FINAL REPORT

Shell Bank: An Oyster shell recycling program for the Texas Coastal Bend

CMP Cycle 15 Final Report
GLO Contract No.: 11-011-000-4309

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Report Submitted to:
Texas General Land Office
Coastal Management Program

Edited and resubmitted: November 10, 2012

A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA10NOS4190207.

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ACKNOWLEDGEMENTS

We would like to acknowledge and thank project partners Water Street Restaurants and the Port of Corpus Christi. The support of these partners has been, and continues to be, crucial to the successful development and growth of this oyster shell recycling program.

INTRODUCTION

Eastern oysters, *Crassostrea virginica*, are important ecological and economic natural resources. Their distribution ranges from the Gulf of St. Lawrence in Canada to the Gulf of Mexico, the Caribbean, and the coasts of Brazil and Argentina (Buroker 1983). The U.S. produces the largest quantity of oysters throughout their range, and Texas produces the second-largest oyster harvest in the U.S., with over 5 million pounds harvested and an estimated $19 million generated in 2010 (Texas Parks and Wildlife Department (TPWD) data). Oyster reefs are also valued for the variety of ecosystem services they provide to humans, including water filtration and augmentation of fish production (Grabowski and Peterson 2007).

Recent work by The Nature Conservancy identified oyster reefs as one of the most threatened marine habitats on earth, with an estimated 85% lost globally in recent decades (Fig. 1; Beck et al. 2011). In Texas, historical and ongoing threats to reef sustainability include storm damage, disease, and historical shell dredging for industry and road construction (Doran 1965, McKinley and Crawley 2009). The sustainability of present-day oyster reefs continues to be threatened as a result of water quality degradation and the lack of mechanisms for returning harvested oyster shells to bay waters in order to maintain and restore degraded reef structure and functions. This project meets the latter need by reclaiming oysters from local restaurants and seafood wholesalers, and stockpiling them for future use in oyster reef restoration projects within Texas Coastal Bend Bays.

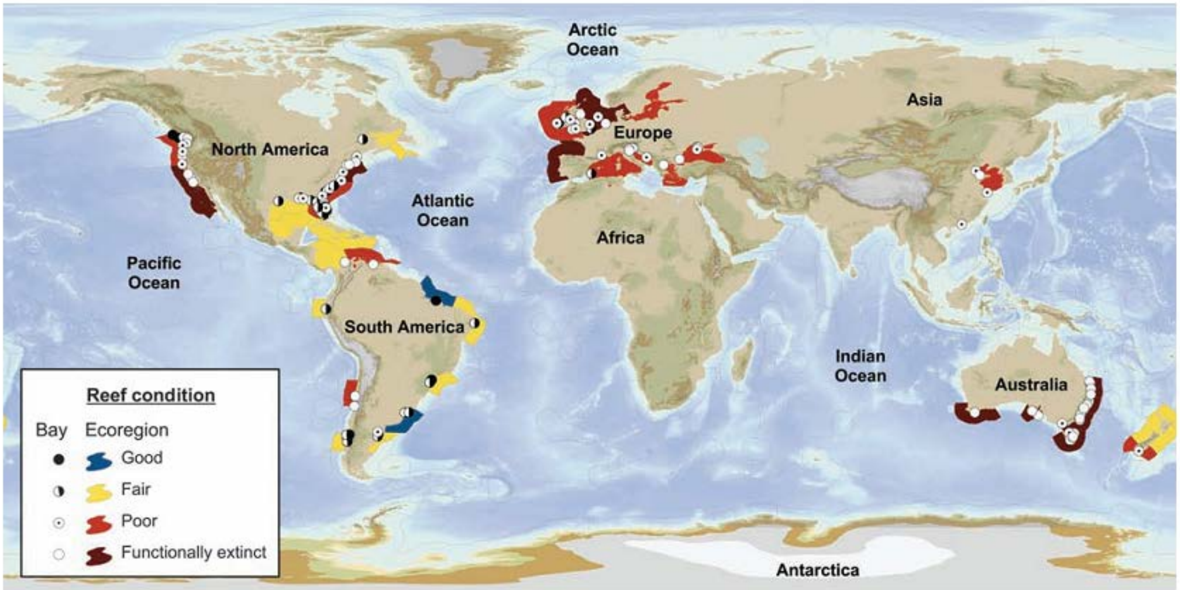

Figure 1. The global condition of oyster reefs as good (< 50% lost), fair (50-89% lost), poor (90-99% lost), functionally extinct (> 99% lost). From Beck et al. 2011.

Habitat loss is particularly damaging to oyster populations because of their life cycle (Fig. 2). The eastern oyster has both male and female individuals that release sperm and eggs into the water column for fertilization. The oyster larvae are initially planktonic and float freely in the water column while undergoing several stages of metamorphosis. Within 2-3 weeks, the larvae become pediveligers, forming a “foot” and coming out of the water column in search of a hard surface to adhere to (EOBRT 2007; NOAA 2009). In the soft sediment bays of Texas, oysters depend upon the hard shell substrate provided by existing oyster reefs to settle and colonize. However, when these shells have been removed due to harvest or lost due to storms or other events, the larval oysters lack in substrate for attachment, and will not survive. As a result, habitat is reduced.

Despite the recent and historical losses in oyster reef habitat, there are a considerable number of groups who have become involved in reef restoration, from small non-profit and community groups, to large state agencies and national environmental groups. However, oyster reef restoration efforts are often limited by a shortage of available shell material, with groups often being forced to use less-preferred substrates such as concrete or rock.

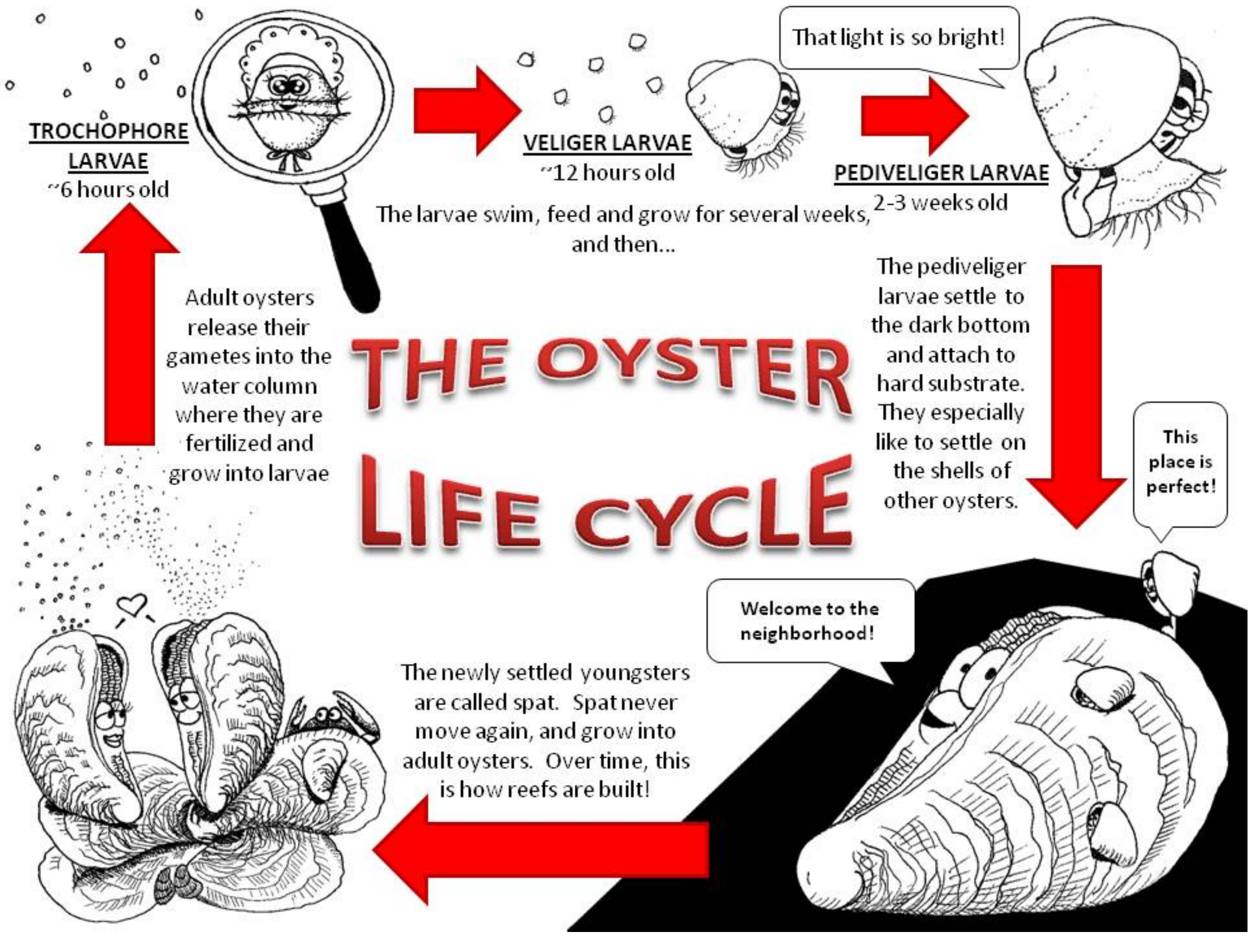

Figure 2. Oyster life cycle. Copyright Elani K. Morgan, Harte Research Institute, Texas A&M University-Corpus Christi.

Project Goals and Partners

As part of CMP Cycle #14, we created the Shell Bank Project, an innovative oyster shell reclamation, storage, and recycling program for the Texas Coastal Bend. This project began as a partnership between the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi, the Port of Corpus Christi Authority, and Water Street Seafood

Company in Corpus Christi, TX. As part of CMP Cycle #15, our project goals were to build on accomplishments of CMP #14 and expand our efforts (Table 1).

Table 1. Accomplishments of CMP Cycle #14 and project goals for CMP Cycle #15.

Accomplishments: CMP Cycle #14	Project Goals: CMP Cycle #15
1. Creation of the Shell Bank Repository for stockpiling oyster shells in Corpus Christi	1. Expansion of oyster shell collection efforts from Corpus Christi to the Rockport-Fulton area
2. Creation of maps that illustrate changes in size, location, and footprint of oyster reefs	2. Health assessment of existing oyster reefs
3. Economic analysis of oyster shell recycling	3. Create maps that illustrate bay-bottom hardness and suitability for supporting new reefs
4. Public Education – oyster shell recycling logo, informational brochures and website	4. Public Education – public service announcements, tabletop guide, website updates

The oyster shell recycling process utilized by The Shell Bank Project is a closed loop with four principal steps (Fig. 3). First, oysters are harvested from bay waters. In Texas, this is accomplished using a dredge, which removes both live oysters and associated shell material. Second, oysters are consumed, most often in restaurants. At this point, the shells would typically be discarded. Instead, our recycling program steps in to reclaim and stockpiles the shucked shells at our storage location at the Port of Corpus Christi. Lastly, once enough oyster shells have been reclaimed, the recycled shells are used in oyster reef restoration projects in Texas Coastal Bend bays (using external funding).

SHELL COLLECTION EFFORTS

In the Texas Coastal Bend, the majority of oysters are consumed in restaurants. In addition, seafood wholesalers can sell up to 90% of their product as shucked oysters (Alby's Seafood, personal communication) and thus are constantly producing large quantities of shell. Therefore, we targeted local restaurants and seafood wholesalers for shell reclamation and recycling. Shells are collected twice weekly from Water Street Seafood and Water Street Oyster Bar in Corpus Christi using a flatbed trailer and custom-built bins. They are transported to the Shell Bank Repository at the Port of Corpus Christi (created during CMP Cycle #14; Fig. 4) and are quarantined for at least 6 months to remove any potential for disease before being used in oyster reef restoration projects.

Figure 3. The four steps of The Shell Bank oyster shell recycling process: harvest, consumption, reclamation, and recycling of shells. Image by Brittany Blomberg, Texas A&M University – Corpus Christi.

Figure 4. Custom bins used to collect oyster shells from partner restaurants.

Figure 5. Oyster shells stockpiled at the Shell Bank Repository at the Port of Corpus Christi.

At the start of CMP Cycle #15, oyster shell collection activities remained steady at approximately 8,000-10,000 pounds per month (Fig. 6). On October, 26, 2011, the Texas Department of State Health Services closed all Texas coastal waters to oyster harvesting due to 'red tide', an algal bloom of *Karenia brevis*. The Texas Department of State Health Services did eventually open some of the bays to commercial harvest for a much protracted season. As a result, restaurants and oyster wholesalers had to purchase oysters from out of state, sometimes at almost double the price they would normally pay. This resulted in a reduction of available shell at our partner restaurants and seafood wholesalers during the spring and summer of 2011. As a consequence, we are behind on our target for total collection and sought alternatives to meet this deficit in suitable substrate for reef restoration (see below). The total weight of shells reclaimed from our restaurant partners during the period of the grant was 171,600 lbs (approximately 130 cubic yards) of shell.

