs. This results in limited knowledge of successful approaches and an inability to prioritize restoration across a region. When projects are monitored and documented properly (i.e., over a longer time horizon), restoration practitioners internal and external to the sponsor organization can learn more effective approaches for future work. Without multi-year monitoring, there is limited confidence in the results, often requiring further pilot projects; and when the aim is to maximize conservation, organizations cannot continue running pilot projects indefinitely – organizations must run a pilot, monitor it properly, then move to full-scale work immediately. Additionally, multi-year monitoring will help direct future spend to the areas where it is expected to be most effective. In Ridlon et al. 2021, inconsistent monitoring data was cited as a key barrier of their efforts to prioritize the next set of west coast restoration sites. Further, monitoring data must be standardized, which is the intention of the national oyster monitoring guidelines (Baggett et al. 2014; Baggett et al. 2015), and publicly accessible to be most useful. In a future with access to multi-year monitoring data, proposed restoration sites can be looked at more factually, based on the success of past projects, to make the best use of scarce dollars.

Despite the benefits, it is likely that some grants will continue to not fund sufficient monitoring. In this case, when a grant does not provide the resources, the sponsoring organization should consider funding it internally. Another approach is for specific organizations within the oyster reef restoration community (such as a state resource agency or an NGO) to take on monitoring of many projects as their contribution, instead of or in addition to their in-water work.

Advancement #8: Increased prevalence of, and competition among, contractors

As oyster reef restoration efforts grow, marine contractor availability will increasingly become an issue. The construction phase, typically deployment of substrate and oyster seed, is the largest cost of most projects but many regions have few options for contractors who can complete this specialized work. Interviews revealed that some projects would issue an RFP but receive no bids, or that only a single contractor operates in a given region. This represents not only a barrier when trying to scale, but also to achieve low prices, given both the lack of competition as well as contractors pricing in risk when they are unfamiliar with a new type of project driving up costs.

Additionally, marine contractors are often more comfortable building traditional grey infrastructure, lacking experience or training in the skillsets required for nature-based projects such as living shorelines. One avenue organizations can pursue is contractor training programs. Several states, including Florida and North Carolina, have begun contractor training programs, often specific to living shoreline work, to increase both the availability of contractors as well as encourage contractors to present living shorelines as a viable alternative when private landowners require a shoreline protection solution.

Advancement #9: Support for restoration from commercial and recreational fisheries

In many regions, restoration remains at odds with the interests of commercial and recreational fisheries as it typically reduces harvestable area. Therefore, for the restoration industry to thrive and undertake large-scale efforts, support must be gained from these parties.

There are some emerging programs which seem to be effective at gaining support from the commercial industry. NRCS EQIP's oyster purchase program in Rhode Island and TNC's SOAR oyster purchase program across Maine, New Hampshire, Massachusetts, New York, New Jersey, Maryland, and Washington have aligned incentives of commercial growers to restoration. Both programs have aquaculture farmers grow oysters on their leases, then pay them to outplant the mature oysters on sanctuary reefs. This provides a stable source of income for the farmer, and mature oysters for restoration. Although these programs have a higher restoration cost, they may yield other benefits, many mentioned previously, such as garnering support for restoration from the commercial industry, integrating industries to leverage efficiencies, securing restoration permits, and access to consistent funding sources.

Additionally, in Australia there is strong support for oyster reef restoration from recreational fishing groups who enjoy increased fish stocks after their habitat is restored (i.e., oyster reefs provide excellent fish habitat). The U.S. has a significant recreational fishing industry, with a total recreational harvest over 350,000,000lbs and nearly 250,000,000lbs from inland or nearshore[33] sources in 2019 (National Marine Fisheries Service, 2021). However, the U.S. has had limited success engaging the recreational fishing communities and gaining their support to protect and restore oyster reefs, representing a future opportunity to tip the scales in favour of restoration. One recent study by Carlton et al. 2016 on the Half Moon Reef in Matagorda Bay, Texas clearly quantifies the benefit of restoration to recreational fishers, representing a future opportunity for the U.S.; select promising results include:

- 94% of anglers reported that the restored habitat at Half Moon Reef offers a more satisfying experience than other fishing locations
- Half Moon Reef anglers reported catching more fish per trip (5) than did other anglers (3.7)
- Increased recreational fishing at Half Moon Reef added $691,000 to Texas' gross domestic product each year and generated an additional $1.273 million in annual economic activity

Ability to absorb potential funding windfalls

It should be noted that without making these advancements, the industry does still have potential to absorb and implement some additional funding, often at a better rate than current efforts given

[33] Nearshore is 0 to 3 miles from shore (state territorial sea)

economies of scale. However, these 9 advancements will make scaling easier as well as avoid discouraging groups attempting to restore oyster reefs due to a lack of support and/or difficult processes. Therefore, in the case of a funding windfall, there remains a strong case to continue directing dollars to in-water oyster reef restoration. However, there will come a point of diminishing returns where these advancements should be prioritized ahead of additional in-water projects to make future efforts more efficient.

