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Artificial oyster reefs in the northern Gulf of Mexico: management, material, and faunal effects

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ARTIFICIAL OYSTER REEFS IN THE NORTHERN GULF OF MEXICO: MANAGEMENT, MATERIALS, AND FAUNAL EFFECTS

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ABSTRACT

Artificial oyster reefs seek to restore reef ecosystem services, such as water filtration, shoreline protection, and habitat for nekton. This study established three objectives to address the dispersed nature of artificial reef information in the Gulf of Mexico (GoM) and lack of post-construction monitoring assessments. First, to document the extent of activities in the GoM, we developed a database of all inshore artificial oyster reefs created for restoration purposes. Of the 422 reefs in the resultant database, a third or less provided records of entities involved (27%), restoration goals (24%), area (20%), monitoring efforts (15%), relief (9%), and costs (8%). Material (89%) and age (66%) records showed reefs were primarily built with rock (48.6%, limestone or concrete) or shell (12.8%) materials; a quarter of projects (26%) occured after Hurricane Katrina (2005). Second, in a field study we examined the success of artificial subtidal reefs using the presence of (a) living oysters and (b) hard substrate as indicators of success. This field study sampled historic (N=7) and artificial shell (N=5) and rock (N=8) reefs in 8 bays along the northern GoM. Rock artificial reefs were more successful on average than shell, providing significantly higher mean adult oyster density and hard substrate volume. In addition to material effects, design (i.e., relief) and placement specific environmental variations (i.e., hydrodynamics) may have affected success. Lastly, to assess artificial reef use by nekton communities, we sampled nekton assemblages with 3 gear types (gillnet, castnet, and shrimp trawl), during 4 trips in summer 2011. Overall, abundance, richness and diversity were similar between historic reefs and both artificial reef materials (shell, rock). It is probable that biophysical variations may have affected nekton use, more than reef structure. Of the reefs sampled, only 65% of the artificial reefs were fully successful in providing reefs with hard substrate and living oysters, while all reefs provided similar nekton support. This project highlights the need to better track restoration

projects in order to inform future activities. Identifying aspects of design and/or location that influence reef success is critical for improving restoration activities.

CHAPTER 1. INTRODUCTION

Oyster reefs are one of, and quite possibly the most, imperiled marine habitats on earth, according to a global assessment of shellfish reefs. More degraded than coral reefs, up to 85% of oyster reefs have been lost worldwide, as estimated from historical accounts and current data (Beck et al. 2011). Along the northern Gulf of Mexico and Atlantic coastline of North America, there has been extensive research documenting changes, and in some areas, declines in oyster resources. Along the Atlantic coastline of the United States specifically, the decline of the native eastern oyster *Crassostrea virginica* (Gmelin) has been hypothesized to result from numerous issues including destructive harvesting practices (Lenihan and Micheli 2000, Kirby 2004), changes in sedimentation regimes (Thomsen and McGlathery 2006), disease (Ford and Smolowitz 2007), hypoxia (Lenihan and Peterson 1998), lack of hard substrate (Breitburg et al. 2000, Coen and Grizzle 2007), as well as erosion, coastal development and boat traffic (Coen et al. 2007, Grabowski and Peterson 2007). Although reefs along the northern shore of the Gulf of Mexico are not thought to be as heavily impacted and in trouble as in other areas (Beck et al. 2011), substantial coast-wide changes impacting oyster habitat and growing areas, such as, freshwater diversions, hurricanes, and the Deepwater Horizon oil spill (Livingston et al. 1999, La Peyre et al. 2003, Banks 2011, McCrea-Strub et al. 2011) have led to increased concern, and concerted efforts to restore and create more oyster habitat.

Changes in oyster quantity, as well as their geographic location, are of concern as the oysters themselves create biogenic habitat, and are a valuable part of estuarine ecosystems. For example, oysters enhance local biodiversity (Wells 1961, Meyer and Townsend 2000, Quan et al. 2009, Scyphers et al. 2011) and provide important habitat for mollusks, fish, decapods, and crustaceans (Meyer and Townsend 2000). Furthermore, as oysters build reefs, the three-

dimensional structure can create refugia from predation, feeding habitat for mobile juvenile and adult species, and nesting grounds (Lehnert and Allen 2002, Lingo and Szedlmayer 2006, Coen and Grizzle 2007). Not only do the oysters and the reefs they create provide important habitat, but as filter feeders, oysters affect the nutrient dynamics and phytoplankton assemblages of their surrounding waters (Cloern 1982, Dame and Libes 1993), and are hypothesized, by providing hard structure, to contribute to shoreline protection and erosion control (Meyer et al. 1997, Piazza et al. 2005) Due to their valuable services provided to the ecosystem, any real or perceived change or loss of oyster resources within an estuary is of concern, and in many cases prompts restoration efforts.