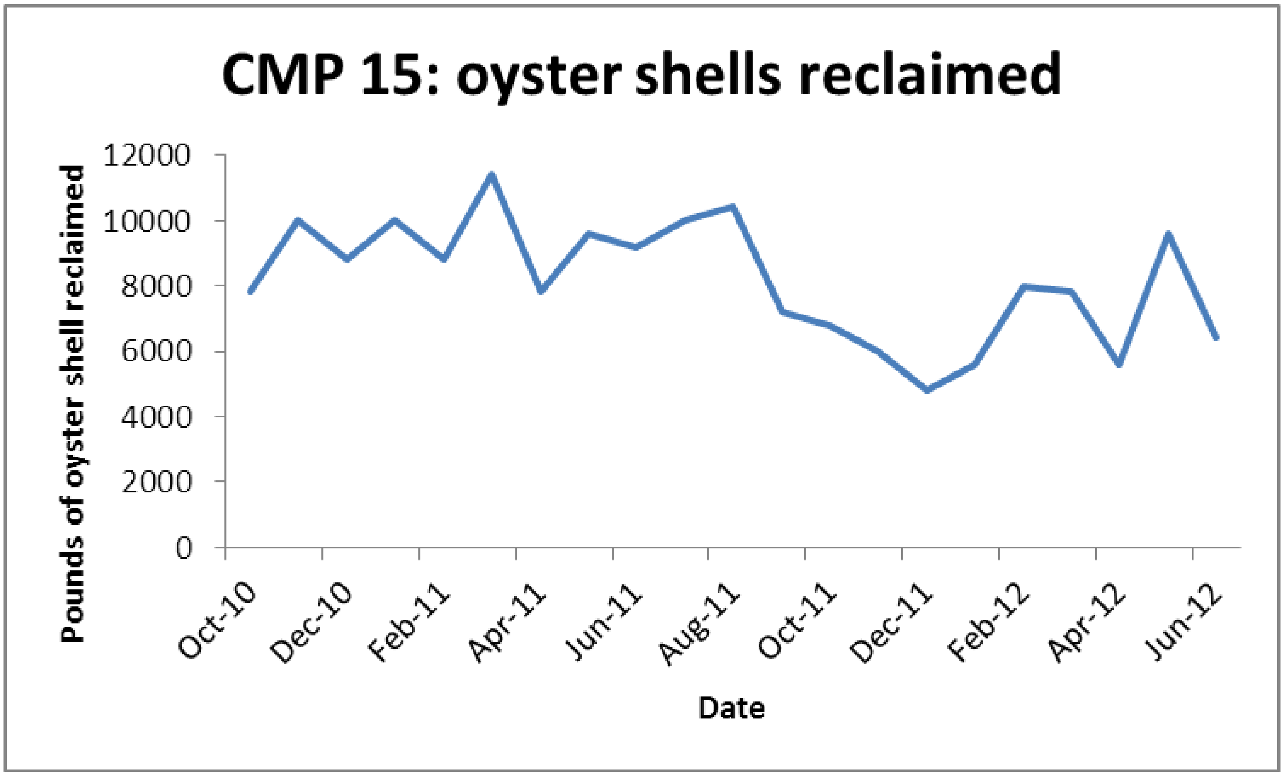

Figure 6. Monthly weights of reclaimed oyster shells, October 2010-June 2012.

Program expansion and recycling of alternative substrates

As part of CMP Cycle #15, we expanded our program to begin reclaiming oyster shell from Alby's Seafood in Fulton. The benefit of working with Alby's is that they have a large yard next to their shucking house where they can store large amounts of shell. Therefore, we are able to minimize trucking mobilization costs by transporting larger volumes of shell fewer times. We had originally planned to collect ~600 cubic yards of shell from Alby's Seafood. However, due to the slowdown in oyster harvesting /consumption associated with the red tide, there simply wasn't as much shell available. However, we still were able to reclaim approximately 400 cubic yards from Alby's. In total, we collected 130 cubic yards of oyster shells from restaurants plus 400 cubic yards of oyster shells from Alby's Seafood wholesaler for a grand total of 530 cubic yards.

In order to make up for the deficit in oyster shells, we sought alternative substrates for reef restoration that would be appropriate for reclamation and recycling as part of the Shell Bank program. We found a local source for recycled, clean crushed concrete that fit our needs. This particular source of concrete is recycled from the inside of concrete trucks and thus is clean and petroleum and rebar-free. Additionally, we are able to work with our supplier to crush the concrete to 3-4" size, comparable to oyster shell. This material was also readily available.

The crushed concrete fills an important need for reef restoration. The material is used as the foundation, or base layer of the restored reefs, which are then then topped with oyster shell to give the maximum volume of hard substrate for reef restoration and maximum height in the water column to enhance exposure to oyster larvae. We spoke with the Texas General Land Office and the Army Corps of Engineers and received approval to use this substrate as the base for constructing oyster reefs. In addition, monitoring reports from the NOAA Chesapeake Bay Office have determined the irregular surfaces and pore spaces of both natural oyster shell and crushed concrete protect growing oysters from predation. Therefore, in order to make up for the deficit in available oyster shell substrates, we purchased 200 cubic yards of clean, recycled crushed concrete as an alternative substrate for use in oyster shell restoration projects.

Reef restoration (outside funding) using reclaimed oyster shells

Over 65 cubic yards of oyster shells collected as part of CMP Cycle #15 were used to create a 2.5 acre oyster reef in Aransas Bay, adjacent to Goose Island State Park in July, 2012. This reef restoration project was funded by the Fish America Foundation / NOAA Community Based Restoration Program (Fig. 7). Because complex reef structures provide habitat for numerous fish and invertebrate species, the reef was constructed as a series of 4 reef mounds (dimensions 30 yards x 20 yards x 12 inches high) where "hills and valleys" are essential elements. Crushed concrete (10 inches) was used as a base material to prevent subsidence of shells (and oysters) into the surrounding sediments. All mounds were topped with oyster shell (Fig. 8) All shells were quarantined for 6 months before use in the project. No tissue was remaining on any of the clean, sun-baked shells and therefore it was unnecessary (and impossible) to conduct any disease spot checks.

Figure 7. Location of 2.5 acre oyster reef complex in Aransas Bay, TX (directly adjacent to Goose Island State Park, 28.124254° N, -96.984860° W).

Figure 8. Underwater view of reclaimed oyster shells on newly restored reef in Aransas Bay, TX.

HEALH ASSESSMENT OF EXISTING OYSTER REEFS AND CREATION OF MAPS THAT ILLUSTRATE SUITABILITY FOR NEW REEFS

Data Collection

Oysters were collected quarterly at 7 sampling locations on known reefs throughout the Mission-Aransas Estuary during the project period (white dots, Fig. 9). At each location, 20 live oysters were randomly selected and measured for shell length. Oysters were also examined at these locations for spat (shell length ≤ 25 mm) settlement. Oysters were also provided to Dr. Sammy Ray, for determination of the presence of *Perkinsus marinus*, a parasite that causes severe oyster mortalities throughout the Gulf of Mexico (Ray 1996). A section of mantle tissue was removed from 10 submarket (26-75 mm) and 10 market-size (≥ 76 mm) oysters and incubated in Ray's fluid thioglycollate medium for 2 weeks following the culture method of Ray (1966). Tissue cultures were stained with Lugol's solution and examined under the microscope. The percentage of oysters infected by P. marinus was calculated by dividing the number of oysters infected by the number of oysters tested. Data are available online at www.oystersentinel.org. Environmental measurements of salinity, dissolved oxygen (mg/l), temperature (°C), and turbidity (NTU) were also collected from each station during each sampling period.

Data were also obtained from the TPWD Resource Monitoring Program within the Mission-Aransas Estuary from January 1986 through December 2009 (purple dots, Fig. 9). Spatially resolved environmental measurements of salinity, dissolved oxygen (mg/l), temperature (°C), and turbidity (NTU) were collected throughout the bay system from January 1975 through April 2009. Depth was represented using the Aransas Bay bathymetric digital elevation model from the National Oceanic and Atmospheric Administration – National Ocean Service.

Perkinsus marinus levels increased along the salinity gradient, with the lowest disease levels observed at Shellbank Reef at the upper end of Copano Bay (Fig 12c). Disease levels were overall highest in Aransas Bay, as might be expected due to overall higher salinities (Fig. 10a) which are more favorable for disease development.

Abundance of live oysters and spat displayed an opposite pattern, with higher abundances observed in the lower salinity areas; perhaps to due lower numbers of predators and reduced disease. This is illustrated as a reef quality index in Fig. 12b, where higher numbers indicate higher abundances of live oysters and spat, and lower numbers of dead shells.

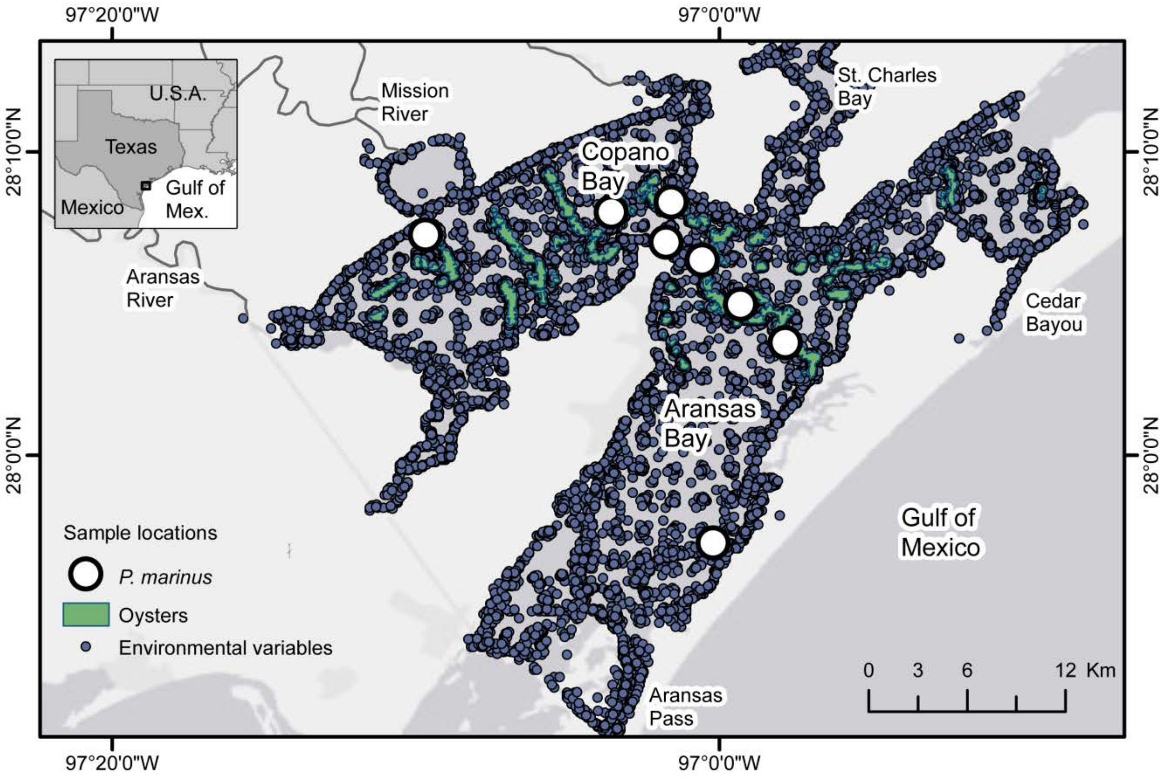

Figure 9. Sampling locations for oysters, disease, and environmental variables throughout the Mission-Aransas Estuary, TX. From Beseres Pollack et al. 2012.

Spatial Analysis

Environmental measurements were imported as point data into a Geographic Information System (GIS; ArcGIS 10, ESRI) and temporally aggregated based on TPWD sampling stations. At each TPWD sampling station, mean and standard deviation were generated for salinity, turbidity, and temperature, as well as frequency of occurrence (%) of low dissolved oxygen measurements (<4 mg/l). New aggregated environmental measurements were spaced 1 minute of longitude on average from each other (approximately 1.8 km).

