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Habitat assessment of a restored oyster reef in South Texas

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ABSTRACT

Oyster reefs are important foundational habitats and provide many ecosystem services. A century of habitat degradation has resulted in substantial reductions in the extent and quality of oyster reefs in many estuaries, thus spurring restoration efforts. In this study, a 1.5 ha oyster reef complex was constructed in Copano Bay, Texas to restore habitat for oysters and associated fauna. Oysters and resident and transient fishes and crustaceans were monitored at the restored reef as well as at nearby natural oyster reef and unrestored bottom (i.e., dense mud with shell hash) habitats for two years following reef construction. The restored reef had substantial oyster recruitment and growth, with oyster abundance and size comparable to nearby habitats within the first year. Resident and transient fauna communities recruited to the restored reef within six months post-construction, and abundance and diversity were comparable to nearby habitats. Significant changes observed in oyster densities between the first and second year post-restoration demonstrate the importance of monitoring over multiple years to capture multiple recruitment cycles and growth to market size. Nekton densities did not change significantly after the first year, but changes in community assemblages were observed through the end of the study. The high densities of oysters and resident nekton relative to other studies indicate that this restoration project was successful in restoring suitable habitat. The design of the reef complex, consisting of relatively high-relief reef mounds and deeper corridors, likely contributed to the relatively high oyster and nekton densities observed in this study. Overall, the restored reef in this study showed tremendous near-term success in providing important ecological functions associated with habitat provision and oyster production.

1. Introduction

Marine ecosystems have experienced critical levels of degradation over the past century through various natural and anthropogenic stressors (e.g., climate change, coastal development, increased nutrient loading, extraction of natural resources) (Aubrey, 1993; Montagna et al., 2002; Stegeman and Solow, 2002; Lotze et al., 2006; Bricker et al., 2008). Seagrass and mangrove habitats have experienced global losses of about 30% from historic estimates; salt marsh habitats have declined by 50% world-wide (Jackson, 2008; Barbier et al., 2011). Oyster reefs are the most imperiled marine habitat on Earth, exhibiting estimated losses of 85% from historic abundances (Jackson, 2008; Beck et al., 2011; zu Ermgassen et al., 2012). Habitat degradation and loss is of concern because of associated losses in biodiversity and the provision of ecosystem services (Worm et al., 2006; Grabowski and Peterson, 2007; Rey Benayas et al., 2009). Restoration projects have increased in an effort to reverse losses of habitat and decreases in ecosystem service provision.

Eastern oysters (*Crassostrea virginica*) are the most common oysters in North America, forming extensive reefs in estuaries throughout their range (Atlantic coast from Canada throughout the Gulf of Mexico to Brazil) (EOBRT, 2007; Beck et al., 2009). As a foundation species, oysters contribute to the integrity and functionality of estuarine ecosystems, and are an important ecological and economic resource. Oysters have been an important food source for humans for centuries, but have recently gained recognition for many other services they provide (Luckenbach et al., 1999; Brumbaugh et al., 2006; Grabowski and Peterson, 2007; Coen et al., 2007). In particular, the complex structure of oyster reefs provides essential habitat for a variety of fish and invertebrates (Zimmerman et al., 1989; Breitburg, 1999; Peterson et al., 2003; Plunket and La Peyre, 2005; Tolley and Volety, 2005; Stunz et al., 2010; Reese Robillard et al., 2010). Oyster reefs can have 50 times the surface area of an equally sized flat bottom, and provide important structure in often otherwise barren landscapes (Coen et al., 1999; Henderson and O'Neil, 2003). Young oysters depend upon the hard shell substrate provided by reefs for attachment and growth, and this is

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the mechanism by which oyster reefs are formed and maintained. Many commercially important fishes and crustaceans depend on oyster reefs during some part of their life, whether as nursery habitat or foraging areas (Beck et al., 2003; Coen and Grizzle, 2007). Thus, oyster reefs can enhance tertiary productivity of estuaries and fishing opportunities for humans.

Efforts to restore oyster reef habitat have increased, and often include goals of providing suitable habitat for the many resident and transient fishes and crustaceans that use reefs (Breitburg, 1999; Peterson et al., 2003; Plunket and La Peyre, 2005; Baggett et al., 2014). However, relatively little is still known about reef and community development following restoration. It is important to understand how long it may take for the goals to be met, if they are met, and whether oyster reef restoration is a good investment (Grabowski et al., 2012, La Peyre et al., 2014a). Better understanding will improve knowledge of what metrics to monitor and at which timescales for assessing project success. Additionally, reef design can be a critical precursor for restoration success. Vertical relief of reef structures can be critical for oyster recruitment and survival, as sedimentation can impede attachment and growth (Jordan-Cooley et al., 2011; Colden et al., 2016). Also, considering the diversity of organisms that use oyster reef habitats, it is important to consider structural complexity and function at a variety of scales and employ reef designs that will benefit a variety of resident and transient reef-associated species (Breitburg, 1999; Eggleston et al., 1999; Boström et al., 2011).

The goal of this study is to determine success of a restored oyster reef in Copano Bay, Texas, in terms of habitat provision and oyster production. Oysters and resident and transient fishes and crustaceans were monitored at the restored reef in addition to nearby natural oyster reef and unrestored bottom (consisting of dense mud and shell hash) habitats. The natural oyster reef represents the minimum end goal of restoration, while the unrestored bottom allows examination of the connecting landscape within natural and restored oyster reef habitats. An understanding of the dynamics of habitat provisioning by restored reefs is essential for assessing whether these habitats can function similarly to natural reefs, and how reef design elements can enhance habitat use by a variety of organisms.

