Shell Bank: Enhancing coastal resiliency via shell recycling, restoration & community partnerships

Final Report for GLO Contract # 21-060-007-C667

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Prepared for

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Acknowledgements

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Project Partners

Introduction

Coastal environments are recognized for providing ecological benefits and supporting coastal resiliency. However, the Gulf of Mexico and the Texas coast are vulnerable to pressures from natural disasters and human activities. In the Gulf of Mexico, over 50% of oyster populations are estimated to be lost compared to historic levels (Beck et al. 2011). Restoration of oyster reefs can help communities become more resilient by providing natural buffers against storms, improving water quality, supplying critical habitat, and supporting coastal recreation and tourism. The economic benefits of oyster reef restoration are substantial. Oyster reefs provide estimated economic benefits of $2,200-$40,000 per acre in the form of enhanced water quality, shoreline protection, seagrass populations, and recreational fishing (Grabowski et al. 2012). Oyster reefs are also valued for increasing fish and crustacean production, with economic benefits estimated at $4,123 per hectare per year (Peterson et al. 2003; Grabowski and Peterson 2007). Economic benefits of oyster reefs to recreational fishing alone are estimated at $2 million (Henderson and O'Neil 2003). Half Moon Reef, a 57-acre restored oyster reef in Matagorda Bay, is estimated to provide annual economic benefits of $691,000 to Texas' GDP and $1.273 million in overall economic activity (Carlton et al. 2016). Although many studies have focused on one ecosystem service, there is interest in gaining a more comprehensive understanding the suite of ecosystem service benefits generated by reef restoration projects.

This project sought to support public education, environmental stewardship, and coastal resilience by (1) Recycling oyster shells for habitat restoration, (2) Transitioning from plastic-based to natural fiber-based materials for community based restoration events, (3) Increasing student understanding of oyster reef restoration science by providing resources and expertise through a citizen science integrator, and (4) Assessing ecosystem services provided by sanctuary-style versus harvestable-style restored oyster reefs.

This project implements CMP goal 1) "to protect, preserve, restore and enhance the diversity, quality, quantity, functions, and values of coastal natural resource areas (CNRAs)" by (a) reclaiming oyster shells for use in habitat restoration to restore and enhance the diversity, quality, quantity, functions, and values of oyster reefs, defined as CNRAs in Texas Natural Resources

Code, §33.203(13). As well as 2) "to educate the public about the principal coastal problems of state concern and technology available for the protection and improved management of CNRAs" by (a) engaging students and teachers through our citizen science integrator, to ensure that the next generation of young scientists and coastal stewards have more than just a textbook-level understanding of local environmental issues, and (b) delivering educational outreach to students and the public through targeted presentations and participation in community events.

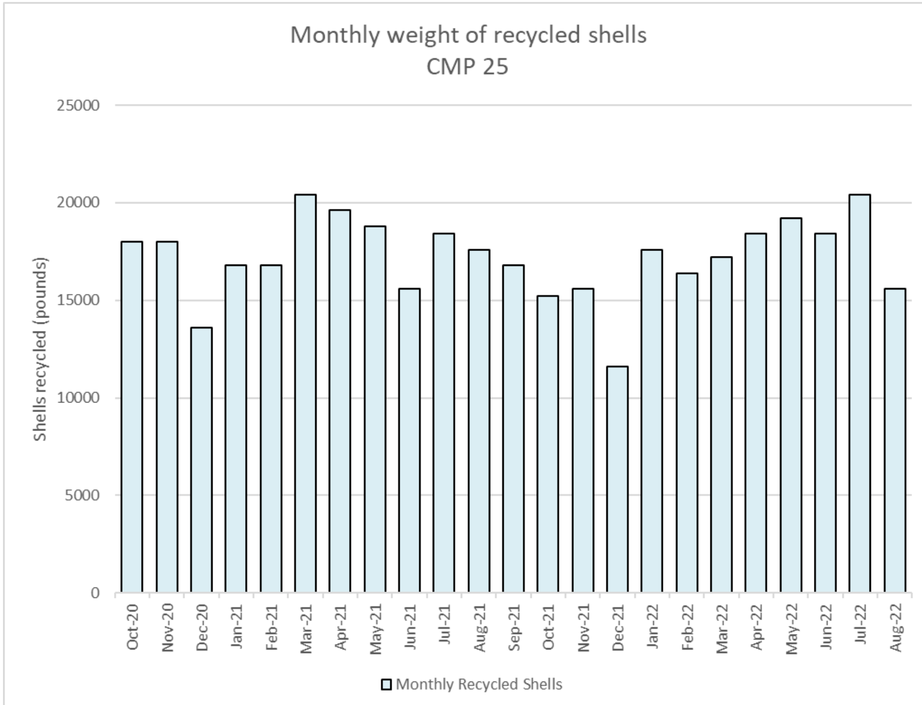
Project accomplishments

Goal 1: Recycling oyster shells for habitat restoration

Oyster reefs are valued ecological and economic resources. However, their populations are in decline throughout the Gulf of Mexico. Restoration efforts to rebuild lost habitat are often limited by a lack of oyster shells, the preferred substrate for constructing reefs. Our "Sink Your Shucks" program reclaims shucked oyster shells and recycles them back into Texas Coastal Bend bays to restore oyster reefs.

Water Street Oyster Bar in downtown Corpus Christi and Virginia's by the Bay in Port Aransas were the most consistent contributors of shucked shell to the recycling program. Shell pickups were run approximately 1-3 times per week to each restaurant. During each pickup, shell bids are loaded onto a flatbed trailer and transported to our Shell Bank stockpile location at the Port of Corpus Christi where they are quarantined for at least 6 months before use for habitat restoration.