In addition to their value through providing critical ecosystem services, oysters are an economically valuable product, particularly for the Gulf Coast. For example, in 2009, over 90% of the national eastern oyster landings, valued at over $70M were landed in the northern Gulf of Mexico (Vorhees and Lowther 2011). Interestingly, while not studied for the northern Gulf of Mexico (but see Beck et al. 2011), harvest practices are often listed as one of the contributing factors to the decline of the oyster industry in some parts of the country (Lenihan et al. 2001). In addition to losing ecosystem services, the decline in oyster reefs can negatively affect economic livelihoods, such as commercial fisheries, by destroying important habitat. The loss of oyster reef habitat can lead to a reduction in these harvested populations which leads to a loss in profits (Peterson et al. 2003), and provides further impetus for restoration efforts related to oyster reefs.

Artificial oyster reefs are recognized as a viable method for enhancing, restoring, or creating reefs (Meyer and Townsend 2000, Coen et al. 2007, Powers et al. 2009b, Quan et al. 2009). The first documentation of artificial reefs in the United States comes from the mid-1800s (Stone 1974). These man-made reefs can also be referred to as created or bio-engineered, a term

which refers to applying engineering, such as reef design, structure, and materials, to living organisms- in this case the eastern oyster. The materials used for artificial reefs can range from oyster shell (Meyer et al. 1997, Piazza et al. 2005), to limestone (Gregalis et al. 2008) to pulverized fuel ash, a waste material from coal burning power plants bound with cement and aggregate, and even tires (Jensen 2002). Other techniques use automobiles or tanks (Bohnsack and Sutherland 1985) and specifically designed structures. Examples of designed structures include reef balls, reef blocks, and “reef replicating armor units”, all of which are concrete forms designed to mimic reef qualities like relief and sheltered areas (Lukens and Selberg 2004). The need for restoration has become more apparent with the increase in concern for oyster reef decline and the variety and number of artificial reefs being built.

In the northern Gulf of Mexico, oysters are not only important economically, but are also the primary reef-building organism, providing valuable hard habitat in the inshore coastal areas. Although not considered to be in as serious decline here as other parts of the United States (Beck et al. 2011), continuing marsh loss and habitat degradation along this coast has led to increasing interest in habitat conservation, restoration, and creation, of not only marsh habitats, but of all estuarine habitat types, including oyster reefs. In particular, more recent studies have focused on oyster reefs and their provision of ecosystem services such as marsh stabilization (Piazza et al. 2005, Scyphers et al. 2011), and nekton habitat (Harding and Mann 2001, Coen and Grizzle 2007, Humphries et al. 2011), indicating that oyster reefs may play a valuable role within northern Gulf of Mexico estuaries. Despite all the services that these oyster reefs potentially provide, reefs along the northern shore of the Gulf of Mexico remain threatened by harvest practices, natural (Hurricane Katrina) and man-made disasters (2010 Deepwater Horizon Oil

Spill), and environmental stresses resulting from hypoxia, coastal management practices (i.e., diversions) and climate change.

While no central database exists documenting oyster reef restoration and creation activities across the northern Gulf of Mexico, there has been significant reef creation activity, particularly in recent years (Coen and Luckenbach 2000, Baine 2001, Sherman et al. 2002, Henderson and O'Neil 2003, Coen et al. 2004, NOAA 2007, Seaman 2007, Scyphers et al. 2011). Documentation of and access to, information on artificial reef activities, especially post-construction, remains critical for ensuring restoration efforts are effective and provide long-term benefits.

The goal of this study was to document the extent of inshore artificial oyster reef creation, and to evaluate the success of restoration efforts focusing on the dominant sub-tidal reef restoration materials used in the northern Gulf of Mexico. Specifically, this project (1) compiled information on number, location, age, material and design of sub-tidal oyster reef restoration attempts along the northern Gulf shore from Texas to northern Florida (Chapter 2), (2) examined artificial sub-tidal reef success using two indicators of reef establishment success (living oysters, hard substrate) and quantified nekton use of sub-tidal artificial reefs of different age, and different material types (Chapter 3).

Chapter 2 presents a database of all identified inshore oyster reef restoration projects, ranging from Texas through the Gulf side of Florida. This information provides a basic compilation and look at the extent of activity related to inshore oyster reef restoration (not for harvest purposes), including, reef locations, material used, date of activity, funding sources, and follow-up monitoring. This information provides data to identify dominant material types used,

locations of reefs, and whether any outcome data are associated with the reef restoration activities, all of which can help in informing future restoration efforts.