CONCLUSION

Oyster reef restoration is a substantial industry with $70-90M of annual spend, directly supporting nearly 1,500 jobs, and generating nearly $210M of total economic output. To date, the oyster reef restoration industry has grown impressively, and it is expected to continue to do so. Still, the market is quite regionally concentrated with nearly 85% of spend within the mid-Atlantic and Gulf of Mexico states. Consequently, for other regions, such as the northeast and west coast states, this presents an opportunity for those regions to learn best practices from the leading states. Furthermore, this analysis demonstrates the potential economic opportunity of increased restoration.

With an industry of this size, it is prudent to ensure dollars are used most effectively, especially given that despite the growth of the industry, the current pace and scale of restoration remains insufficient to achieve meaningful ecosystem goals in a reasonable timeframe. Therefore, this report sought to identify opportunities to support growth efficiently by making the most of limited funding to restore oyster reefs as fast as possible. Through the six cost reduction opportunities, it is realistic to optimize how projects are run to reduce restoration costs by ~50%, doubling the pace of restoration with existing funding. Further, by supporting the nine advancements required to scale, each project will be simpler and cheaper for restoration practitioners, catalyzing a further step-change of reduced oyster reef restoration costs.

Lastly, although this report did not explore the funding side of restoration, it is worth noting the substantial potential of the industry if more funding were available. The oyster reef restoration industry seems exceptionally positioned to benefit from additional funding given the large number of organizations running small-scale projects. Each of over one hundred organizations operates quite independently, and each have baseline fixed costs to cover. Many of the organizations interviewed mentioned that if they received more funding, nearly all of it would go to additional substrate or oyster purchases since they already have the structures in place to make use of the funds. Therefore, oyster reef restoration efforts could achieve outsized incremental benefits with more funding compared to other industries operating at closer to their full capacity. Achieving large-scale conservation outcomes will necessitate the oyster restoration industry to have multiple shifts in mindsets and methods of restoration, but these modifications have the potential to leave an immense impact and restore oyster reefs for future generations.

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APPENDIX

Appendix A: Project data collection template

- This template is intended to record valuable information about your most recent oyster reef restoration project(s)	**Legend:**
- Please complete this worksheet for each of your projects within the last 5 years if possible (use a new worksheet for each project)	Drop-down response (blue)
- Use the drop-down options in the blue boxes where available, and add optional commentary to the right to clarify when necessary	Free form text entry - no limit (yellow)
- Thank you very much for your help -- your responses will be critical to the successful completion of our project	Optional commentary - no limit (light grey)