The weight of shells reclaimed each month was consistent throughout the project period, but was highest in March 2021 and July 2022 at 20,400 pounds of shell collected (Figure 1). The lowest weight of shells was collected in December 2020 and 2021, when the program took a brief holiday break from shell pickups. Regardless, the cumulative weight of shells reclaimed increased steadily throughout the project period, with a total of 396,000 pounds of oyster shells reclaimed throughout CMP Cycle 25.



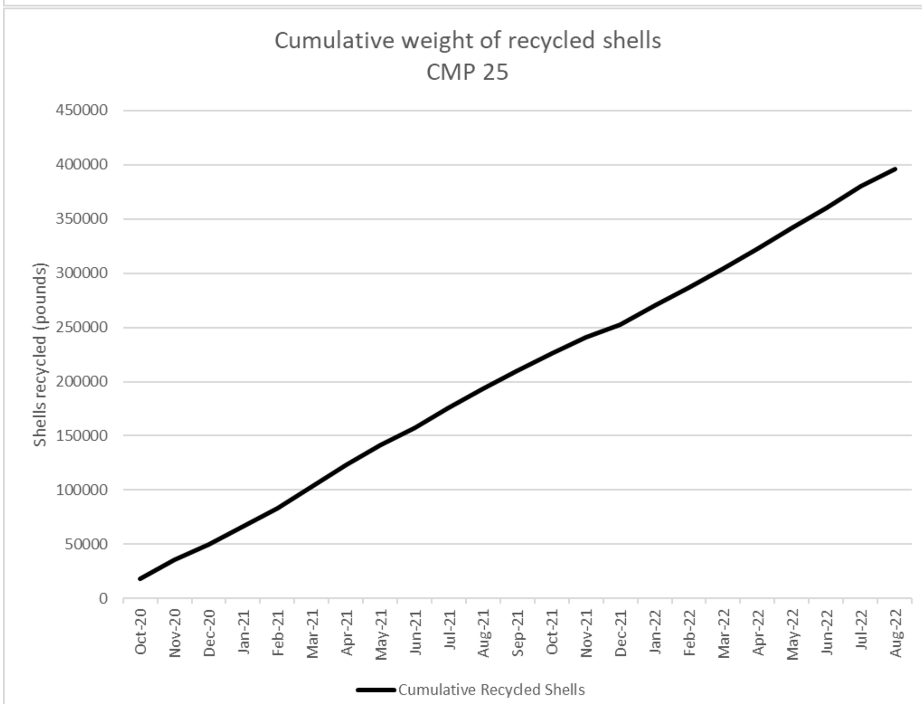


Figure 1. (Top) Monthly weight of shells recycled during CMP 25, and (Bottom) cumulative weight of shells recycled during CMP 25.

Snoopy's Restaurant on Padre Island expanded this year to add Snoopy's Pearl Oyster Bar, and committed to donating their oyster shells to the program (Figure 2). However, during the project period, we found that the oyster bar was not opened for continuous operation. We have stayed in communication with the owner and plan to initiate shell recycling as part of CMP 26 or beyond, depending on their operations timeline. We halted shell recycling pickups from Scuttlebutts Restaurant on Padre Island due to turnover in management and continued problems with trash in the shell bins; we remain open to the possibility of reestablishing this relationship in the future.

We are happy to report that we have been working with Brad Lomax and Peyton Gardner from the Texas Surf Museum to institutionalize and grow the oyster shell recycling activities beyond the horizon of CMP funding. We want to acknowledge that the support from CMP over the years that has made the evolution of this shell recycling partnership possible, by instilling confidence and fostering a culture of stewardship in our project partners.

As part of Task 1, we provided public outreach opportunities to teach the public about the ecological and economic importance of oysters and oyster reefs, and the need for restoration to ameliorate the effects of habitat loss. We developed educational activities that were offered in at public 'Luau' events sponsored by the Texas Surf Museum: one on July 31, and the other on October 9, 2021 (Figure 2, Figure 3). Our activities were developed for children, but we could easily adapt them for all ages. One activity involved creating art from recycled oyster shells, while in another, we used real and 'larger-than-life' 3D printed models of reef-dependent organisms to illustrate the role of oyster reefs in providing essential habitat. Researchers and students staffed the booths and shared information about the shell recycling program and the numerous acres of habitat restoration that has resulted from these efforts. We also gave public presentations to expand the reach of our project. We presented *"Community and Conservation: Bridging Interests on Oyster Reef Use"* to ~35 attendees at the Rockport Aquarium on March 22, 2022. We also *presented "Community impact of the Sink your Shucks Program"* to ~100 attendees at the Council of Principal Investigators and Research Administrators' Annual Research Forum at Texas A&M University-Corpus Christi on March 30, 2022.

Figure 2. Snoopy's Pearl Oyster Bar, located on Padre Island.

Figure 3. Creating oyster shell art at the Texas Surf Museum 'Luau' event.

Figure 4. (Top) Viewing real and "larger than life" 3D printed oyster reef organisms. (Bottom) Student researchers setting up the educational outreach table at the Texas Surf Museum 'Luau'.

Goal 2: Community-based restoration events using biodegradable materials

Community-based oyster reef restoration events strengthen community resiliency by providing a nature-based solution for protecting shorelines and reducing coastal erosion. One of the most common techniques used for community-based restoration is to place recycled oyster shells into aquaculture-specific polyethylene mesh bags. The mesh bags contain the shells in shallow water and can be stacked into different orientations to create stable, three-dimensional structures for oyster recruitment. Although polyethylene mesh has been used for years in community-based reef restoration efforts—largely due to its low cost and durability—there are growing concerns about introducing plastics into the marine environment (Law 2017).