2. Material and methods

2.1. Study area

The Mission-Aransas Estuary is a bar-built estuary in South Texas composed of several shallow bays, the largest being Copano Bay and Aransas Bay (Fig. 1A). The area is characterized by a semi-arid, subtropical climate with infrequent rain events. The average tidal range is small (0.15 m) and water movement is predominantly wind-influenced (Evans and Morehead Palmer, 2012). Oyster reefs are common throughout the system (Fig. 1A). Reefs are primarily subtidal, and more prominent in areas of low to moderate salinity (Beseres Pollack et al., 2011, 2012). The Mission-Aransas estuary is the southern-most extent of commercial oyster harvest in Texas, and oysters are the most profitable fishery in the estuary (NMFS, 2010).

2.2. Reef construction

An oyster reef complex was constructed in Copano Bay in July-August 2011, to restore habitat for oysters and associated fauna (Fig. 1B). The restoration site (28.13°N, 97.05°W) was chosen based on previous efforts to identify suitable areas for oyster reef development (e.g., water quality, oyster health, substrate characteristics) (Beseres Pollack et al., 2012). The three-dimensional reef complex was designed to maximize available resources and create a structurally complex habitat that incorporates hills and valleys as essential design elements (Lenihan and Peterson, 1998; Lenihan, 1999; Stunz et al., 2010). These valleys create important corridors that can increase habitat use across a larger spatial scale (Lenihan and Peterson, 1998; Lenihan, 1999; Darcy and Eggleston, 2005; Stunz et al., 2010). Eight reef mounds, each measuring 20 × 30 m (0.06 ha), were constructed of a concrete rubble base topped with oyster shell to achieve a vertical relief of 0.3 m. Concrete was reclaimed from chutes and hoppers of concrete trucks and crushed to class 3 riprap size to resemble the size of large oysters and maintain natural interstitial space within the reef. Oyster shell was reclaimed from Alby's seafood wholesaler in Fulton, Texas and through the Oyster Recycling Program founded by the Harte Research Institute (HRI, 2012). All shell material was sun-bleached for at least six months before use to ensure shells were free of oyster tissue and harmful bacteria (Bushek et al., 2004; Cohen and Zabin, 2009). Construction occurred using barges with excavators during July 2011. The footprint of the restored reef complex encompasses approximately 1.6 ha, and is situated in close proximity to a subtidal natural oyster reef complex (Fig. 1B). Commercial harvesting via oyster dredges maintains a low vertical relief (~0.1 m) across much of the reef. The surrounding unrestored bottom is characterized by muddy sediments with dense shell hash and few scattered oysters. Though dredging in the area was not restricted during this study, experiment signage prevented harvest disturbance to the actual sampling sites.

2.3. Experiment setup

Six sites were haphazardly chosen at the restored reef as well as at natural reef and unrestored bottom habitats for a total of 18 fixed sampling sites (depth 0.6–1.7 m; Fig. 1B). Plastic sampling trays (0.64 × 0.70 m; 0.44 m^2) were lined with 0.6 cm aquaculture mesh and used to assess colonization and habitat use by oysters and resident crustaceans and fishes (Eggleston et al., 1998; Plunket and La Peyre, 2005; Rodney and Paynter, 2006; Gregalis et al., 2009). In August 2011, following reef construction, trays were filled with approximately 20 L of corresponding substrate and secured in place with rebar hooks by divers. Trays deployed on restored reefs were filled with reclaimed oyster shell to match the veneer of the constructed reefs. An oyster dredge was used to collect natural reef material (i.e., oysters and shells), and this material was used to fill trays deployed on the natural reef. For the unrestored bottom habitat, trays were first deployed, secured and then filled with surrounding substrate (i.e., mud, shell hash, oysters) by divers using shovels. Six trays were deployed at each site so that sampling could occur for two years without tray replacement. This was done to ensure that sampling captured successional trends in reef development. Three additional sites were haphazardly chosen within each habitat type (9 sites total; Fig. 1B) for sampling of transient crustaceans and fishes using a beam trawl (2 m wide, 6 mm stretch mesh; Froeschke, 2011).

2.4. Field sampling

Sampling commenced in February 2012 (six months following experiment setup) and occurred three times per year through September 2013, for a total of six sampling periods (February 2012, June 2012, September 2012, March 2013, June 2013, and September 2013). Environmental parameters were measured at each tray sampling site. Water temperature (°C), salinity (psu) and dissolved oxygen ($mg\,L^{-1}$) were measured 0.1 m from the bottom with a handheld Hydrolab data sonde. Water clarity was measured by Secchi depth (m). Discrete water quality samples were collected 0.1 m from the bottom using a horizontal van Dorn water sampler. Water samples were stored in amber Nalgene bottles and placed on ice until further processing in the lab to quantify chlorophyll-*a* and total suspended solids (TSS).

One tray was retrieved by divers from each site during each sampling period (i.e., total of six trays per habitat type per sampling period). Once lifted out of the water and onto the boat, each tray was quickly emptied into a large tub, and contents were rough sorted in the field. Oysters were thoroughly rinsed within the tub to dislodge mobile