Environmental data were spatially interpolated over the area of the estuary (Fig. 10). The best interpolation method was local polynomial interpolation (1st order polynomial with barriers) weighted by temporal frequency of sampling each station. Rasters were created using a 0.1 minute cell size (approximately 180 m) for mean and standard deviation of salinity, temperature (°C), and turbidity (NTU), as well as frequency of occurrence (%) of low dissolved oxygen measurements (>4 mg/l). For depth, the Aransas Bay bathymetric digital elevation model from NOAA-NOS was resampled to 0.1 minute cell size to match the spatial resolution and extent of the environmental variable rasters. Sediment grain size data available had low spatial resolution and sampling points were avoided on reef areas, and therefore were not useful in the current study. Side scan sonar and sub-bottom profiling data were not available for the entire study area so were also not used.

Oyster data (except for disease data) from TPWD were imported as point data into the GIS. Where oyster samples were collected with the presence of live oysters, points were buffered by 80 m (the area covered by dredge sampling) to create polygons that represent live oyster reef. Live reef polygons were then used to aggregate oyster sampling data, where mean abundance of live oysters (> 25 mm shell length), dead shell (> 25 mm shell length), and spat (5-25 mm shell length) on live oysters and dead shell were calculated for each continuous reef polygon. Disease data were incorporated, but because they were only collected from 8 fixed sampling locations (rather than the spatially distributed sampling conducted by TPWD), these values were incorporated separately to more accurately illustrate their distribution (see Figure 12c).

All data were normalized by scaling from 0-1, where values of 1 are optimal, and values of 0 are unacceptable. Specific environmental values used for generating the restoration suitability index are presented in Fig. 11. All spatial analysis procedures are described in more detail in Beseres Pollack et al. 2012.

The normalized environmental rasters were then combined using a weighted geometric mean function, producing a restoration suitability index (Fig. 12). Using this method, the overall suitability at a specific location is given a ranked value of 0 if any single parameter is unsuitable (has a value of 0). All normalized environmental variables except salinity were given equal weights of 2 and all standard deviations were given equal weights of 1. Salinity plays the most important role in oyster health in the study area and thus was given a corresponding weight of 4.

The result of the spatial analysis and assessment was published in July, 2012 in PLoS ONE and is included as Appendix 3 to this document. The results were also presented at two national conferences in October and November, 2011: The Society for the Advancement of Chicanos and

Native Americans in Science (SACNAS) meeting in San Jose, CA, and The Coastal and Estuarine Research Federation (CERF) meeting in Daytona Beach, FL.

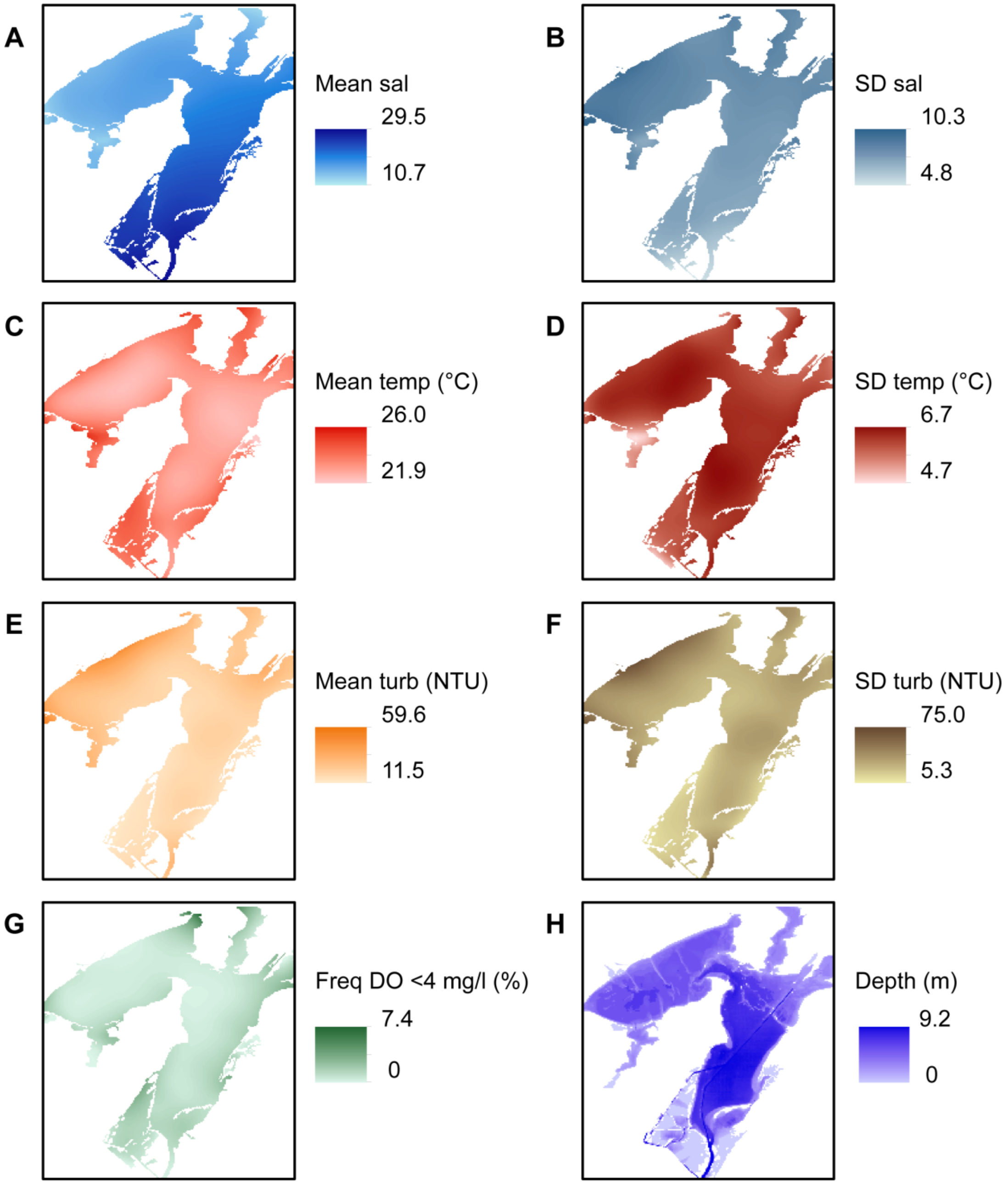

Figure 10. Spatially interpolated environmental measurements in the Mission-Aransas Estuary, TX, USA. Mean (left column) and standard deviation (SD, right column) for salinity (sal; A and B), temperature (temp; C and D), and turbidity (turb; E and F). Frequency of dissolved oxygen < 4 mg/l (G); and depth (H). From Beseres Pollack et al. 2012.

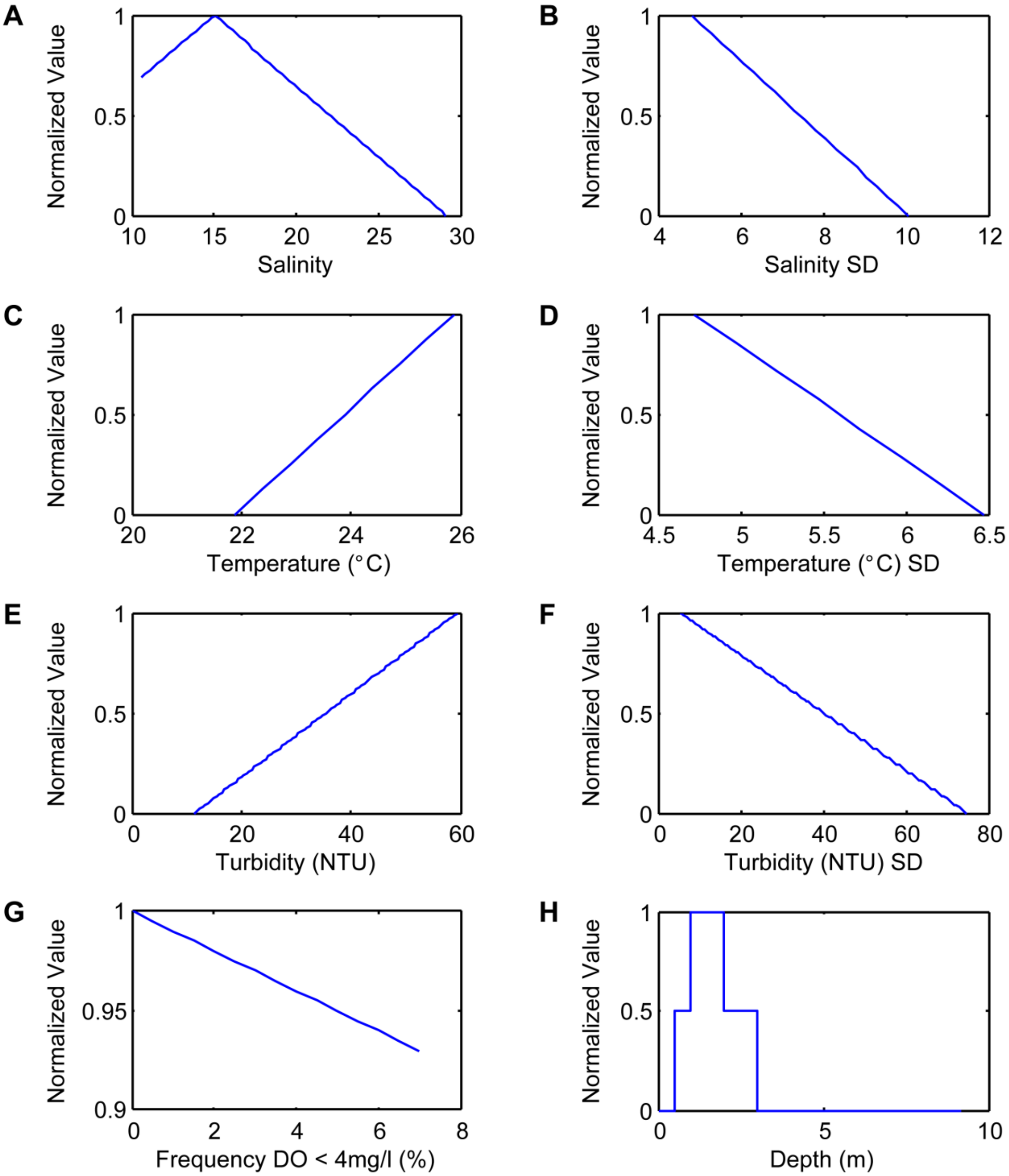

Figure 11. Suitability index graphs for model variables. Relationship between actual values of environmental variables and their corresponding restoration suitability values: values of 1 are optimal, and values of 0 are unacceptable. From Beseres Pollack et al. 2012.

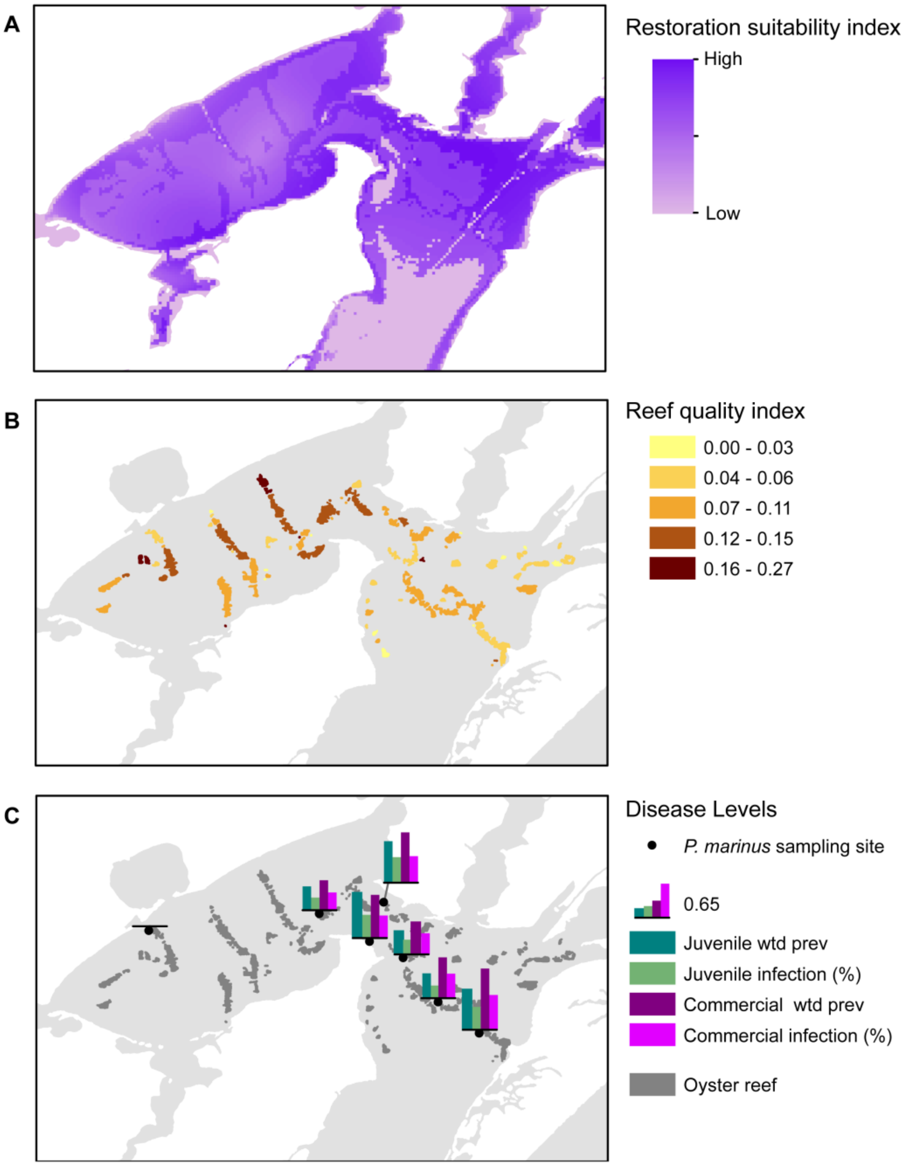

Figure 12. A) Restoration suitability index. Darker shading indicates higher index value. B) Reef quality index. Dark shading indicates higher index value. C) P. marinus disease levels: at each of 7 sampling stations, bar graphs illustrates percent infection and weighted prevalence for juvenile (<76 mm shell length; green-hued color bars) and commercial oysters (<76 mm shell length; pink-hued bars). From Beseres Pollack et al. 2012.