As part of a related project, we evaluated the efficacy of using natural fiber, biodegradable mesh materials as alternatives to the polyethylene mesh for community-based restoration: cotton, jute, and cellulose (Figure 4). Cotton bags were purchased from Alibaba (China) and had dimensions 55 x 30 cm with 5 mm mesh size. Cellulose bags were purchased from BESE Ecosystem Restoration Products (Netherlands) and had dimensions 70 x 30 cm with 3 mm mesh size. Jute bags were purchased from Tissus Papi (France) and had dimensions 50 x 30 cm with 7 mm mesh. The traditionally used polyethylene bags had dimensions 50 x 20 cm with 2 cm mesh size.

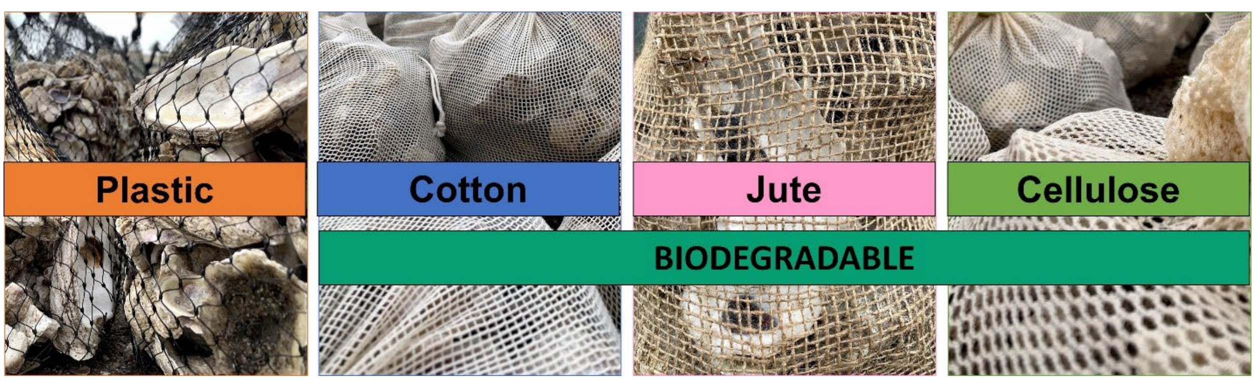


Figure 5. Three biodegradable, natural fiber mesh bags pictured alongside the traditionally used polyethylene mesh bag for community-based oyster reef restoration events.

We planned to host two community-based restoration events for CMP 25 using the best-performing biodegradable mesh material, with the larger goal of promoting more environmentally-friendly habitat restoration approaches that eliminate the potential for introduction of plastics to the marine environment. To adhere to CDC and state COVID safety protocols in place at the time, we planned two events in May 2021 that required pre-registration, were adult-only, and were capped at 20-30 people maximum. Contrary to our plans, spring 2021 ended up being a very wet period, and unfortunately, both restoration events were cancelled due to inclement weather.

In lieu of this restoration event, we hosted an oyster reef restoration-focused event for 94 women participating in *Leadership Women Texas* on June 4-5, 2021. We used our newly created outreach banner and signs at the event. On June 4, we gave presentations to the group as part of their dinner at Water Street Oyster Bar, one of our shell recycling partners. On June 5, we began the day with educational presentations during the group's breakfast at the Omni Hotel, followed by a bus trip to the Harte Research Institute for our main education event. We subdivided the large group into smaller subgroups, who then rotated through four different educational stations facilitated by our research staff and students: (1) importance of water quality for oysters, (2) oyster reef habitat value, (3) oyster life cycle and how it allows habitat restoration to work, and (4) oyster reef restoration from shell recycling to biodegradable bags, including bagging recycled oyster shells. Each subgroup spent approximately 20 minutes at each interactive, hands-on station before rotating to the next station (Figure 4-Figure 11).

Figure 6. Assistant Research Scientist, Dr. Terry Palmer, teaches the group about the importance of water quality to oysters.

Figure 7. Measuring the salinity of bay water samples using refractometers.

Figure 8. Master's student Alexis Neffinger teaches about the important role that oysters play as habitat builders, while Hannah Bueltel and Daunte Gaither look on.

Figure 9. Learning about the anatomy of the oyster.

Figure 10. Master's student Monisha Sugla and Ph.D. student Alyssa Outhwaite teach about the oyster life cycle and why it is critical for restoring reefs.

Figure 11. Ciro Mendoza and Natasha Breaux demonstrate the process of filling mesh bags with recycled oyster shells to restore reefs.

Figure 12. Master's student Jennifer Gilmore provides guidance on how to measure the salinity of different bay water samples using a refractometer.

Figure 13. Using a stereo microscope to determine whether an oyster is male or female.

To summarize individual testing of the biodegradable mesh bags: After one month in the water at St. Charles Bay, approximately 25% of the cellulose and cotton bags were fully disintegrated, and 25% of jute bags had large (>30 mm) holes. All the natural-fiber, biodegradable mesh bags were fully disintegrated within two months of deployment. Polyethylene plastic bags remained fully intact throughout the study period. Even though all biodegradable mesh bags were quickly reduced to piles of loose shells, we found that oyster density and size were quite similar to those in the (intact) plastic mesh bags for five and seven months after deployment, respectively. In terms of overall costs for use in restoration events, we found that plastic bags had the lowest material ($127) and shipping costs ($188.44), compared to cellulose bags that had the highest material ($4,400) and shipping costs ($660.45). Plastic bags took the longest time to fill 1000 units (~25 h) because they needed to be constructed onsite from a tubular roll of mesh, and therefore had the highest labor costs ($716.67). Cellulose was the quickest to fill 1000 units (~12 h) and therefore had the lowest labor costs ($338.82). Overall, our testing of the biodegradable mesh bags indicates that natural fibers are a suitable alternative to plastic mesh, particularly in low energy environments where loose shells will not be dispersed after material breakdown. Although the biodegradable mesh had higher total costs, we contend that the value of reducing plastic pollution to the marine environment provides a considerable advantage for use of natural fiber mesh in future community-based oyster reef restoration efforts.