Section	Question	Response	Optional commentary
General info			
	Your name		
	Project name		
	Leading organization / project sponsor		
	Lead/sponsor type		
	Estuary/waterbody name		
	State (project location)		
	Region (project location)		
	Primary project goal		
Overview			
	Project start year (i.e., year first funding was received)		
	Project completion year (excl. monitoring)		
	Restoration footprint (# + unit)		
	Restoration area (# + unit)		
	Organizations involved	*List organization and % of involvement by each*	
	Organization 1 (lead/sponsor)		
	Organization 2		
	Organization 3		
	Organization 4		
	Organization 5		
	All other organizations		
Costs & funding			
	Budgeted project costs		
	Estimated additional unbudgeted project costs		
	Total project costs	$0	
	Project costs split by step (budgeted + unbudgeted)	*Split total project costs among each step (approximately)*	
	Pre-planning (site selection, outreach, securing funding)		*Please indicate if these costs were recovered through grants*
	Regulatory process (permitting incl. required field work)		
	Design & engineering (of structure, excl. permitting field work)		
	Raw materials		
	Construction/contractor labour		
	Other equipment (exclude costs within contractor cost above)		
	Conservation aquaculture - hatchery (larvae, spat, and/or adult oysters)		
	Conservation aquaculture - deployment		
	Monitoring		*Please indicate length of monitoring included in this cost*
	Other (specify in comments)		
	Total project costs	$0	*This value should match row 36 'total project costs'*
	Outsourced costs	*Specific outsourced costs, broken down differently vs above*	
	Project management		
	Other consultants		
	Sources of funding	*List source and % of total funding contributed for each*	
	Source 1		
	Source 2		
	Source 3		
	Source 4		
	Source 5		
	Primary source of funding		
	Secondary source of funding		
	Funding schedule		
	Use of in-kind labour		
	Use of in-kind materials and/or equipment		
	Estimated total value of in-kind labour, materials, and/or equipment		
	Use of volunteer labour		
	Estimated total value of volunteer labour		
Substrate deployed			
	Type of primary substrate		
	Amount of primary substrate (include number and unit)		
	Materials cost of primary substrate ($/unit)		
	Transportation cost of primary substrate (incl. cost, distance, and transport mode)		
	Type of secondary substrate		
	Amount of secondary substrate (include number and unit)		
	Materials cost of secondary substrate ($/unit)		
	Transportation cost of secondary substrate (incl. cost, distance, and transport mode)		
Conservation aquaculture (if applicable)			
	Use of conservation aquaculture components		
	Type of conservation aquaculture used		
	Amount of oysters deployed (include number and unit)		
	Cost per oyster unit (include cost and type - larvae/spat/juvenile/adult)		
	Transportation cost of oyster unit (incl. cost, distance and transport mode)		
Other info			
	Location accessibility (1-5; 5=difficult)		
	Proximity to shore		
	Tidal elevation in restoration area		

Appendix B: Restoration project datasets characteristics and limitations

Dataset	Characteristics	Limitations
Deepwater Horizon Project Tracker *(dwhprojecttracker.org)*	Includes 1,537 projects since 2010, 53 of which had oyster reefs as the primary resource targeted. Each project details spend data (incl. leverage), restored area, year, and project descriptions. Funding agencies cite source as most accurate, although some ongoing projects may not be included yet	Includes only projects funded from the Deepwater Horizon oil spill damage assessment. $18.5B allocated primarily through NFWF GEBF, RESTORE, and NRDA to initiatives in the Gulf of Mexico. Single funding source does not cover all projects, spans only ~10 years, and includes commercial reef replenishment as well
NOAA Restoration Center projects *(NOAA RC contacts)*	Includes 644 oyster reef restoration projects since 1992 funded by NOAA RC. Each project details NOAA RC's contribution with other leverage and match dollars, year, restored area, and project descriptions. All projects are for restoration per this report's definition.	Represents <10% of the estimated market size, oyster allocation fluctuates annually, funding is regionally concentrated with majority of funds allocated to Chesapeake Bay (MD and VA) and North Carolina
Olympia Oyster Restoration Survey Database *(Ridlon et al. 2021)*	Includes 39 west coast oyster reef restoration projects from 2001 - 2018; this source covers the vast majority of west coast work over that time period. Each project details the total cost, restored area, year, and project descriptions. All projects are for restoration per this report's definition.	Represents <2% of the estimated market size as only west coast Olympia projects are included. Dataset ends in 2018.
Restoring the Eastern Oyster: Progress Report *(Bersoza Hernández et al. 2018)*	Includes 1,768 oyster reef restoration projects from 1964 - 2015 gathered from a variety of sources to write associated paper. Project database was requested separately, not shared within the paper. Project details vary significantly, with most detailing only the location and year. All projects are for restoration per this report's definition.	Includes only projects from major sponsoring agencies. Dataset ends in 2015, with only disparate data 2010-2015. Majority of projects have no cost or restored area data. Project entries are listed from multiple agencies providing no consistency to one 'entry'.
Review of U.S. Coastal Habitat Restoration *(DeAngelis unpublished dataset)*	Includes 8,018 projects from 2006 - 2015, 373 of which had bivalve (majority oysters) as the primary habitat targeted. Project details include year, state, and restored area. All projects are for restoration per this report's definition.	Includes only projects from major sponsoring agencies. Dataset ends in 2015. Projects have no cost data.