Chapter 3 reports on field data collected to assess the basic outcome of a selection of artificial reefs previously placed in the northern Gulf of Mexico. Success criteria related to actual reef establishment and sustainability were selected to reflect bare minimum criteria and include (1) existence of hard substrate, and (2) maintenance of live oyster populations, as indicators of functional and sustainable artificial oyster reefs. These data were collected on a subset of reefs identified in Chapter 2, stratified by dominant reef creation material (shell, rock), and compared to nearby historic reefs. A second measure of success examined the provision of reef support for nekton, and reports on field data of nekton species to assess whether these artificial reefs provided similar habitat value as historic reefs. Specifically, this work focuses on whether nekton use artificial reefs to the same degree as historic reefs, and whether the artificial reef substrate impacts the abundance, diversity or species assemblage found over the reefs.

Collectively, this work provides an overview on the current state of inshore subtidal reef restoration along the northern shore of the Gulf of Mexico, with the ultimate goal of assessing success, based on reef sustainability and provision of nekton habitat. Understanding whether reef material type or age affect success, and if location effects modify reef success, is critical and will provide information that can aid future restoration efforts. With knowledge gained from past artificial reef approaches and their outcomes- seen through monitoring efforts to assess their continued provision of valuable hard substrate habitat -future efforts may proceed with plans adapted from lessons learned and thereby continue to improve upon restoration endeavors.

CHAPTER 2. INSHORE SUBTIDAL ARTIFICIAL REEF RESTORATION EFFORTS IN THE NORTHERN GULF OF MEXICO

INTRODUCTION

Ecological restoration cannot progress without optimizing efforts through the review of practices and adapting approaches based on evidence of success and or failure. Linking success criteria to specific goals is instrumental in adaptive management and begins with defining the goals (Coen and Luckenbach 2000). With a clear direction in mind, success criteria can then be set, efforts monitored for effects on criteria parameters, and results referenced for areas of improvement for use in the current project or future endeavors (Hackney 2000, Thom 2000). This adaptive management framework is ideal in theory, but not consistently used in practice for artificial reef efforts despite numerous statements of its need (Bohnsack and Sutherland 1985, Carter et al. 1985, Breitburg et al. 2000, Hackney 2000, Baine 2001, Coen et al. 2007, Seaman 2007, Johnson et al. 2009, Beck et al. 2011, Borsje et al. 2011). Limitations and complications to evidence-based improvements in artificial reef restoration efforts involve multiple issues ranging from differing approaches to lack of data aggregates.

Despite worldwide restoration activities centered on the use of artificial reefs, a lack of consensus is apparent in methods, materials, monitoring, and management. Evidence suggests that artificial reefs have the potential to enhance water quality (Cloern 1982, Grizzle et al. 2008), biodiversity (Wells 1961), fisheries production (Powers et al. 2003), oyster populations (Powers et al. 2009b), and shoreline protection (Meyer et al. 1997), but the associated options for restoring these ecosystem services offer complicated and unclear choices, likely confounded by local conditions. Typically differences in artificial reef activities stem from differing initial goals and which ecosystem service(s) is the focus of restoration efforts. Other differences branch

from there regarding design , budget (Baine 2001, Henderson and O'Neil 2003), responsible entities (NOAA 2007), regional variations (Bohnsack and Sutherland 1985), site specific considerations (Grizzle et al. 2008, Johnson et al. 2009), and combinations of these and more.

Despite what appear to be significant artificial reef activities across the coast of the northern Gulf of Mexico (Sherman et al. 2002, Coen et al. 2004, Seaman 2007, Scyphers et al. 2011), no central database of locations or affiliated information exists. This scattered hodgepodge of artificial reef information is a hindrance to regional assessments, and provides an obstacle to truly implementing adaptive management. The apparent need for a regional database to consult in order to adapt and improve upon future artificial reef activities led us to develop our own database to address the problem.

Specifically, this project (1) compiles locations and associated information on any inshore artificial oyster reefs located along the northern shore of the Gulf of Mexico from the South Texas border to central Florida, and (2) provides an assessment of information available for the resulting database, including limitations, conclusions, and areas for improvements. The intent is to provide an overview of documented efforts of oyster reef restoration for the northern Gulf of Mexico by compiling reefs' 1) location and identification; 2) physical descriptions involving materials, area, relief, and age; and 3) information on parties involved and associated costs, monitoring efforts, or specific goals.