PUBLIC EDUCATION AND OUTREACH

Oyster shell recycling outreach materials

We continued working with Debbie Lindsey-Opel and Matt Opel of 3DD results and Opel Creative, who designed our original set of recognizable oyster shell recycling program logos as part of CMP Cycle #14. As part of CMP Cycle #15, we worked with 3DD to design an informational table topper for our restaurant partners (Appendix 1) as well as an informational coaster that can also be used at special events hosted by the Harte Research Institute (Appendix 2).

We also created a short educational film on oyster shell recycling that premiered at the Beneath the Waves Film Festival in Mobile, AL. The film, titled "Sink Your Shucks" won the award for best Conservation Film. The film was directed by TAMUCC M.S. Lauren Hutchison, written by TAMUCC PhD student Brittany Blomberg, and animated by Tiara Marshall, a student at Savannah College of Art and Design (and Corpus Christi native). The film is posted on the Harte Research Institute for Gulf of Mexico Studies website (What's New → Videos), as well as on our project website, http://oysterrecycling.org.

We also provided Oyster Shell Recycling Program brochures to the coordinators of Fiesta Oyster Bake 2011 in San Antonio, to educate festival goers about the process of oyster shell recycling.

Our project website has ongoing project updates, media coverage, and other information. We are continuing to develop and update this page with new material as we continue our oyster shell recycling efforts as part of CMP cycle 16.

Local Media

To educate the public about the process of oyster shell recycling, we have appeared on local radio and television during the grant period. We were featured on KRISTV on October 3, 2011, in a program by Dave Fraser titled "Restaurants Team Up with Texas A&M for Oyster Recycling" that highlighted the Shell Bank program's unique partnership between the university and local restaurants in reclaiming shells for restoration. The video and text are available at http://www.kristv.com/videoplayer/?video_id=17220. On March 9, 2012, Jennifer Pollack appeared on KKTX News Radio for an interview with Jim Lago, host of "Lago in the Morning" about oyster shell recycling. Lastly, in May 2012, Sean Hilbe from the GLO submitted an article to NOAA for Coastal Management News about the Shell Bank Program titled "Texas shell recycling program a success" (Appendix 4).

CONCLUSION

We are happy to report that The Shell Bank oyster shell reclamation and recycling program continues to grow and thrive, thanks to continued funding from the Coastal Management Program. We accomplished all of our stated goals as part of CMP Cycle 15: We expanded our shell collection efforts from Corpus Christi to the Rockport-Fulton area. In addition, we developed a new partnership for recycling clean concrete for use as the foundation for supporting restored reefs. We conducted quarterly monitoring of oysters at 7 locations along a salinity gradient within Copano and Aransas Bays and then used these data to create maps illustrating the suitability of areas for supporting new reef restoration projects. These data were presented at 2 national conferences and were published in a peer-reviewed journal. Lastly, we continue to develop educational and outreach materials to increase public awareness of oyster shell recycling and oyster reef restoration. With support from funds provided through CMP Cycle 16, we are conducting community-based restoration events where local volunteers from students to retired folks are involved in bagging events to prepare shells for use in reef restoration. Using funds provided by NOAA-Community-based Restoration Partnership grants, we have constructed two large scale oyster reef restoration projects in Copano and Aransas Bays using shells reclaimed as part of the Shell Bank Project. We will provide ongoing project updates as part of CMP Cycle 16.

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APPENDICES

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Appendix 1

FAST FACTS

DID YOU KNOW?

- Oysters can switch between being male and female
- A female oyster can produce over 100 million eggs per year
- Young larval oysters don't have a shell, they swim freely in the water
- After about three weeks, oysters form a shell and cement themselves to a hard substrate
- Over time, reefs are formed by the numerous oyster shells built up into the water
- Oysters in Texas can reach market size (three inches) in 18 months
- Oysters can live up to 20 years

WWW.OYSTERECYCLING.ORG

THE PROCESS

SINK

Oysters are commercially harvested in Texas from November through April. The majority of these oysters are sold to restaurants and seafood wholesalers.

YOUR

After an oyster is eaten at one of our partner restaurants, the shucked shells are reclaimed. They are separated from the trash and stockpiled throughout the year.

SHUCKS

When a large enough volume of shells has been stockpiled, the shells are recycled. They are brought back out to bay waters and used to restore degraded oyster reefs.

CONTACT

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OYSTER RECYCLING

IT'S HABITAT FORMING

Appendix 2

Did you know?

WaterStreet Restaurants and
Texas A&M University-Corpus Christi
are on a MISSION to

SINK

build habitat for fish & crabs by

YOUR

recycling oyster shells

SHUCKS

and tossing them back in the bay
to restore the reef

Fun Facts

- Oysters can live up to 20 years
- Oysters in Texas can reach market size (3 inches) in 18 months
- Oysters can be consumed year-round
- Oysters can filter up to 50 gallons of water per day

Funding provided by Texas General Land Office, Coastal Management Program

IT’S HABITAT FORMING

OPEN ACCESS Freely available online

PLoS one

A Restoration Suitability Index Model for the Eastern Oyster (*Crassostrea virginica*) in the Mission-Aransas Estuary, TX, USA

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Abstract

Oyster reefs are one of the most threatened marine habitats on earth, with habitat loss resulting from water quality degradation, coastal development, destructive fishing practices, overfishing, and storm impacts. For successful and sustainable oyster reef restoration efforts, it is necessary to choose sites that support long-term growth and survival of oysters. Selection of suitable sites is critically important as it can greatly influence mortality factors and may largely determine the ultimate success of the restoration project. The application of Geographic Information Systems (GIS) provides an effective methodology for identifying suitable sites for oyster reef restoration and removes much of the uncertainty involved in the sometimes trial and error selection process. This approach also provides an objective and quantitative tool for planning future oyster reef restoration efforts. The aim of this study was to develop a restoration suitability index model and reef quality index model to characterize locations based on their potential for successful reef restoration within the Mission-Aransas Estuary, Texas, USA. The restoration suitability index model focuses on salinity, temperature, turbidity, dissolved oxygen, and depth, while the reef quality index model focuses on abundance of live oysters, dead shell, and spat. Size-specific *Perkinsus marinus* infection levels were mapped to illustrate general disease trends. This application was effective in identifying suitable sites for oyster reef restoration, is flexible in its use, and provides a mechanism for considering alternative approaches. The end product is a practical decision-support tool that can be used by coastal resource managers to improve oyster restoration efforts. As oyster reef restoration activities continue at small and large-scales, site selection criteria are critical for assisting stakeholders and managers and for maximizing long-term sustainability of oyster resources.

Citation: Beseres Pollack J, Cleveland A, Palmer TA, Reisinger AS, Montagna PA (2012) A Restoration Suitability Index Model for the Eastern Oyster (*Crassostrea virginica*) in the Mission-Aransas Estuary, TX, USA. PLoS ONE 7(7): e40839. doi:10.1371/journal.pone.0040839

Editor: Simon Thrush, National Institute of Water&Atmospheric Research, New Zealand

Received February 4, 2012; **Accepted** June 14, 2012; **Published** July 11, 2012

Funding: This study was supported by grant number NA09NMF4720179 from the National Oceanic and Atmospheric Administration under the Comparative Assessment of Marine Ecosystem (CAMEO) program, and grant number 11-011-000-4309 from the Texas General Land Office Coastal Management Program. Partial support was also provided by the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

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Introduction

Oyster reefs are one of the most threatened marine habitats on earth, with an estimated 15% remaining worldwide [1]. Within the Gulf of Mexico, an estimated 50 to 80 percent of native oyster populations have been lost relative to historic levels [2]. Declines in the abundance of oysters are a consequence of habitat loss due to historical shell dredging [3], water quality degradation [4], disease [5], oil spill effects [6], and hurricanes [7]. In Galveston Bay, Texas, approximately 50%, or 32 km^2 (8,000 acres) of oysters were lost as a result of Hurricane Ike in 2008 [8]. The resulting sediment deposition smothered live oysters, submerged available hard substrate, and inhibited larval oyster settlement and natural recovery processes. In Louisiana, an estimated 50% of oysters were lost after the Deepwater Horizon oil spill in response to freshwater releases that decreased salinity below oyster tolerance levels [9]. Despite recent and historical losses, there is hope that restoration efforts and adaptive management approaches can revitalize oyster populations in the Gulf of Mexico [10].

For successful and sustainable oyster reef restoration efforts, it is necessary to choose sites that support long-term growth and survival of oysters [11,12]. Selection of suitable sites is an important first step in the restoration process as it can greatly influence mortality factors and may largely determine the ultimate success of the restoration project. Habitat suitability indices are a common tool used by natural resource managers for habitat mapping, conservation and restoration planning [13,14,15]. The Gulf of Mexico coast is ideally suited to developing a standardized site selection framework because areas of relatively abundant oyster populations still exist (Fig. 1). In addition, a substantial long-term database is available from the Texas Parks and Wildlife Department's (TPWD) Resource Monitoring Program that describes oyster characteristics and hydrological parameters.

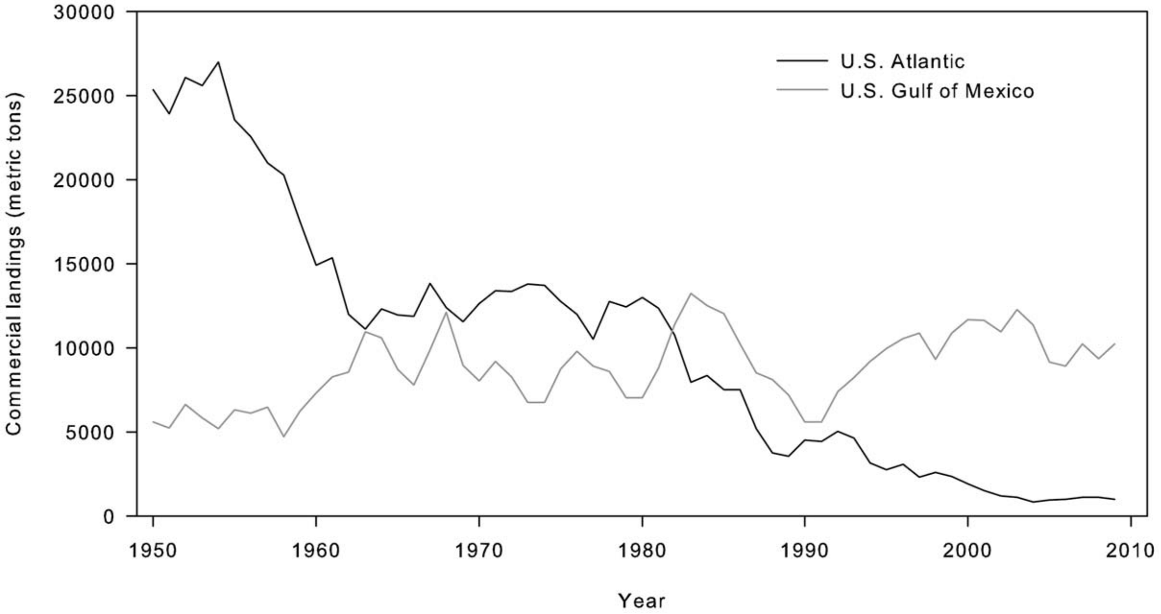

Figure 1. Commercial oyster landings. Commercial oyster landings (metric tons) from the U.S. Atlantic and Gulf of Mexico from 1950–2009 (NOAA 2011).
doi:10.1371/journal.pone.0040839.g001

The aim of this study was to develop a restoration suitability index model and reef quality index model to characterize locations based on their potential for successful reef restoration within the Mission-Aransas Estuary, Texas, USA, using a Geographic Information System (GIS)-based approach. GIS is an effective tool that can be used in identifying suitable sites for oyster reef restoration and removes much of the uncertainty involved in the somewhat trial and error selection process that currently exists. The rationale for this study is similar to that used in previous oyster habitat/restoration suitability studies [16,17,18], where areas are selected based on the highest potential for successful recruitment, growth, and persistence of oyster populations. Long-term data on oyster populations and environmental variables were integrated within a GIS to characterize locations based on their potential for successful restoration programs.