Goal 3: Citizen Science Integration

The goal of the Citizen Science Integration task, modified to account for COVID restrictions and teacher needs, was to provide local educators with the resources to use oysters and existing Sink Your Shucks lessons as a complement to their already existing science/ecology lessons. A subgoal was for each school in the coastal bend region to be provided with at least one Sink Your Shucks Science bucket.

Sink Your Shucks Science buckets were created using 3-gallon buckets with lids (Figure 14, Figure 15). The buckets were chosen based on teacher feedback; they easily hold all the Sink Your Shucks Science materials, they stack easily for storage within the classroom, and they have an additional use for teachers who choose to set up their own classroom oyster tank.

Figure 14. View of the educational materials inside the Sink Your Shucks Science buckets.

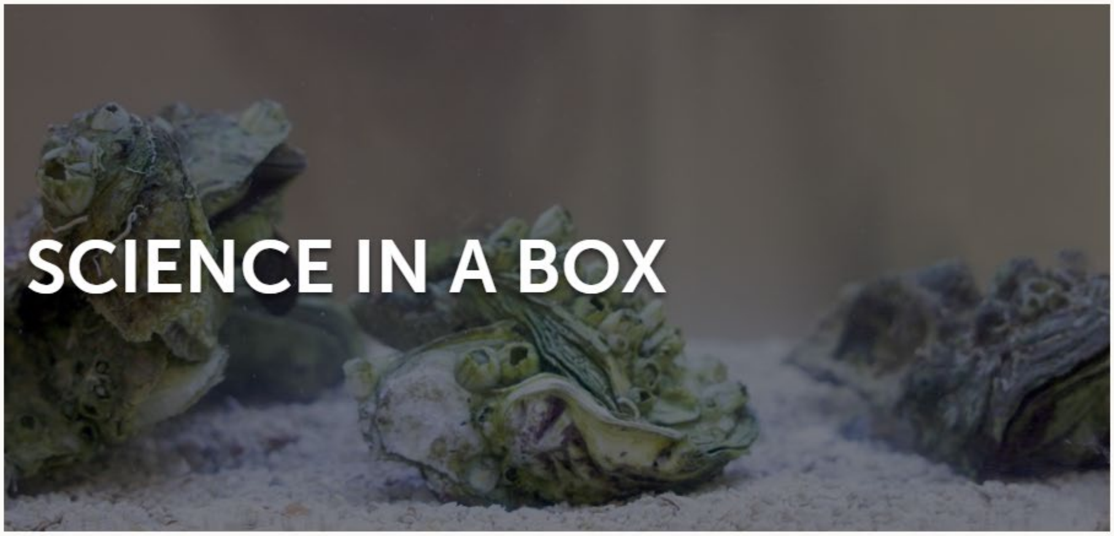
Figure 15. Sorting Sink Your Shucks Science materials to prepare for filling 140 Sink Your Shucks Science Buckets.

In each Sink Your Shucks Science Bucket, we provided:

- Classroom set of oyster shells
- Miscellaneous non-perishable classroom materials (sponges, dried beans, feathers, etc.)
- Aquarium filter
- Hydrometer
- USB memory stick
- Towels
- Links to lesson plans and activities
- Links to videos

We created a QR code that was included on a card inside the Sink Your Shucks Science buckets so that teachers and students can easily access the lesson plans (Figure 15). This code links to a specifically designed website (https://www.harte.org/science-in-a-box) that provides access to the lessons and videos (Figure 17, Figure 18).

Figure 16. Front (top) and back (bottom) of card placed inside of the Sink Your Shucks Science buckets. The QR code will take the teachers to a specifically designed website (https://www.harte.org/science-in-a-box) that includes access to the lessons and videos.



Dear Educator,

Thank you for all you do and for your ability to remain flexible in the current educational climate. Our goal is to provide you with unique educational opportunities and curriculum to reach your students. We also want your students to have an appreciation and basic understanding of their local environmental surroundings in an attempt to increase their environmental literacy on a larger scale.

The Sink Your Shucks™ Science in a Box project is provided to you as an additional resource to supplement your continuing environmental lessons.

Please find enclosed:

- Classroom set of oyster shells
- Aquaria filter
- Hydrometer
- Memory stick
- Towels
- White and red beans
- Sponge
- Feathers

Figure 17. Screenshot of Science in a Box website link provided on QR code.