METHODS

To develop the database, we set several prerequisites for reefs in our search: (1) coastal inshore areas associated with the northern Gulf of Mexico shores of Texas, Louisiana, Mississippi, Alabama and Florida ranging from the Texas and Mexico border to Collier county, Florida (Fig. 2.1), (2) reefs were inshore, which was defined as areas with waters less than 10

meters deep and less than 5 miles from shore, (3) efforts primarily for ecological restoration (not commercial use). This last point is important because many Gulf Coast states have extensive annual cultching programs, where cultch (shell, rock) are placed in public seed grounds for the primary purpose of allowing settlement and removal of the cultch and seed stock each year. We did not consider these as part of our reef restoration activities.

Data collection began with lists compiled through contacts with local, state and federal agencies involved in restoration in the five states. The search was further expanded to include non-profit organizations that are involved in restoration in the region, research organizations, and universities (Table 2.1). Information was gathered from personal contacts, websites, published literature, reports, fishing hotspots literature, and any other available source for addition to the database. For published reports, primarily Web of Knowledge[SM,] was used for searches. Government permits for restoration efforts through artificial oyster reef creation vary by state, region, entities involved, goals, and size (Nix 2011), we therefore did not consult permits but instead focused our efforts on more direct sources of information; our records were kept in an Excel spreadsheet (Appendix Table A.1).

Within our database, we had a list of information targeted. These parameters were categorized as (1) reef identification, (2) physical description, and (3) parties involved and associated efforts (Table 2.2). Reef identification was the basic requirement for our database, and included a GPS location, from which state and body of water could be discerned, and a name. Physical descriptions included construction material, actually recorded or reports of initial design planned, area covered, average water depth at which placed (taken from bathymetry maps if not included), and a date of implementation (age). Parties involved and associated efforts included organizations and/or funders associating their name with the reef, specific restoration

goals or reasons built, cost of materials and/or project, and monitoring efforts. All reefs were designated as being primarily for restoration (not harvesting) purposes, but some had specific goals of habitat enhancement, shoreline protection, or oyster enhancement, for example.

Table 2.1 Organizations contacted for artificial reef information in 2011 by location affiliation. Information sources not listed include local papers grey literature, peer reviewed literature, personal communications without an agency affiliation, and online records of fishing sites, contractor construction records, etc..

Organizations Contacted	
Federal	
	National Oceanic and Atmospheric Administration
	U.S. Department of Agriculture, Natural Resources Conservation Service
Regional	
	Coastal Conservation Association
	Gulf of Mexico Foundation
Texas	
	The Nature Conservancy- Texas Coastal & Marine Program
	Texas Parks and Wildlife: Coastal Region 1
	The Hart Research Institute: for Gulf of Mexico Studies
	Texas A&M
	US Fish & Wildlife- Clear Lake Field Office
	US Fish & Wildlife- South Texas Coast Program
	Texas General Land Office
Louisiana	
	Louisiana Department of Wildlife and Fisheries
	Louisiana State University
	The Nature Conservancy- Louisiana
Alabama	
	Alabama Department of Conservation
	The Nature Conservancy - Alabama Marine Program
	Dauphin Island Sea Lab
	University of South Alabama: Dept. or Marine Resources
Mississippi	
	MS Department of Marine Resources
	Artificial Reef Bureau
	The Nature Conservancy
	U of Southern MS Gulf Coast Research Lab
Florida	
	Florida State University
	University of Florida
	Florida Department of Agriculture and Consumer Services
	The Nature Conservancy - Florida Marine Team
	Sea Grant- Cedar Key Marine Field Station
	Florida Department of Aquaculture
	Fish & Wildlife- Florida Panhandle Coastal Program
	FL Dept. of Environmental Protection: Apalachicola Nat'l Estuarine Research Reserve
	NW Florida Aquatic Preserve Program

RESULTS

Reef Identification

Four hundred and twenty-two (422) artificial inshore oyster reefs were identified, and placed in the database (Figure 2.1; Table A.1). Although much time was spent, and numerous leads were tracked down (Table 2.1), it is unlikely that this dataset captures all reef restoration activities within the northern Gulf of Mexico. Some reefs were mentioned, but no actual location could be identified, and no documentation could be found; these were left out of the database. Further difficulties were encountered due to some loss of physical records following Hurricane Katrina in some parts of the coast. The final database used for analyses included only reefs where, at a minimum, a GPS location and record of creation could be found. Grouped by state, the majority of reefs were found along the Florida coastline (218, 51.6%), followed by Mississippi (74, 17.5%), Alabama (69 , 16.4%), Louisiana (40, 9.5%), and Texas (20, 4.7%) (Figure 2.1).