Methods

Study site

The Mission-Aransas Estuary is a shallow, bar built estuary located in the coastal bend region of the Texas Gulf coast (Fig. 2). The estuary is approximately 540 km^2 with an average depth of 2 m [19]. The two largest bays in the system are Aransas Bay, which is located closest to the Gulf inlets of Aransas Pass and the intermittently open Cedar Bayou, and Copano Bay, which is located closest to the Mission and Aransas Rivers. The estuary experiences a typical salinity gradient from the river mouths to the Gulf of Mexico, which is driven by episodic freshwater pulses [20]. Oysters occur primarily on large subtidal reefs in the low- to moderate-salinity regions of the estuary, with vertical relief ranging from ~0.3 to 1.8 m.

Field surveys

Oysters were collected from January 1986 through December 2009 as part of a fisheries-independent survey conducted by the TPWD Resource Monitoring Program within the Mission-Aransas Estuary (Fig. 2). All necessary collecting permits were obtained from TPWD. Samples were collected by oyster dredge (0.5 m wide, 5 cm diameter mesh) at 20 randomly selected locations on known reefs in Copano Bay and Aransas Bay each month. Latitude and longitude coordinates were recorded using a Garmin GPSMap Geographic Positioning System (GPS) unit. Dredges were towed for 30 s in duration at a speed of 1.3 m s^{-1} for approximately 40 m in distance. Because oysters were collected by oyster dredge, which is a relatively inefficient gear, these data represent a relative index of abundance and oyster size [21]. At each location, 19 live oysters (approx. 95% of all oysters collected) were randomly selected and measured for shell length. A subset of 5 live oysters was also examined for quantification of spat (shell length $\leq$25 mm) settlement. The amount of dead shell (>25 mm) in each sample was enumerated and a subset of 5 shells was also examined for spat settlement.

Spatially resolved environmental measurements of salinity, dissolved oxygen (mg/l), temperature (°C), and turbidity (NTU) were collected throughout the bay system from January 1975 through April 2009 as part of the TPWD Resource Monitoring Program (Fig. 2). The Aransas Bay bathymetric digital elevation model from the National Oceanic and Atmospheric Administration – National Ocean Service [22] was used to represent depth.

Oysters were sampled quarterly from December 2004 through 2009 and examined for the presence of *Perkinsus marinus*, a protozoan parasite that causes severe mortalities in Gulf of Mexico oyster populations [23]. Ten submarket (26–75 mm) and 10 market-size ($\geq$76 mm) oysters were collected from 8 fixed sampling locations on reefs in Copano Bay and Aransas Bay in each quarterly sampling event (Fig. 1). The southernmost site was discontinued because of difficulties locating live oysters; therefore only 7 sites are reported here. A section of mantle tissue was removed and incubated in thioglycollate medium for 2 weeks following the culture method of Ray [23]. Tissue cultures were stained with Lugol's solution and examined under the microscope. The percentage of oysters infected by *P. marinus* was calculated by dividing the number of oysters infected by the number of oysters tested. Infection intensity was ranked using a 5-point scale (after

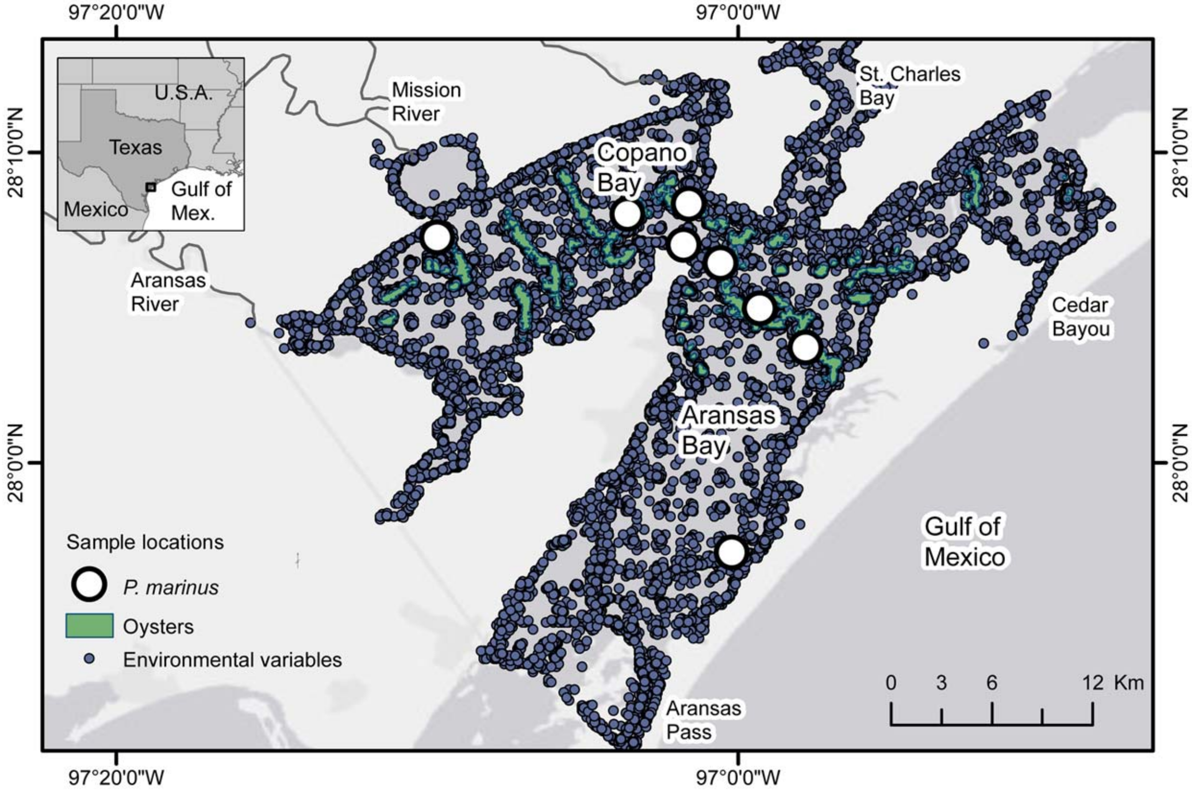

Figure 2. Field sampling locations in the Mission-Aransas Estuary, TX, USA. Sampling locations for oysters (green), environmental variables (gray-blue), and *P. marinus* (white). Environmental variables were also measured at *P. marinus* and oyster sampling locations.
doi:10.1371/journal.pone.0040839.g002

[24], modified by [25]) from uninfected (0) to heavily infected (5). Weighted prevalence was calculated by ranking the infections on the Mackin Scale and then calculating the average.

Spatial analysis

Environmental measurements collected by TPWD were imported as point data into a Geographic Information System (GIS; ArcGIS 10, ESRI) and temporally aggregated based on TPWD sampling stations. A new point dataset was created from these aggregations to represent the temporal variability and average conditions at each sampling station. At each TPWD sampling station, mean and standard deviation were generated for salinity, turbidity, and temperature, as well as frequency of occurrence (%) of low dissolved oxygen measurements (<4 mg/l). Dissolved oxygen concentrations of <4 mg/l (instead of 2 mg/l) were selected because all samples were collected during the day and may therefore have resulted in hypoxic conditions at night. New aggregated environmental measurements were spaced 1 minute of longitude on average from each other (approximately 1.8 km), representing the spatial resolution of the TPWD environmental sampling scheme. Although higher resolution data would potentially reveal more localized patterns and processes, finer scale data were not available. However, the available data accurately represent field observations.

Environmental data were spatially interpolated over the area of the estuary. Root mean square error was used to compare and select interpolation methods. The best interpolation method was local polynomial interpolation (1st order polynomial with barriers) weighted by temporal frequency of sampling each station. This model is a good candidate for mapping data regularly collected from the environmental monitoring networks [26]. Rasters were created using a 0.1 minute cell size (approximately 180 m) for mean and standard deviation of salinity, temperature (°C), and turbidity (NTU), as well as frequency of occurrence (%) of low dissolved oxygen measurements (>4 mg/l). For depth, the Aransas Bay bathymetric digital elevation model from NOAA-NOS was resampled to 0.1 minute cell size to match the spatial resolution and extent of the environmental variable rasters. Sediment grain size data available [27] had low spatial resolution and sampling points were avoided on reef areas, and therefore were not useful in the current study. Side scan sonar and sub-bottom profiling data were not available for the entire study area so were also not used.

Oyster data (except for disease data) from TPWD were imported as point data into the GIS. Where oyster samples were collected with the presence of live oysters, points were buffered by 80 m (the area covered by dredge sampling) to create polygons that represent live oyster reef. Live reef polygons were then used to aggregate oyster sampling data, where mean abundance of live oysters (>25 mm shell length), dead shell (>25 mm shell length), and spat (5–25 mm shell length) on live oysters and dead shell were calculated for each continuous reef polygon.

As for the environmental variable rasters, data were normalized by scaling from 0–1, where values of 1 are optimal, and values of 0 are unacceptable [17,18,28]. Specific environmental values used for generating the restoration suitability index are presented in Fig. 3.

Mean turbidity data were normalized using the following equation:

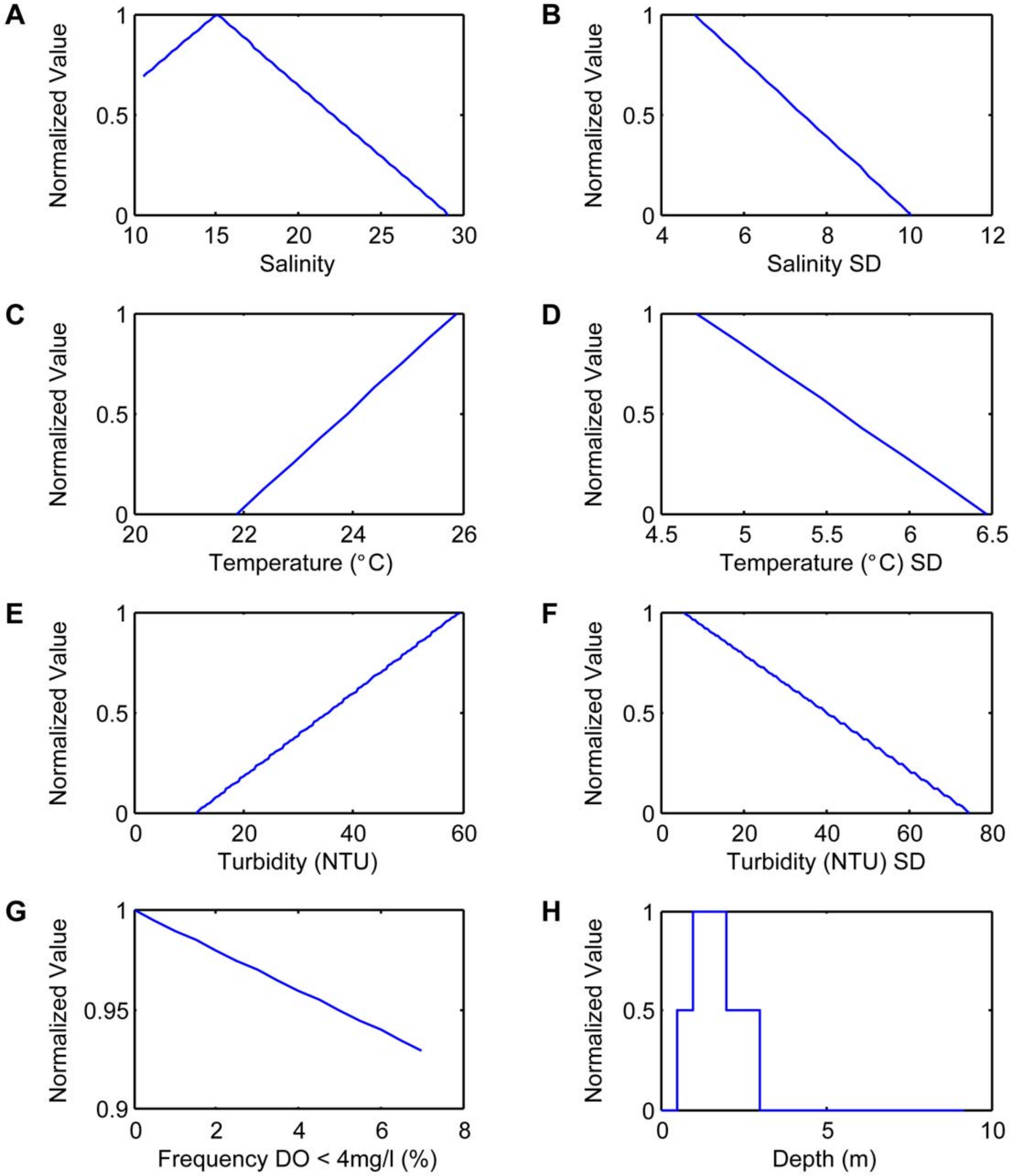

Figure 3. Suitability index graphs for model variables. Relationship between actual values of environmental variables and their corresponding restoration suitability values for *Crassostrea virginica;* values of 1 are optimal, and values of 0 are unacceptable.
doi:10.1371/journal.pone.0040839.g003

$$Normalized(e_{turb}) = \frac{e_i - E_{\min}}{E_{\max} - E_{\min}} \tag{1}$$

where E_{min} and E_{max} = the minimum and maximum values, respectively, for the variable E.