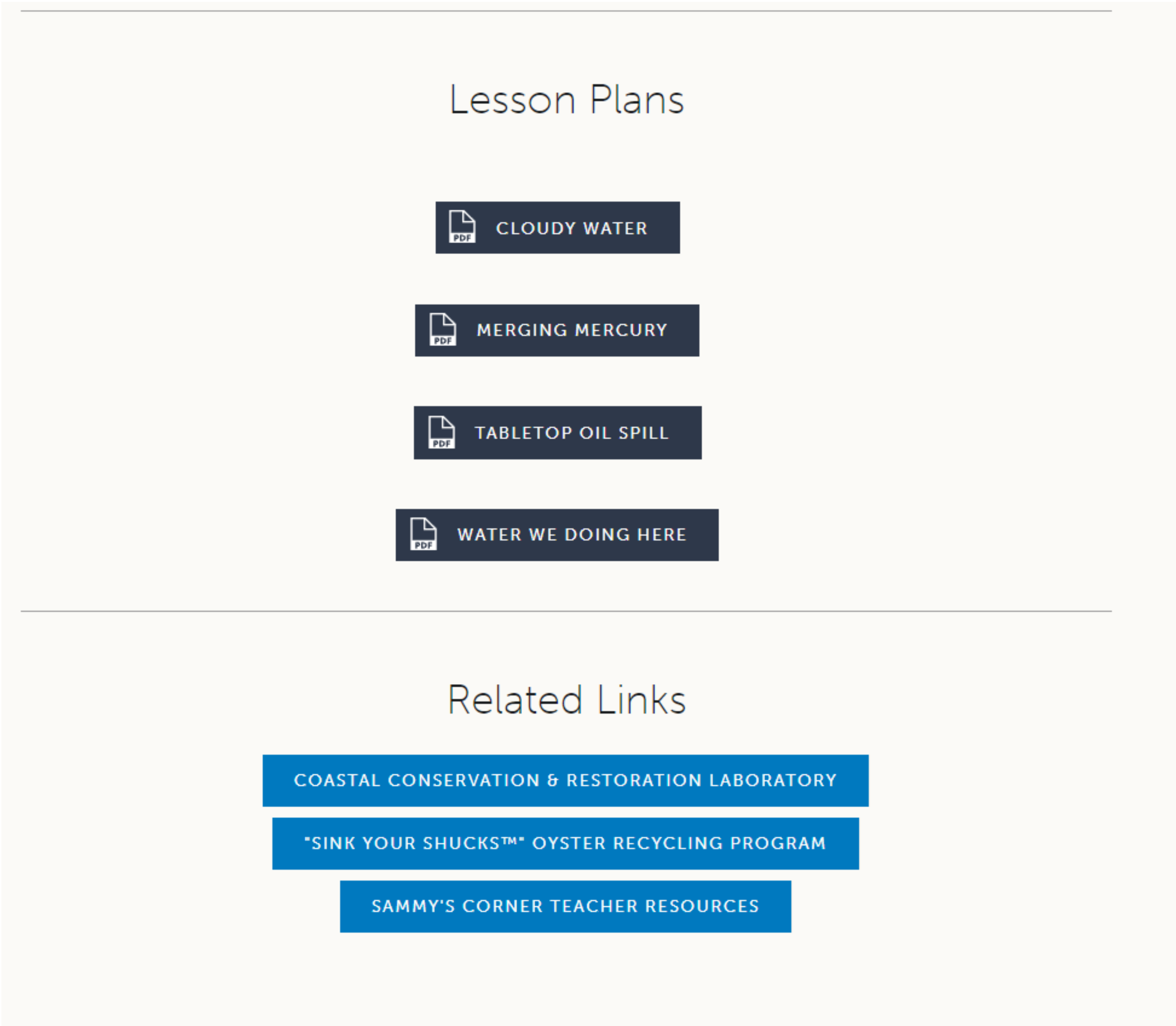


Figure 18. Snapshot of lesson plan links available at the Science in a Box website link provided on QR code.

The video portion (Figure 19) of the Citizen Science Integration task was challenging to complete. Although the content and lessons were prepared, getting into an actual classroom was difficult. Because of COVID protocols, many of the individual school districts did not allow for external entry into the classroom. Toward the end of the school year, we had a limited opportunity to present to students in their classrooms, and we were able to produce three unique classroom specific videos for teachers to use or assist them in their classroom. We are especially proud of the "Shellcrete" video that highlights the use oysters in the development and construction of early coastal settlements along the Texas coast. Together, this lesson and activity will help teachers to bridge the difficult cross-curricular gap between science and history.

Lastly, teachers will be provided with contact information for Harte Research Institute personnel who will be available to teachers throughout the year to assist in additional lessons, presentations, and to encourage participation in future public oyster bagging events.