Physical Description

Very few reefs had detailed documents available regarding all physical aspects (i.e., material used, date of implementation, reef design, reef size); some aspects of the description of actual reef restoration activities were widely found and reported, while others were difficult to locate or not available (Table 2.2). Construction material (89%) and date of implementation (66%) were available for a majority of the artificial reefs, but specific design features such as reef relief (9%) and reef area (20%) were difficult to locate. Similarly, rarely were descriptions of the location where reef placement was to occur included in any reef restoration descriptions. For our purposes, water depth was determined for reefs from bathymetry measurements associated with GPS point locations.

Table 2.2 Extent of information on artificial reefs in the northern Gulf of Mexico as of January 2012. Number of responses indicates that information was found describing the parameter in question. Location and identification were required for inclusion in the database, and further analyses

GOM Artificial Reef Inventory: Categories of Data Sought and Responses Acquired	# Responses	% of Dataset
Location & Identification		
State	422	100%
GPS Point(s) of Location	422	100%
Surrounding Body of Water	422	100%
Individual Reef/Site Name	422	100%
Physical Description		
Construction Material	378	89%
Relief Intended or Actual	38	20%
Area Covered	86	9%
Water Depth at Location *Found via maps if unlisted	422	100%
Date of Implementation	278	66%
Parties Involved and Associated Efforts		
Organizations and/or Funders Contributing to Reef	115	27%
Restoration Goals/Reason Built	102	24%
Cost of Materials and/or Project	32	8%
Monitoring Efforts	52	15%

Materials used in the Gulf can be broadly classified as native or non-native. The non-native subset of rock, per our definition, is used in nearly half of artificial reefs (48.6%) within the Gulf of Mexico and includes crushed limestone, limestone boulders, and various forms (culverts, crushed, bridge and road bed rubble, reef-dome forms, etc.) of the rock aggregate concrete. Shell cultch, usually from oysters and sometimes clams, is essentially the only native material used in Gulf artificial reefs, and was the second most commonly used material, accounting for only 12.8% of the reefs restored in the Gulf of Mexico. The use of shell was also highly state specific, with Louisiana containing 26% (contributed 3.3% to the Gulf's 12.8%) of the Gulf's shell reefs, despite holding less than 10% of all reefs restored coast-wide. The

remaining categories include "unknown", which accounted for 10.9% of projects, mixtures of shell and non-native materials at 9.7%, mixed non-natives only at 8.9%, metal at 5.2%, and other one material non-native subsets falling below 9.0% in total (Table 2.3). While “unknown” was used when no information was available, “other” referred to non-native materials like tires, and ambiguous listings like “pilings”, which could presumably be wood, metal, or concrete, and “roadbed” without designation as steel or concrete as other listings had done. All metal listings were from Florida, and included roadbed (when designated as steel) as well as barge, airplane, and crane wrecks or planned sinkings of these metal objects specifically for reef material.

A third of the identified reefs (34.1%) do not have a record of their implementation date (Table 2.2). Of the reefs where dates were located, nearly half (48.8%) of the artificial reefs have been built since the turn of the century, after 1999, and a quarter (26%) were built post Hurricane Katrina, after 2005 (Figure 2.2). Hurricane Katrina created extensive damage to reefs, but also brought national attention to the Gulf of Mexico, along with federal money for coastal restoration that could be used for artificial reefs. There may be some bias with recent records being more easily accessed, and digitally available, and therefore part of our database, but the fact remains that 206 artificial reefs have been placed in the Gulf in the last 12 years with more projects scheduled.

There is no apparent trend in materials used to support reef restoration with the broad category of rock accounting for close to 50% of all reefs built. The popularity of rock and shell as building materials has also continued; a majority (53.4%) of reefs built since 1999 were either rock or shell, with an additional amount (11.7%) using shell mixed with non-native materials.