Higher values were assigned to high turbidities to maximize available suspended food particles.

Mean temperature data and standard deviation of temperature, salinity, and turbidity were normalized using the following equation:

$$Normalized(e_i) = \left| \left(\frac{e_i - E_{\min}}{E_{\max} - E_{\min}} \right) - 1 \right| \tag{2}$$

where higher values were assigned to lower temperatures because the prevalence and intensity of *P. marinus* infections increase with increasing temperature [29]. Higher values were assigned to low standard deviations to optimize areas with less environmental variability.

Mean salinity data were normalized using the following equation:

$$Normalized(e_{sal}) = \left| \left(\frac{|(Salinity_{mean} - Salinity_{optimum})|}{\max|(Salinity_{mean} - Salinity_{optimum})|} \right) - 1 \right| \tag{3}$$

where the optimum salinity value was 15. At salinities ranging from 10–20, oysters are present in dense populations, have high reproductive ability, and are subject to relatively lower densities of predators and disease [30]. Higher values were assigned to moderate salinities because the relationship with oysters is nonlinear; moderate salinities are more favorable than are low or high levels.

Frequency of DO <4 mg/l was normalized using the following equation:

$$Normalizede_{DO} = 1 - f_{DO<4} \tag{4}$$

where $f_{DO<4}$ is the frequency of dissolved oxygen <4 mg/l. Higher values were assigned to lower frequencies.

Continuous depth values were given 3 different index values. Depths of 1–2 m were given a value of 1 because of the feasibility of large-scale restoration using barges as well as the success of past restoration efforts within this depth range in the Mission-Aransas Estuary. Depths between 0.5 and 1 m were given a value of 0.5 because of suitability for oyster growth but limitations to construction methods. Depths of 2–3 m were also given a value of 0.5 because of suitability for oyster growth, but also increased construction costs and observations of higher proportions of fine sediment accumulation at these depths within the Mission-Aransas Estuary. Depths of <0.5 and depths of >3 m were given values of 0 because of being too shallow or too deep for long-term reef sustainability as observed in previous unsuccessful restoration efforts in this estuary.

The normalized environmental rasters were then combined using a weighted geometric mean function [17,18] using the equation:

$$RSI = \left(\prod_{i=1}^{n} NEV_i^{wi} \right)^{1/n} \tag{5}$$

where w_i is the relative weight of importance of the normalized environmental variables (NEV), producing a restoration suitability index (RSI). Using this method, the overall suitability at a specific location is given a ranked value of 0 if any single parameter is unsuitable (has a value of 0). All NEV except salinity were given equal weights of 2 and all standard deviations were given equal weights of 1. Salinity plays the most important role in oyster health in the study area and thus was given a corresponding weight of 4.

The sensitivity of the model to particular environmental variables was assessed using the following equation:

$$Sensitivity = \frac{RSI - RSI_{less1}}{RSI} \tag{6}$$

where *RSI* is the index of restoration suitability (Eq. 5) and RSI_{less1} is RSI with an individual normalized environmental variable (NEV) removed, one at a time. The output of each scenario is presented in map form to allow for visual comparison of percent change in the base model resulting from removal of an individual variable.

The ratio of live oysters to total (live plus dead) was calculated. Mean abundance of spat was scaled from 0 to1 using Eq. 1. An index of oyster reef quality ($Index_{rq}$) was then derived using the following equation:

$$Index_{rq} - Live_{Proportion} \times NS \tag{7}$$

where $Live_{Proportion}$ is the ratio of live oysters to total and *NS* is the normalized spat value. Higher values of the index indicate oyster reefs with higher quality oyster populations (abundant live oysters and spat, moderate to few dead oysters).

Perkinsus marinus sampling occurred at fixed sampling stations throughout the Estuary; therefore these data were not integrated into the model, but were mapped as a series of bar charts to illustrate disease trends along a salinity gradient. *Perkinsus marinus* accumulates in oyster tissue over time and infections tend to be size-specific, with large oysters having higher infection levels and disease-related mortality than small individuals [31]. Therefore, *P. marinus* data were presented using percent infection and weighted prevalence of both submarket (<76 mm) and market (≥76 mm) size classes to demonstrate size-specificity.

Results

Environmental conditions were variable over the period of the study. Mean salinities ranged from 10.7–29.5 (Fig. 4A). Lower salinities were observed in the secondary bays (Copano and St. Charles) due to river inputs while higher salinities were observed in Aransas Bay, located closest to the Gulf of Mexico inlets. The highest salinity variability was observed in the northwest quadrant of Copano Bay, which is influenced by sporadic pulses of freshwater from the Mission and Aransas Rivers (Fig. 4B). Mean temperatures ranged from 21.9–26.0°C and were highest in the shallow margins of the estuary, adjacent to the slow-moving Aransas River and Copano Creek, and throughout relatively shallow St. Charles Bay (Fig. 4C). The highest temperature variability was observed in the central portion of Copano Bay, which is subdivided by several long oyster reefs that likely constrain water circulation (Fig. 4D). Mean turbidities ranged from 11.5–59.6 NTU and were highest and more variable along the northwestern edge of Copano Bay, where the Mission and Aransas Rivers and Copano Creek drain into the estuary (Fig. 4E, F). The frequency of low dissolved oxygen (<4 mg/l) measurements was fairly small, ranging from 0–7.4% (Fig. 4G). Low dissolved oxygen levels were more frequent in the shallow portions of the estuary. Mean water depth ranges from 0–9.2 m (Fig. 4H). The deepest water occurs in the Gulf Intracoastal Waterway and in the southern portions of Aransas Bay, and the shallowest water exists in areas of existing oyster reef.

Live oyster abundance was highest (>80 oysters per 30 s tow) on several reefs in Copano Bay and at the confluence of Copano and Aransas Bays (Fig. 5A). Live oyster abundance was moderate to low (3–47 oysters per 30 s tow) throughout Aransas Bay. Moderate numbers of dead shell (>25 mm shell length) were observed throughout both Copano and Aransas Bays (Fig. 5B). Spat abundance was highest on several reefs in Copano Bay and moderate to low throughout Aransas Bay, similar to the distribution of live oysters (Fig. 5C).

The restoration suitability index illustrates the range of suitability of environmental variables throughout the Mission-Aransas Estuary (Fig. 6A). Highest index values often correspond with areas of existing oyster reef. Lowest index values occur in the southern, deeper portions of Aransas Bay and in the Gulf Intracoastal Waterway. The reef quality index quality was highest on reefs in Copano Bay (Fig. 6B). Along the 7 fixed sampling sites, *Perkinsus marinus* infection levels and weighted prevalence were highest for juvenile oysters (<76 mm shell length) at the southernmost location in Aransas Bay and at the confluence with Copano Bay (Fig. 6C). Infection levels and weighted prevalence of *P. marinus* in commercial oysters (≥76 mm shell length) were generally higher than in juvenile oysters. Weighted prevalence for commercial oysters was consistently high (>0.50) over 6 of the 7 sites and low (<0.26) at the upstream-most sampling station. The lowest disease levels for both juvenile and commercial oysters were observed at the upstream-most location.

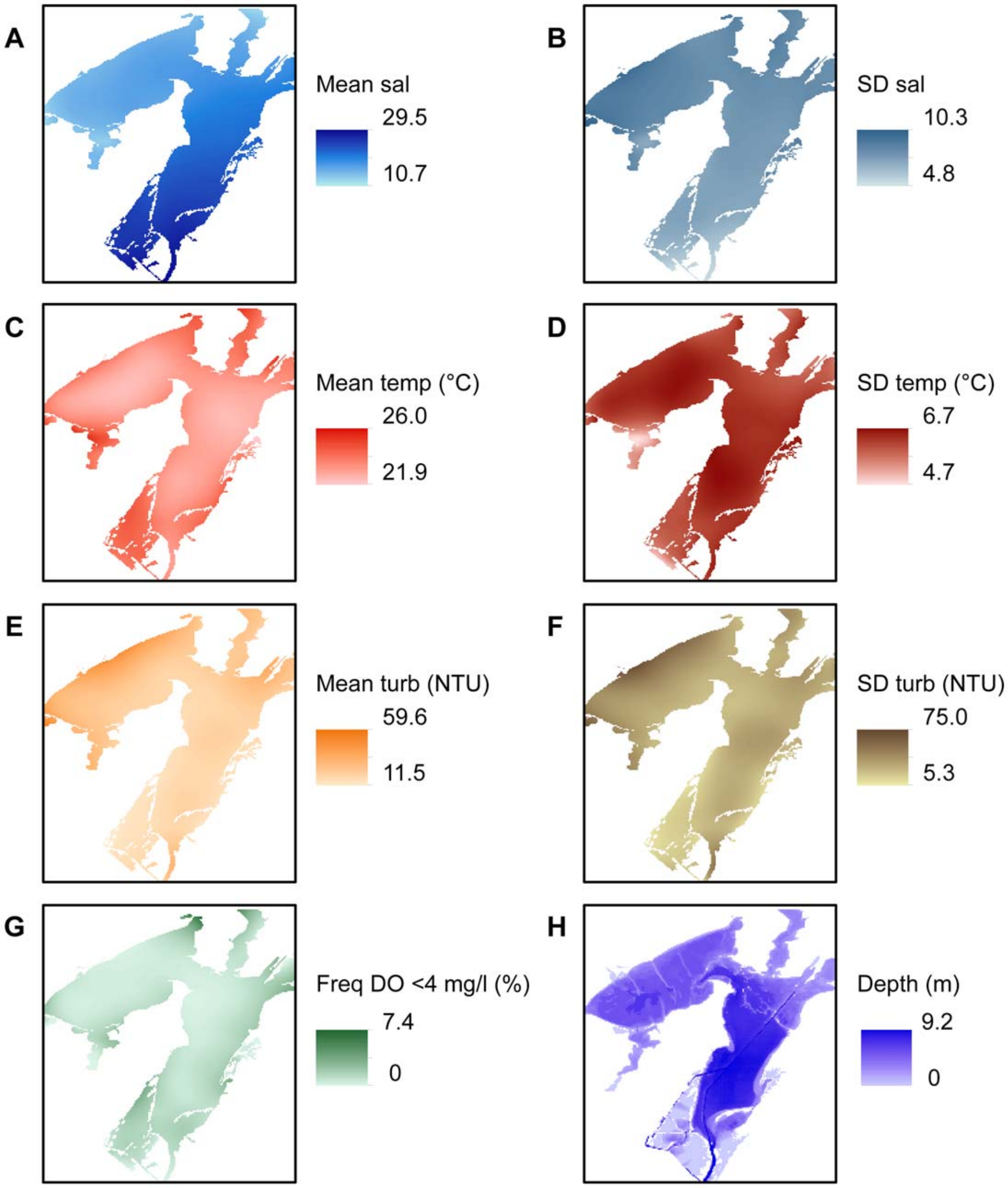

Figure 4. Spatially interpolated environmental measurements in the Mission-Aransas Estuary, TX, USA. Mean (left column) and standard deviation (SD, right column) for salinity (sal; A and B), temperature (temp; C and D), and turbidity (turb; E and F). Frequency of dissolved oxygen <4 mg/l (G); and depth (H).
doi:10.1371/journal.pone.0040839.g004

The sensitivity analysis illustrates the percent change from the base restoration suitability index model when individual normalized environmental variables were removed, one at a time (Fig. 7). Removing mean salinity, mean temperature, or mean turbidity resulted in the greatest percent change in Copano Bay (Figs. 7A, C, E). Removing standard deviation of salinity, temperature, or turbidity, or frequency of low dissolved oxygen, resulted in relatively small changes from the base model throughout the estuary (Figs. 7B, D, F). Removing depth resulted in the greatest percent change in the southern, deeper portions of Aransas Bay.