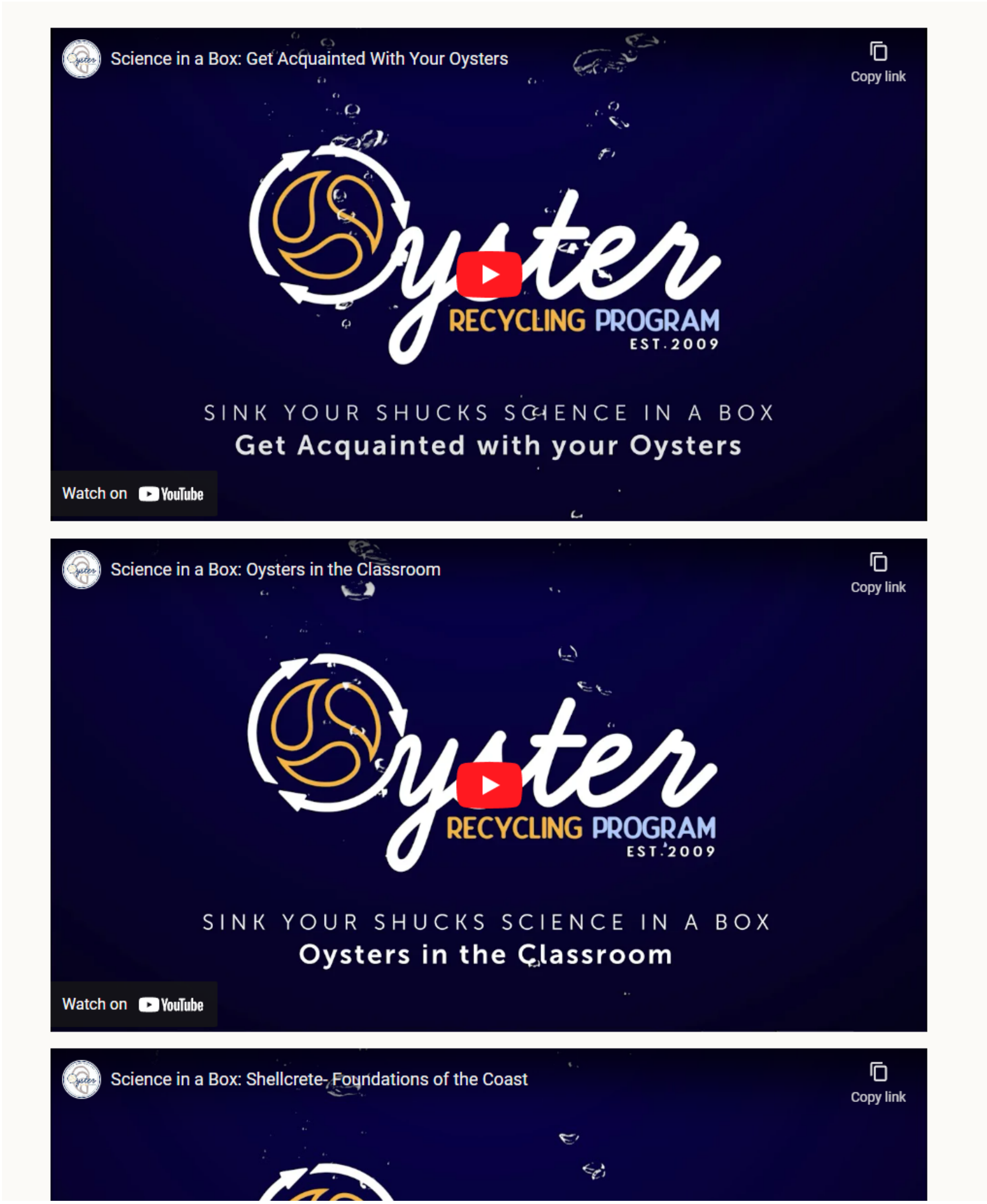


Figure 19. Screenshot of videos available at the Science in a Box website link provided on QR code.

Goal 4: Ecosystem service assessment of reefs

Oyster reef restoration has emerged as a management tool for maintaining oyster fisheries and ecological functions, often with different reef designs used to support different restoration objectives. Understanding both the ecological and ecosystem services of high- versus low-vertical relief restored oyster reefs has been identified as a need by both resource managers and scientists in the Gulf of Mexico. When designing reef restoration projects, low-vertical relief reef designs may be preferred because they 1) cover more area with less material, 2) are logistically easier to implement, and 3) can be used in shallow areas where high-vertical relief reefs would be considered navigational hazards (Dr. Emma Clarkson pers. comm.). Conversely, high-vertical relief reef designs may be preferred because they are 1) more impervious to habitat damage from dredging effects, 2) resilient to sedimentation and low dissolved oxygen events, and 3) provide better habitat provision for marine organisms (Colden et al., 2017; Lenihan, 1999; Powers et al., 2009). Understanding how differing restored reef designs (e.g. high vs. low vertical relief) may affect provision of ecological benefits can help improve the efficiency and cost-effectiveness of future restoration investments.

In August 2020, approximately 16.2 hectares (ha) of oyster reef were restored by the Texas Parks and Wildlife Department (TPWD) adjacent to Grass Island Reef, Aransas Bay (Figure 16). Construction occurred via barge using 6739 m^3 of #4 limestone cobble (diameter: 7.6-10.2 cm) to create 8.1 hectares of high-vertical relief 'reef mounds' (0.6 m high) and 6237 m^3 of cobble to create 8.1 hectares of low-vertical relief 'reef flats' (0.08 m high), at a turnkey cost (i.e. transport, mobilization, labor, construction) of \$284 m^{-3}.

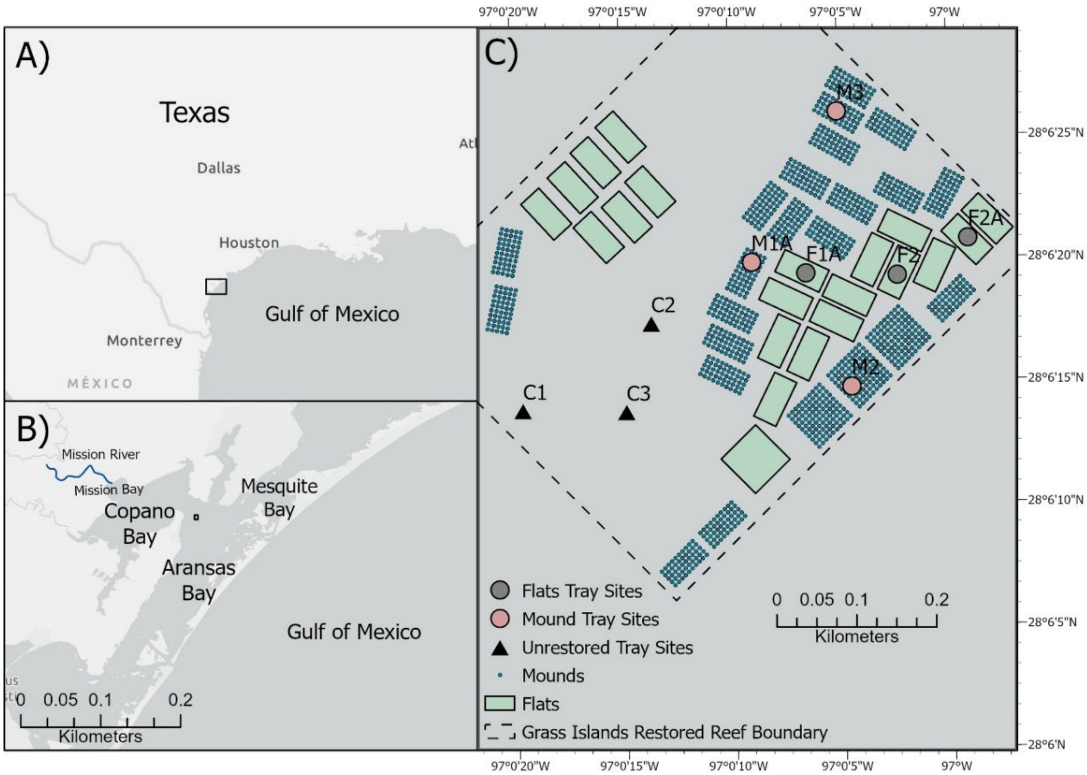


Figure 20. Map of the study area. A) Texas coastline and Gulf of Mexico B) Mission-Aransas Estuary, TX and C) Grass Islands restored reef study area showing restored reef mounds (blue crosshatch), restored reef flats (light green) and unrestored areas (gray).