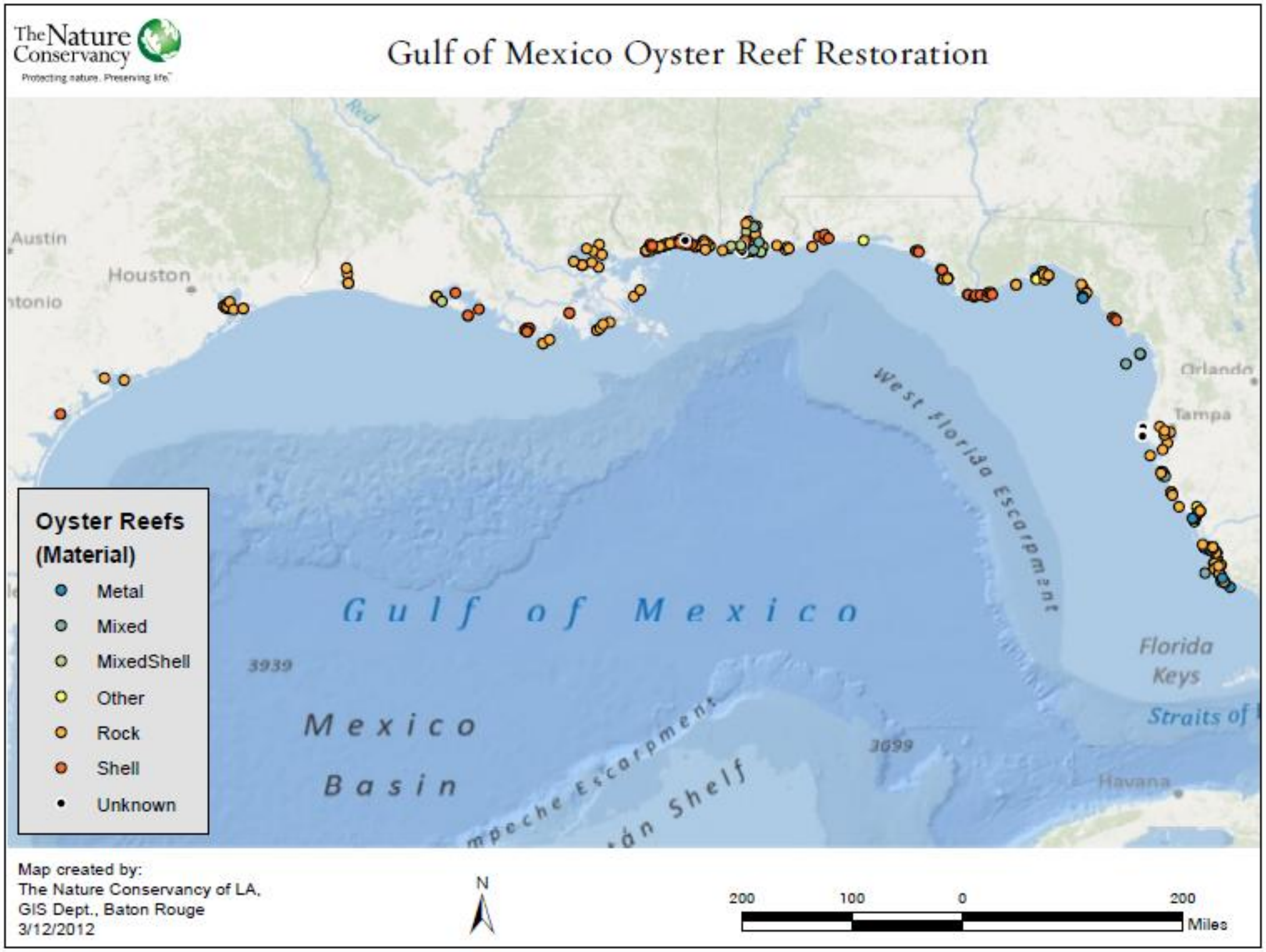


Figure 2.1 Map of individual inshore artificial reef locations and materials across the northern Gulf of Mexico coastline. A total of 422 reefs were located in brackish waters along the coastline; a mix of materials was used for reef creation throughout the region with rock being most common (48.6%; Table 2.1).

Table 2.3 Artificial reef materials used in the northern Gulf of Mexico by state. State % denotes the percentage of reefs, made from a specific material, within the state. Gulf % denotes the percentage of reefs, made from a specific material, each state contributes to the northern Gulf of Mexico.

	All States		Individual State															
Material	**N. Gulf of Mexico**		**Texas**			**Louisiana**			**Mississippi**			**Alabama**			**Florida**		
Non-Native:	N	%	N	State %	Gulf %	N	State %	Gulf %	N	State %	Gulf %	N	State %	Gulf %	N	State %	Gulf %
Rock	205	48.6	20	95.2	4.7	25	62.5	5.9	51	68.9	12.1	9	13.0	2.1	100	45.9	23.7
Metal	22	5.2		0.0			0.0			0.0			0.0		22	10.1	5.2
Other (not mixed)	20	4.7		0.0			0.0			0.0			0.0		20	9.2	4.7
Mixed Non-Natives	34	8.1		0.0			0.0			0.0		10	14.5	2.4	24	11.0	5.7
Native:																	
Shell	54	12.8	1	4.8	0.2	14	35.0	3.3	16	21.6	3.8	1	1.4	0.2	22	10.1	5.2
Mixed Non-Natives & Shell	41	9.7		0.0		1	2.5	0.2	6	8.1	1.4	34	49.3	8.1		0.0	
Unknown	46	10.9		0.0			0.0		1	1.4	0.2	15	21.7	3.6	30	13.8	7.1
TOTAL	**422**	**100.0**	**21**	**100.0**	**5.0**	**40**	**100.0**	**9.5**	**74**	**100.0**	**17.5**	**69**	**100.0**	**16.4**	**218**	**100.0**	**51.7**