Discussion

For successful and sustainable oyster reef restoration efforts, it is necessary to choose sites that support long-term growth and survival of oysters. In general, this requires suitable environmental conditions, adequate larval supply, sustained survival and growth of juvenile and adult oysters, and low disease levels. Proper site selection is one of the most important decisions that restoration groups have to make. Selection of suitable sites is critical as it can greatly influence mortality factors and may largely determine the ultimate success of the restoration project. The application of GIS provides an effective methodology for characterizing locations based on their potential for successful reef restoration and removes much of the uncertainty involved in the sometimes trial and error

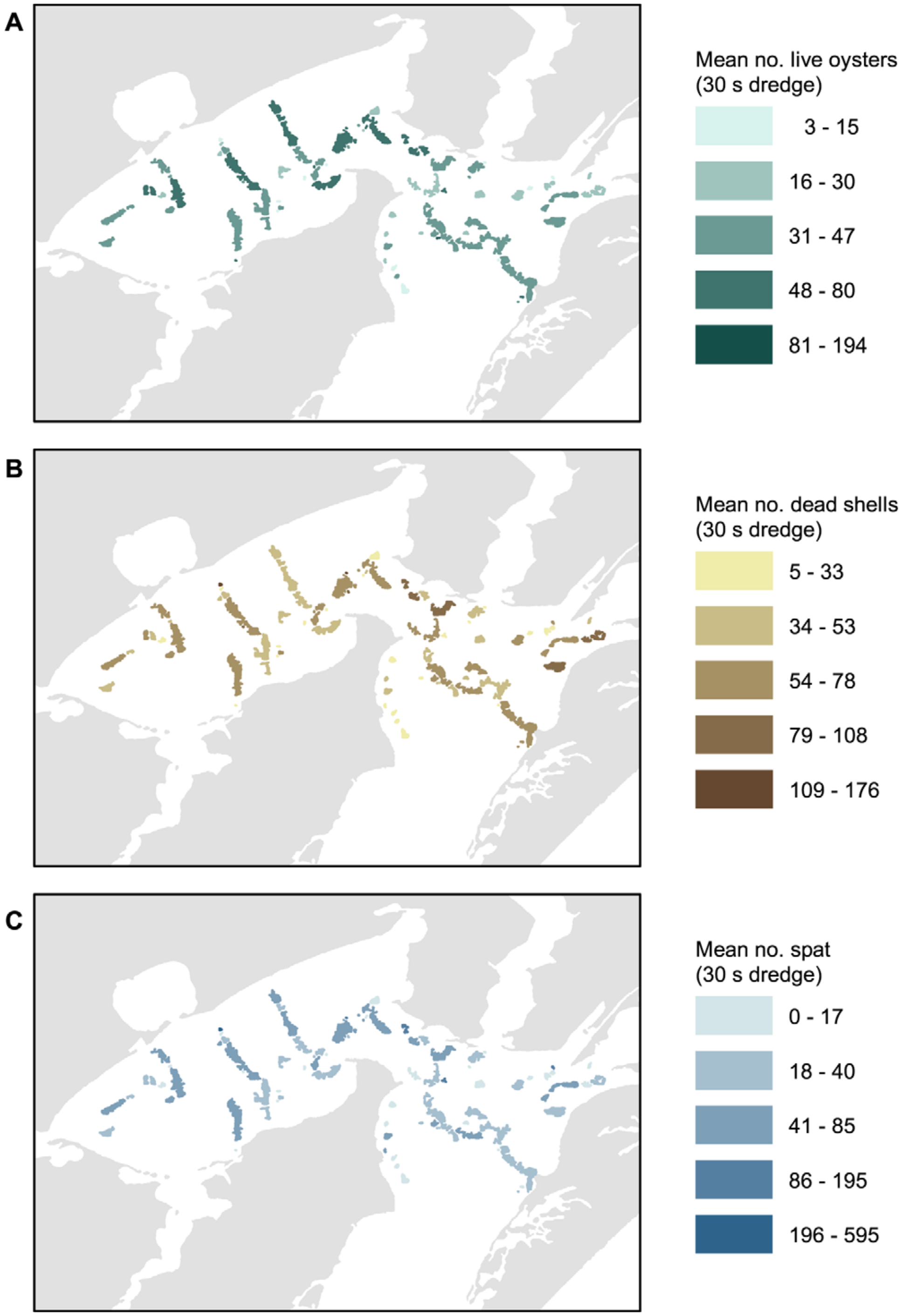

Figure 5. Oyster condition on reefs in the Mission-Aransas Estuary, TX, USA. Mean number of A) live oysters (≥26 mm), B) dead oyster shells ≥26 mm, and C) spat (5–25 mm) collected using 30 second dredge (1986–2009).
doi:10.1371/journal.pone.0040839.g005

selection. This GIS-based approach also provides an objective and quantitative tool for planning future oyster reef restoration efforts.

In this study, we sought to characterize locations within the Mission-Aransas Estuary based on their potential for successful oyster reef restoration. The justification for selecting sites based on their potential for successful recruitment, growth, and survival follows that used in previous restoration/habitat suitability studies [16,17,18]. Depending on project goals, map layers could be integrated in different ways to answer different questions or apply adaptive management strategies. For example, areas with relatively low spat abundance could be targeted for restoration using spat-on-shell [32], reefs with high levels of disease could be targeted for restoration using disease resistant oysters [33], and areas with persistent hypoxia could be restored using reefs with higher vertical relief [12]. This flexibility may be useful to resource

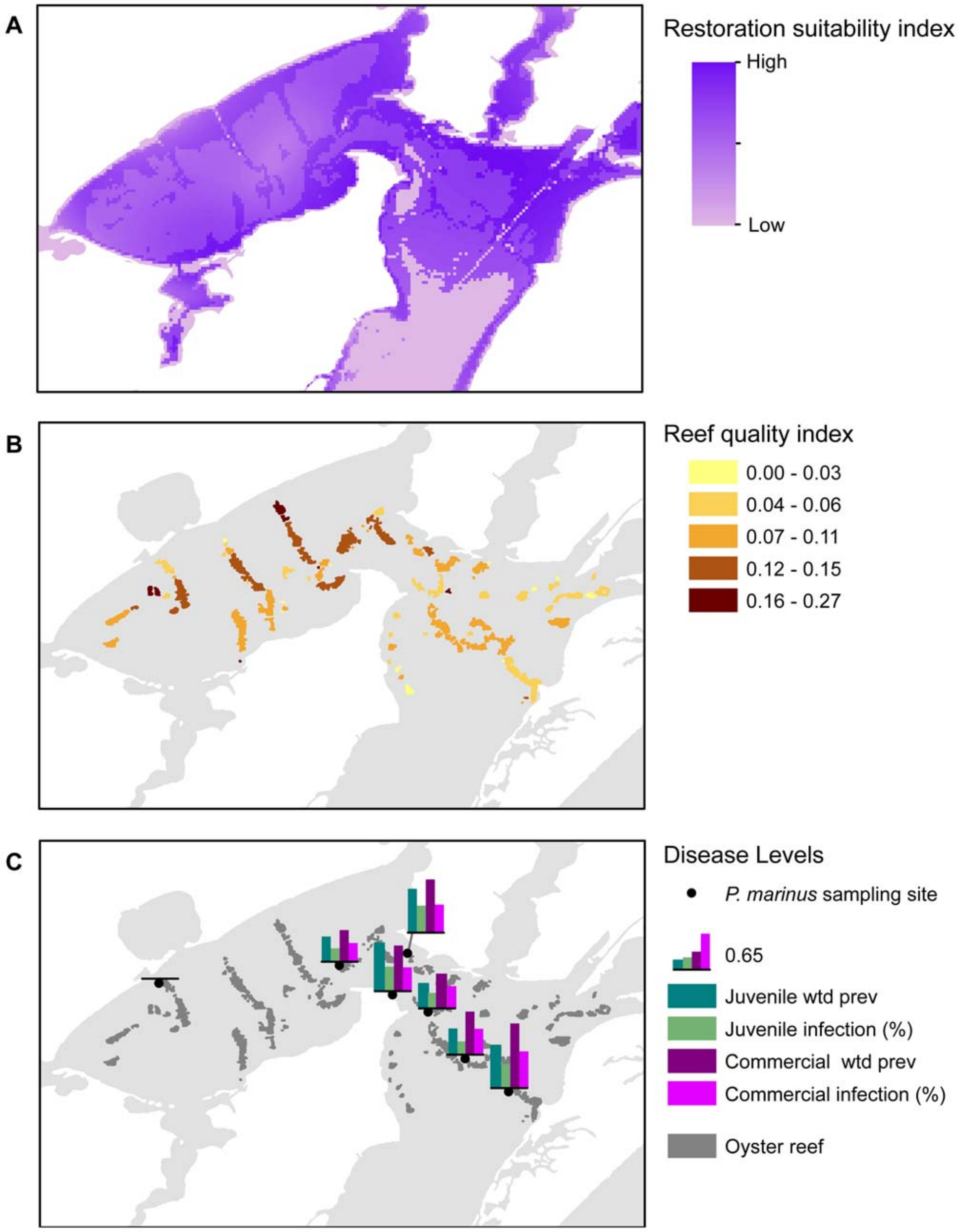

Figure 6. Restoration suitability index and reef quality index. A) Restoration suitability index. Darker shading indicates higher index value. B) Reef quality index. Dark shading indicates higher index value. C) *P. marinus* disease levels: at each of 7 sampling stations, bar graphs illustrates percent infection and weighted prevalence for juvenile (<76 mm shell length; green-hued color bars) and commercial oysters (≤76 mm shell length; pink-hued bars).
doi:10.1371/journal.pone.0040839.g006

managers in dealing with local-scale issues in otherwise high-quality environmental conditions.

In the Mission-Aransas Estuary, it was strongly desired to select sites with moderate salinities to reduce oyster mortalities associated with the high and low ends of the salinity range. The Estuary is located in a semi-arid climate and regularly experiences prolonged droughts. Severe oyster mortalities can result from low flow periods as predators with higher salinity optima, such as the southern oyster drill *Stramonita haemastoma* and the stone crab *Menippe mercenaria* are favored [34,35]. In addition, *Perkinsus marinus* disease initiation and progression are favored by high salinities in combination with high temperatures [24,36]. However, it has also been suggested that it is critically important to protect and restore oyster populations in mesohaline waters, regardless of disease presence, to encourage the development of disease resistant populations [37]. At this time, no such *P. marinus*-resistant populations have been identified within the Mission-Aransas Estuary. At the low end of the salinity range, the Mission-Aransas Estuary is strongly driven by episodic freshwater pulses that depress and then maintain low salinities for a prolonged period [20]. When exposed to sustained periods of low salinities, oysters may reduce their feeding and growth rates, depress or arrest gametogenesis, delay spawning, and/or resorb gonadal material [38,39,40], which can lead to recruitment failure or post-settlement mortality. In general, within the Mission-Aransas Estuary, selecting restoration sites with historically moderate

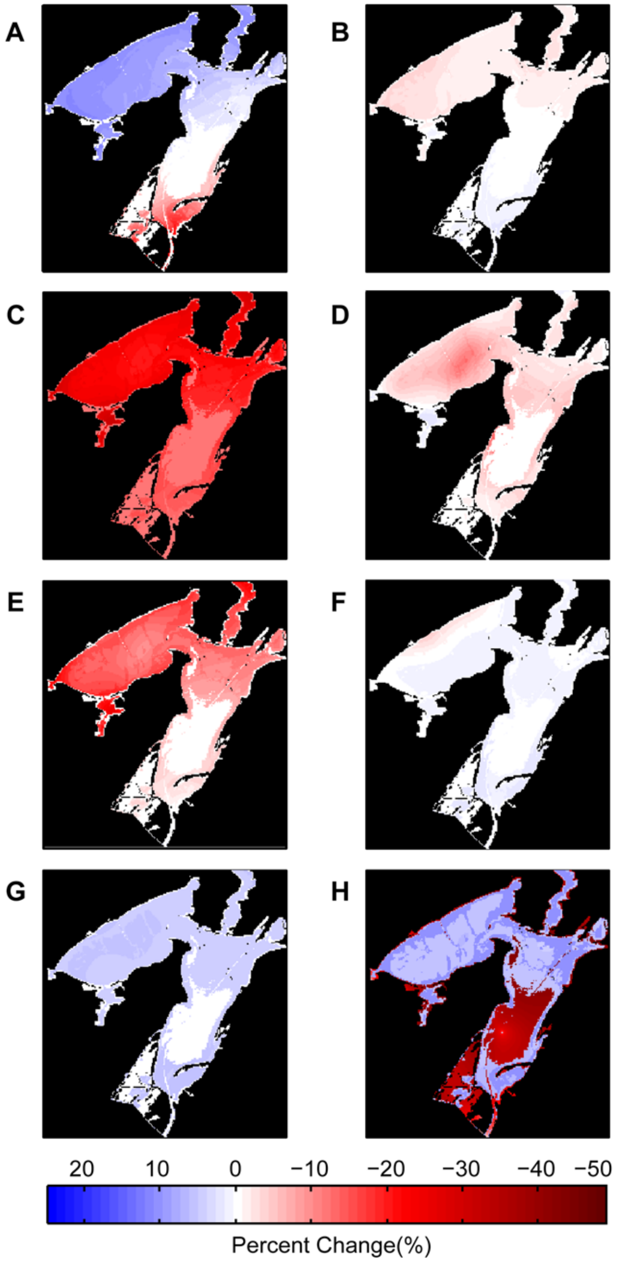

Figure 7. Sensitivity analyses. Percent change from the restoration suitability index base model due to removal of individual normalized environmental variables, one at a time. Removal of: A) mean salinity, B) standard deviation (SD) salinity, C) mean temperature, D) SD temperature, E) mean turbidity, F) SD turbidity, G) frequency of low dissolved oxygen; H) depth.
doi:10.1371/journal.pone.0040839.g007

salinities (~15) and low salinity variability will favor oyster growth and survival over predators and disease [41].