Appendix C: Summary of interviews conducted by type

Stakeholder	Internal (TNC)	External	Total
Project sponsors and managers	21	18	39
Consulting, design, and engineering firms	--	6	6
Construction firms	--	3	3
Hatcheries and nurseries	--	8	8
Materials suppliers	--	1	1
Government funders & regulators	--	5	5
Academics	--	6	6
Total	21	47	68

Interviews conducted March to May 2022; average interview length was 1-hour

Appendix D: Full list of interviewees, sorted by region

Name	State	Region	Organization	Category	Contact
[redacted]	New York	Mid-Atlantic	[redacted]	Academics	Interview
[redacted]	Virginia	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	Virginia	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	New Jersey	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	Virginia	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Design and engineering firms	Interview
[redacted]	New York	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	New York	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	New York	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Hatcheries and nurseries	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Hatcheries and nurseries	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Hybrid: Project sponsors and managers, contractor, hatchery	Interview
[redacted]	Maryland	Mid-Atlantic	[redacted]	Project sponsors and managers	Interview
[redacted]	New Jersey	Mid-Atlantic	[redacted]	Academics	Interview
[redacted]	Texas	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Louisiana	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Florida	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	n/a	Gulf of Mexico	[redacted]	Government funders and regulators	Interview
[redacted]	Texas	Gulf of Mexico	[redacted]	Design and engineering firms	Interview
[redacted]	Louisiana	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Texas	Gulf of Mexico	[redacted]	Design and engineering firms	Interview
[redacted]	Florida	Gulf of Mexico	[redacted]	Design and engineering firms	Interview
[redacted]	n/a	Gulf of Mexico	[redacted]	Government funders and regulators	Interview
[redacted]	Alabama	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	n/a	Gulf of Mexico	[redacted]	Government funders and regulators	Interview
[redacted]	Alabama	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Florida	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Florida	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Texas	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Florida	Gulf of Mexico	[redacted]	Construction firms	Interview
[redacted]	n/a	Gulf of Mexico	[redacted]	Design and engineering firms	Email
[redacted]	Florida	Gulf of Mexico	[redacted]	Academics	Interview
[redacted]	Louisiana	Gulf of Mexico	[redacted]	Construction firms	Interview
[redacted]	Louisiana	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Mississippi	Gulf of Mexico	[redacted]	Project sponsors and managers	Interview
[redacted]	Georgia	Southeast	[redacted]	Project sponsors and managers	Interview
[redacted]	North Carolina	Southeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Georgia	Southeast	[redacted]	Construction firms	Interview
[redacted]	South Carolina	Southeast	[redacted]	Project sponsors and managers	Interview
[redacted]	North Carolina	Southeast	[redacted]	Project sponsors and managers	Interview
[redacted]	North Carolina	Southeast	[redacted]	Design and engineering firms	Interview
[redacted]	South Carolina	Southeast	[redacted]	Project sponsors and managers	Interview
[redacted]	North Carolina	Southeast	[redacted]	Materials suppliers	Interview
[redacted]	Georgia	Southeast	[redacted]	Project sponsors and managers	Interview
[redacted]	North Carolina	Southeast	[redacted]	Academics	Interview
[redacted]	New Hampshire	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Connecticut	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Maine	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Rhode Island	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Massachusetts	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Connecticut	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	Rhode Island	Northeast	[redacted]	Project sponsors and managers	Interview
[redacted]	California	West	[redacted]	Academics	Interview
[redacted]	Washington	West	[redacted]	Project sponsors and managers	Interview
[redacted]	California	West	[redacted]	Project sponsors and managers	Interview
[redacted]	California	West	[redacted]	Hatcheries and nurseries	Interview
[redacted]	California	West	[redacted]	Project sponsors and managers	Email
[redacted]	California	West	[redacted]	Hatcheries and nurseries	Interview
[redacted]	California	West	[redacted]	Hatcheries and nurseries	Interview
[redacted]	California	West	[redacted]	Hatcheries and nurseries	Interview
[redacted]	California	West	[redacted]	Project sponsors and managers	Interview
[redacted]	Oregon	West	[redacted]	Project sponsors and managers	Interview
[redacted]	Oregon	West	[redacted]	Hatcheries and nurseries	Interview

[redacted]	n/a	National	[redacted]	Academics	Interview
[redacted]	n/a	National	[redacted]	Government funders and regulators	Interview
[redacted]	n/a	National	[redacted]	Design and engineering firms	Interview
[redacted]	n/a	National	[redacted]	Government funders and regulators	Email
[redacted]	n/a	National	[redacted]	Government funders and regulators	Interview
[redacted]	n/a	International	[redacted]	Project sponsors and managers	Interview
[redacted]	n/a	International	[redacted]	Project sponsors and managers	Interview
[redacted]	n/a	International	[redacted]	Project sponsors and managers	Interview
[redacted]	n/a	International	[redacted]	Academics	Email

Appendix E: Contractor bids for living shoreline project in the Gulf of Mexico