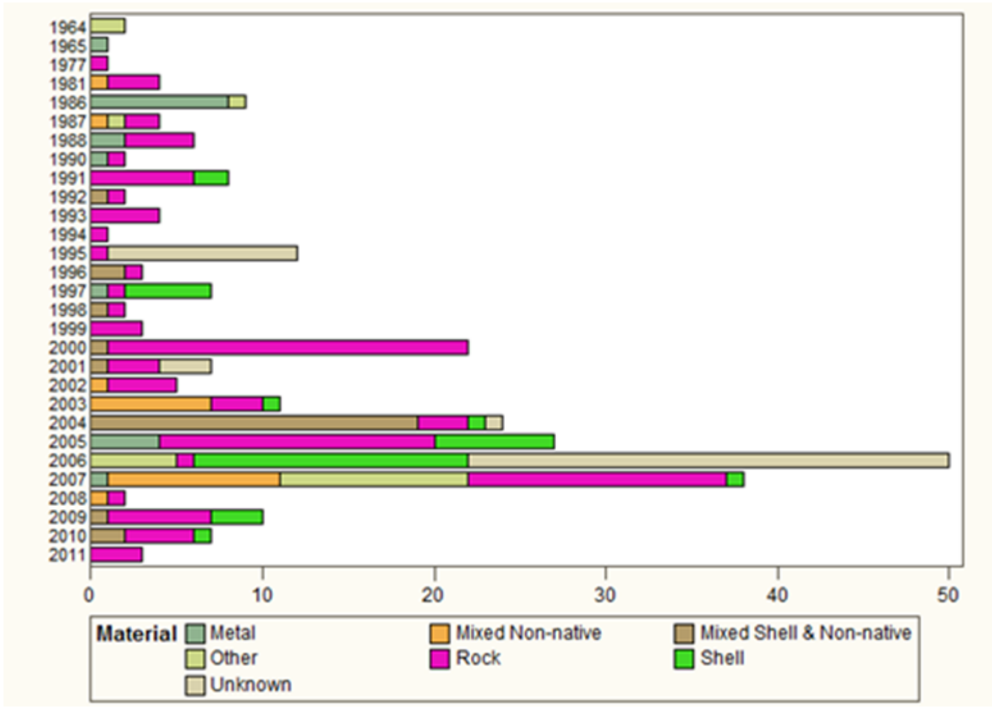


Figure 2.2 Number of artificial reefs created, by year and by material type.

While most constructed projects would be expected to have detailed accounting of reef dimensions and other parameters, it was rare that this information could be tracked down, even by individuals managing the reef databases. Measurements of area covered are not always reported with reef placement and nearly 80% of the database reefs did not have an associated area measurement. Of the reefs with detailed information available, the range of sizes was from 0.15 acres (24 of Alabama's experimental reefs; Gregalis et.al. 2008) to 283 acres covered by a single reef in Mississippi (Pass Marianne Reef). This lack of information regarding total area of habitat affected makes it difficult to assess actual restoration effort, and potential impact. Similarly lacking was information on created reef relief, whether targeted, as-built, or later measured from monitoring.

Parties Involved and Associated Efforts

Information on parties involved and associated efforts were available for less than a third of all reefs (27%). To obtain this information, we cast a wide net to determine who was involved in conceptualization, designing, locating, funding, constructing, monitoring or any aspect of the individual reef creation. Associated efforts referred to information specifically detailing the actual goals of the reef creation project (24%), cost (8%), and monitoring efforts (15%).

The Gulf of Mexico has multiple entities implementing artificial reefs for restoration purposes including conservation non-profits (e.g., The Nature Conservancy, Lake Ponchartrain Basin Foundation, Coastal Conservation Association), government organizations (e.g., Mississippi Department of Marine Resources, Texas Parks and Wildlife, National Marine Fisheries Service/NOAA), private companies (e.g., Cheniere Energy, Florida Gas Transmission Company), research programs (Sea Grant, Dauphin Island Sea Lab), and combined efforts/partnerships from these differing sectors. For those reefs where goals were identified, goals included restoration of oyster and nekton habitat, creation of recreational fishing and diving hotspots, shoreline protection, water quality enhancement, and meeting mitigation requirements. Of the reported goals, habitat creation (41.1%) and recreational areas (47.1%) motivated a majority of efforts. Monitoring efforts were documented for less than 15% of artificial reefs. This low percentage may not be a true reflection of monitoring efforts and instead a result of uncoordinated and/or publicly unavailable monitoring efforts, but the end result is the same. Monitoring efforts ranged from a simple check-mark on a list to scientific literature reporting with goals, methods, and results.