For oyster reef restoration in the Mission-Aransas Estuary, it was also desirable to select areas with low to moderate temperatures. Oysters in Gulf Coast estuaries experience extended periods of warm temperatures compared to northern USA estuaries. Because of the positive correlation with *P. marinus* infection, high temperature values were reclassified with low rankings. Reproduction of *P. marinus* increases at temperatures above 20°C and the parasite proliferates rapidly at temperatures of 25°C or higher [42,43]. Because water temperatures in Gulf of Mexico estuaries generally exceed 20°C for 6 months of the year, oysters do not receive the long reprieve from disease pressures experienced by oysters in northern USA and other high latitude estuaries [30]. Although temperature is a more difficult environmental parameter to control in terms of restoration site selection, particularly in sub-tropical and tropical regions, it is advisable to select locations with sufficient circulation to limit temperature extremes and reduce the probability of disease related mortalities.

Dissolved oxygen concentrations in estuarine waters are another critical component of water quality affecting the survival of oysters. Although the Mission-Aransas estuary has not historically experienced low dissolved oxygen concentrations (Fig. 4G), many estuaries (e.g. Chesapeake Bay) exhibit seasonal salinity and temperature stratification that can lead to hypoxic or anoxic bottom waters. Early developmental stages of oysters may experience negative effects on survival and feeding due to prolonged reductions in dissolved oxygen concentrations [44], whereas adult oysters are better able to survive extended anoxia through the use of anaerobic metabolic pathways [45]. However, the potential negative effects of bottom water hypoxia may be overcome through reef design, particularly increasing reef height, which can provide refuge for oysters and other reef organisms above hypoxic bottom waters [46]. Nevertheless, it is advisable to consider historical frequency of low dissolved oxygen concentrations/hypoxia when selecting the location for (and design of) a restoration site [47].

The Mission-Aransas Estuary experiences a wide range of turbidities; higher values are generally associated with windy conditions in the spring (personal observation). Although previous laboratory studies have reported reduced oyster feeding activities under high turbidity conditions [48], these studies examined much higher levels of suspended solids than present in this system. Conversely, oysters in the Mission-Aransas Estuary appear to experience increased stress and during low turbidity periods, perhaps as a response to low food availability (personal observation; SM Ray, personal communication). Because only 15–30% of surface inflows to the system are from rivers [20,49], the primary driver of turbidity is via re-suspension of bottom sediments. The high amount of re-suspension is due to a combination of seasonal winds and a shallow water column.

The GIS approach employed in this study to characterize locations based on their potential for successful reef restoration in the Mission-Aransas Estuary is flexible and provides a mechanism for considering alternative approaches. Coastal resource or fishery managers can compare different preferred ranges of values for each variable, develop alternative restoration strategies based on these choices, and visualize the effects of these alternative strategies in real time.

The current study has attempted to include as much available and relevant information as possible in the analysis of sites for oyster reef restoration in the Mission-Aransas Estuary. Nevertheless, the approach could be refined further with additional information. For example, side scan sonar and sub-bottom profiling methods are being used more frequently to characterize the bottom and sub-bottom conditions of estuarine systems [50,51,52]. These data have been collected for a portion, but not all, of the Mission-Aransas Estuary and thus were not able to be included in this study [53]. Side scan sonar can cover large areas quickly and can produce a detailed picture of the bay bottom, which is useful for identifying the distribution and scale of oyster reefs and other surficial features. Sub-bottom profilers provide additional information about the shallow structure of the bay bottom, which is important for identifying the presence of hard substrates for supporting reef building materials. New reef materials may sink or experience high rates of sedimentation if an appropriate location is not selected [54]. In estuaries where bay bottom conditions are unknown, it is advisable that these methods be considered and utilized in advance of site selection.

In general, the restoration suitability index model matches the current distribution of oyster reef throughout the Mission-Aransas Estuary. However, there are some differences, particularly in the NE region of the system, where the restoration suitability index predicts favorable conditions for oysters, yet there are few reefs. The reason behind this mismatch may be due, in part, to missing information on bay bottom conditions. Particularly within Aransas Bay, these areas tend to have softer sediments (personal observation) and therefore may not facilitate oyster reef development. Future collection of comprehensive side scan sonar and sub bottom profiling data throughout the Mission-Aransas Estuary and inclusion in the model could improve restoration suitability index results. In addition, we have ongoing restoration efforts throughout the estuary, and thus will be able to empirically test the suitability of the selected regions.

This study sought to support oyster reef restoration efforts by developing a GIS-based methodology for *a priori* improvement of restoration success via an informed site selection process. This approach provides an interactive and quantitative tool for planning future oyster reef restoration efforts. The proposed restoration suitability model could be further refined when additional data (e.g. sub-bottom conditions) become available. Although it is critically important to continue restoring degraded habitats, it is also essential to develop standardized, science-based tools to inform this process. This model provides a practical, objective, and quantitative decision support tool for assisting stakeholders and managers in planning for future oyster reef restoration efforts and for maximizing long-term sustainability of oyster resources.

Acknowledgments

We thank Texas Parks and Wildlife Department's Coastal Fisheries Division in Rockport, Texas, especially Nick Ahrens, Willy Cupit, Mark Fisher, Christopher Mace, Karen Meador, and Luis Uballe. We also thank Rick Kalke for performing *P. marinus* oyster collections and Dr. Sammy Ray from Texas A & M University–Galveston for conducting the *P. marinus* assays (data available on OysterSentinel.org).

Author Contributions

Conceived and designed the experiments: JBP PAM. Performed the experiments: JBP AC TAP ASR. Analyzed the data: JBP AC TAP ASR. Contributed reagents/materials/analysis tools: PAM. Wrote the paper: JBP. Development of the modeling approach: AC ASR. Extensive editorial comments, insight into results: TAP PAM.

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Appendix 4

COASTAL MANAGEMENT NEWS
Volume 7, Issue 2, May 2012

Texas Shell Recycling Program a Success

Oyster reefs are a big business in Texas. In 2010, the state's commercial oyster harvest, valued at $19.1 million, ranked second among all states according to NOAA's annual commercial landing statistics. That does not include the value the reefs provide to other fishing industries—providing critical habitat for many commercially and recreationally important species—or other benefits such as protecting shorelines from erosion and filtering and cleaning coastal waters.

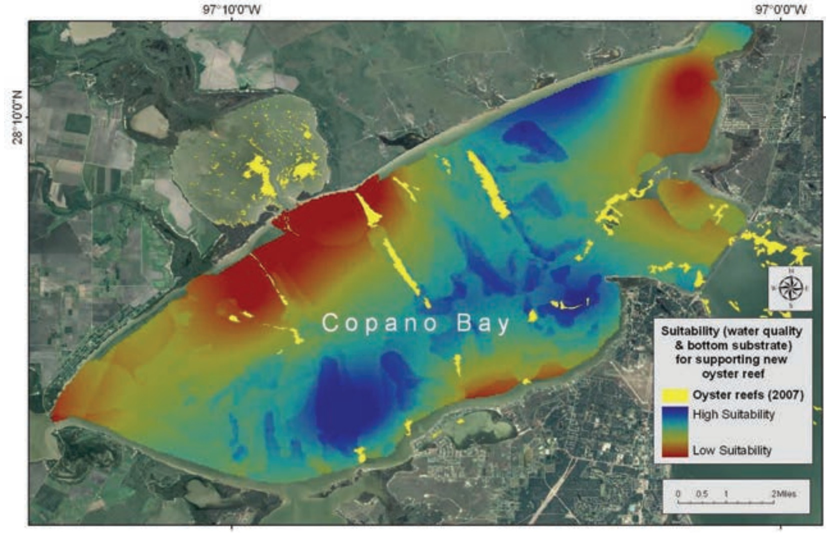
Although 2.8 million pounds of oysters were harvested from Texas waters in 2008, there was no mechanism to return the shucked shells to the water to maintain the reefs. The shells were simply discarded into the trash. Baby oysters, or spat, require hard substrates, preferably oyster shell, to settle and grow into harvestable oysters. Throwing oyster shell into landfills disrupts the natural reef regeneration process. The Texas Coastal Management Program, within the Texas General Land Office, provided funding to launch a new oyster shell recycling program to reclaim the shell, restore Texas oyster reefs, and maintain continued oyster production.

The Harte Research Institute for Gulf of Mexico Studies at Texas A&M-Corpus Christi partnered with the Port of Corpus Christi and Waterstreet Seafood to develop the shell recycling program. Modeled after several shell recycling programs along the East Coast, the Shell Bank, launched in November 2009, began collecting discarded shell from area restaurants and seafood wholesalers. The shells are then transported to the Port of Corpus Christi where they are stockpiled and sun-dried for at least six months to quarantine and remove any disease before they are used for oyster reef restoration projects.

Not only does the Shell Bank help restore reefs, but it saves restaurants and seafood wholesalers money too. Businesses that are charged for trash removal based on weight no longer have to pay to dispose of heavy shucked shells in the landfill. For example, the Waterstreet Oyster Restaurant typically produces 60-70 tons of shucked oyster shells each year so participating in the Shell Bank results in significant cost-savings. Area restaurants will also benefit from the reef restoration activities that will enable continued harvesting of local oysters.

As part of developing the Shell Bank, the Texas Coastal Management Program supported the Harte Research Institute to conduct an economic analysis of the shell recycling program. Using data from the program's first year, they projected the recycling program, even with its start-up costs, would cost about $150,000 less compared to traditional commercial trash disposal over a five-year period.

The Texas Coastal Management Program also helped fund a study to determine what sites would be most appropriate for oyster restoration based on water quality, presence of oyster disease, and overall health of the reef. In addition, the program supported a robust education and outreach effort to promote the new shell recycling program which included a new website, educational video, brochure, and community outreach. The Shell Bank was also featured in several radio spots and local television news segments to increase publicity.



A reef suitability study helped to determine the best areas to restore oyster reefs based on water quality, presence of oyster disease, and overall reef health. Credit: Jennifer Pollack, HRI/TAMCCU

The hard work to initially develop the shell recycling program has paid off. The program had reclaimed over 170,000 pounds of oysters by October 2011. By Summer 2011, the program had amassed enough shell for its first restoration project. Funded through the NOAA-Gulf of Mexico Foundation Community-based Restoration Partnership grant and equipped with knowledge from the reef restoration study, the Harte Research Institute was able to restore nearly four acres of reef habitat using recycled shell and crushed concrete in Copano Bay, far surpassing the program's initial goal to replace one acre of oyster habitat.

The program is conducting community reef restoration projects this spring to increase community awareness, create an invested constituency for preserving natural resources, promote oyster reef restoration, and provide educational opportunities for volunteers. They have already exceeded their original goal of filling at least 800 shell bags, the essential building blocks for a reef restoration. By early May, volunteers had returned over 1,250 bags of reclaimed oyster shell to the water.

For additional information about the oyster shell recycling program visit www.oysterrecycling.org/ or contact Sean Hilbe at sean.hilbe@glo.texas.gov.