Following reef construction at the beginning of August 2020, six sampling trays (45 x 30 x 10.5 cm; 0.135 m^2) with a layer of limestone were placed by divers at 9 sites: three unrestored, three reef mounds, and three reef flats (n = 54). One tray was sampled from each of the sites without replacement monthly for the first three months after reef construction (September, October, November 2020), and then quarterly thereafter (February, May, August 2021; Figure 17, Figure 18). Oyster size and height, motile epifauna biomass and abundance, encrusting organisms, and *Perkinsus marinus* were monitored on each sampling date. One final sampling of reef mounds, reef flats, and unrestored areas was conducted using 0.25 m^2 or 0.5 m^2 quadrats at eighteen months after reef construction.

Figure 21. A sampling tray that was retrieved from one of the high-vertical relief (mounds) restored reefs.

Figure 22. A sampling tray that was retrieved from one of the low-vertical relief (flats) restored reefs.

Results indicate that reef mounds provide a higher ecological return on investment than reef flats. In terms of habitat provision, reef mounds produced 75% higher oyster density, 201% higher motile epifauna biomass, and 360% higher motile epifauna density per m^{-2} than reef flats one year after construction (Figure 17, Figure 18). In terms of faunal enhancement, 1 m^2 of reef mounds is expected to yield 63% higher additional production of resident fish and crustaceans compared to reef flats (1.8 kg y^{-1} vs. 1.1 kg y^{-1}) over the functional lifetime of the reef. Estimates of nitrogen regulation (from denitrification, burial, harvest) provided by reef mounds were 166% greater and provided 75% greater cost equivalent value those provided by reef flats one year after construction. If the goal of oyster reef restoration is to optimize habitat provision, faunal enhancement, nitrogen regulation benefits, results indicate that constructing reef mounds is a better investment than reef flats. Although the cost of construction for reef mounds in this study (\$236,288 ha^{-1}) was slightly higher (8%) than for reef flats (\$218,680 ha^{-1}), reef mounds produced greater ecosystem benefits than reef flats.

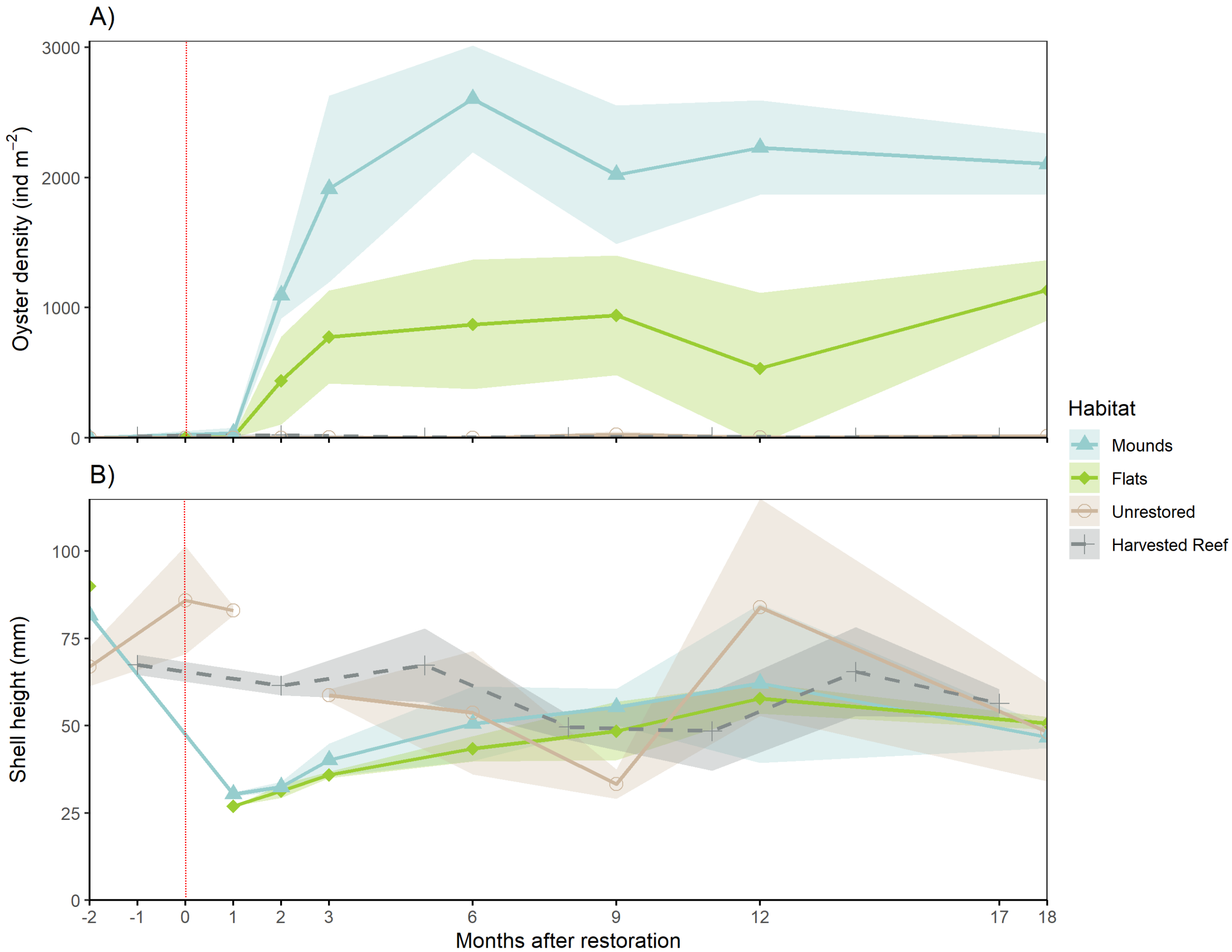


Figure 23. A) Oyster density (ind. m-2) and B) shell height (mm) measured at reef mounds (blue), reef flats (green), unrestored sites (brown) and nearby harvested reef are shown (gray) during sampling events from June 2020 (-2 months before restoration) to February 2022 (18 months after restoration). Shading indicates standard deviation. Unrestored and harvested reef are < 25oysters m-2 on top graph. Break in unrestored line (brown) illustrates no oysters found in October 2020 (2 months after restoration). Red dotted line indicates month of restoration (0 months).

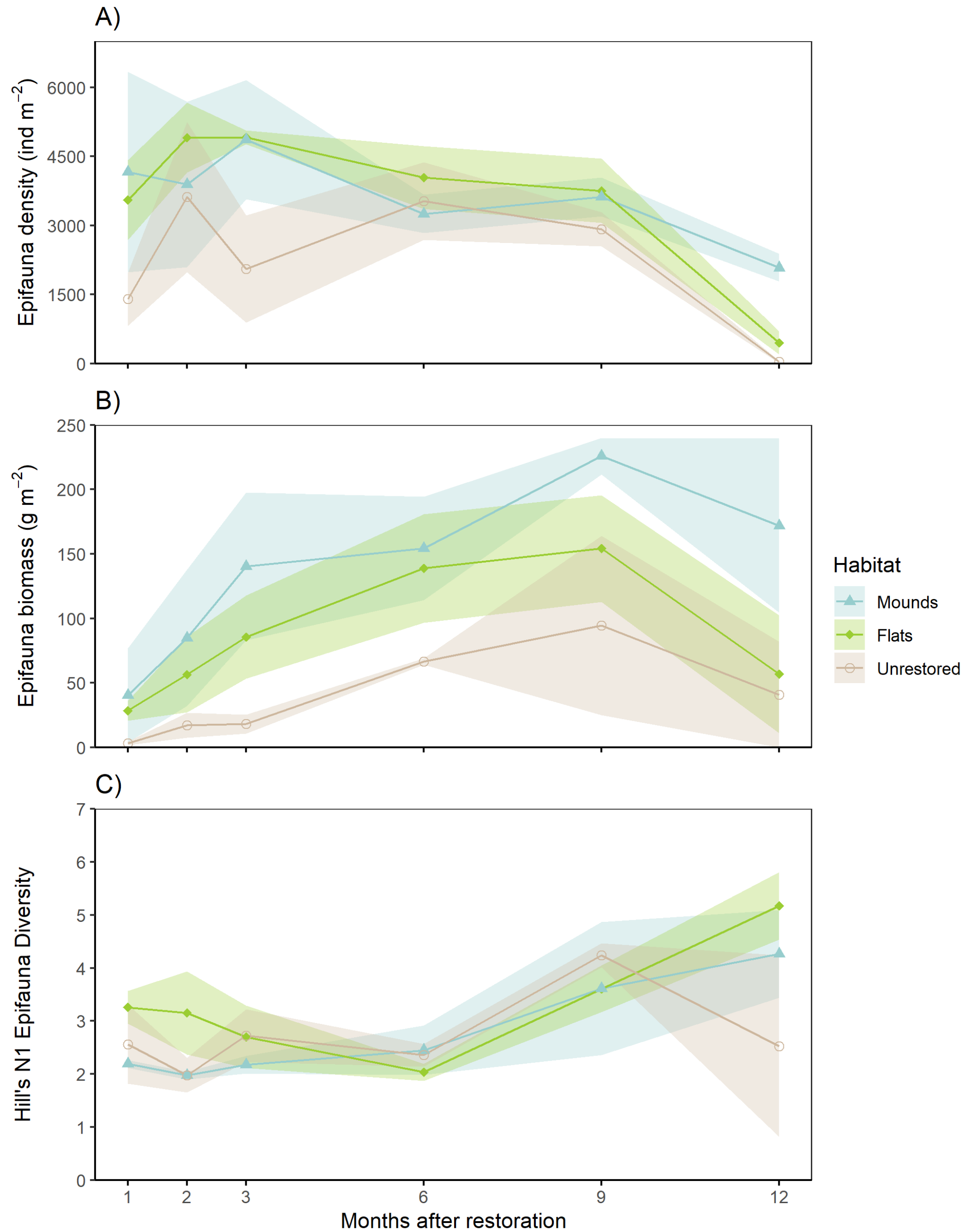


Figure 24. A) Motile epifauna density, B) biomass (g m-2), and C) epifauna diversity (Hill's N1) for motile epifauna at reef mounds (blue), reef flats (green), and unrestored sites (brown) during sampling events from August 2020 (0 months after restoration) to February 2022 (18 months after restoration). Shading indicates standard deviation.

Understanding differences in ecosystem service provision stemming from reefs constructed from the same amount and type of material, but with differing vertical relief, will allow resource managers to improve cost-efficiencies in future restoration projects. Cost of oyster reef restoration and ambiguous restoration goals are often limiting factors when planning oyster reef restoration (Mann and Powell, 2007). Therefore, by targeting specific ecosystems services such as habitat provision, faunal enhancement, and nitrogen regulation, resource managers can better manage their funds to meet their specific goals. Although both reef mounds and reef flats increased oyster densities and motile epifauna biomass, especially when compared to unrestored areas, reef mounds would serve as a better restoration tool due to higher return of ecological benefits. Provision of vertical height in restored oyster reefs appeared to be a key factor in yielding higher ecological benefits such as oyster density, epifauna biomass, nitrogen regulation, and faunal enhancement. Understanding differences in ecosystem service delivery resulting from restored reefs constructed with similar cutch volumes but built with different vertical relief can help inform oyster reef restoration decisions and improve cost-efficiencies in future restoration projects.

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