The cost of artificial reefs ranged from $2,068 to just over $1 million. From the few reefs where cost and area were available, cost per acre ranged from $5,000 to $ 13,750. Due to inconsistent and sometimes ambiguous reporting styles it was difficult to discern for many projects if the costs reported accounted for only material costs or the total project (design, construction, transportation, etc.) costs.

DISCUSSION

Clearly, there have been extensive efforts in inshore oyster reef restoration across the northern Gulf of Mexico. These efforts can be tracked back close to 50 years, and suggest that the primary materials used for oyster reef restoration remain unchanged, but that information related to reef design, and creation success remain limited because of a lack of detailed tracking of reef creation and monitoring activities. It is possible that reef restoration activities have failed to evolve during this past half century due to this lack of documenting and sharing even the most basic facts related to reef restoration efforts. An example highlighting this issue entails a State of California Fisheries report from 1969 (Turner et al. 1969) with very specific goals, methods, data monitoring, management recommendations and results, that directly address many points still the focus of studies today (Baine 2001). The clearest message to emerge is that the lack of basic information on reef restoration efforts from design to construction, to cost, and finally to monitoring of success hinders any adaptive learning process. Beyond basic location and identification, artificial reef documentation was often difficult to acquire for this study. Even lists maintained by state government entities, typically the largest lists within states when measured by reef count, often lacked information essential for assessment. For example, readily available website lists of inshore artificial reefs are provided by Louisiana Department of Wildlife and Fisheries (2012) and Mississippi's Department of Marine Resources (2010), but

beyond identification information, these lists provided only materials and/or donors, and further inquiries with the parties indicated no other information was available through the agencies, and there was no institutional knowledge of where more information could be available.

This inability to learn from past efforts is particularly troubling given the high level of activity currently on-going with reef restoration in the Gulf, and the increasing scrutiny related to restoration projects. Numerous studies from the east coast indicate taller (higher relief) reefs are more likely to provide areas that are above bottom associated hypoxic conditions that can impede oyster settlement and/or growth (Baker and Mann 1992, Gregalis et al. 2008, Johnson et al. 2009). However, there is little evidence for the northern Gulf as to how critical the relief of the reef is, and what magnitude of reef relief is needed to avoid either sedimentation or hypoxic related death, or if this is even a consideration. This is a particularly important question when combined with considerations for the amount of materials to be used, and the cost, as the same amount of materials can create very different reef sizes depending on how they are spread. For maximum acres covered, materials can be spread more sparsely, and for greater reef relief a thicker application can be made at the loss of surface area covered. The risk obviously, is that if spread too thinly, the reef will either sink, be covered in sediment and/or not provide an appropriate settlement area for oyster larvae.

The lack of clear information related to cost and success of reefs prevents managers from making informed decisions. In particular, as engineered techniques tend to, in general, be more expensive than loose, often recycled, materials (Lukens and Selberg 2004), it would clearly be a benefit to understand the pros and cons of such an approach in terms of the long-term sustainability of the created reef, and provision of ecosystem services. The limited information on past artificial reef projects is a hindrance to improvements upon new projects. This problem

is not unique to the Gulf of Mexico. Attempts to aggregate data in Maryland and Virginia (Kennedy et al. 2011), the Persian Arabian Gulf (Feary et al. 2011), Japan and the United States (Bohnsack and Sutherland 1985), and globally (Baine 2001) have found similar issues with lack of clear goals, post-construction monitoring, comparative qualitative methods, and regional data reporting.

The amounts of planning, money, and resources devoted to artificial reefs are deserving of adaptive management practices that provide the best assurance currently available of successfully and sustainably meeting goals. Not recording and reporting methods, materials, monitoring, and management can inevitably lead to wasted resources when unreported failures are repeated out of ignorance. As suggested for a recent assessment of restoration efforts in Virginia and Maryland (Kennedy et al. 2011), clearly defining goals, and then coordinating monitoring techniques, success criteria, and methods of reporting for artificial reefs of similar goals is needed in order to identify the most efficient sustainable restoration efforts.

While information from individual projects on reefs may help in improving restoration techniques, identifying best practices, and designing the most cost-effective reef, a treasure chest of information is missed in not properly accounting constructed restoration projects. At minimum, a coast-wide tracking system of artificial oyster reef projects would provide a means, most likely online, to allow entities ease of reporting basic location information including GPS points, state, body of water, and name. Further details would follow similar to our inquires in Table 2.2, for physical description (area, relief, depth of water body, date) and could provide drop down menus for clear choices and easy sorting and searching, along with the option to input unique responses. Entities involved and associated efforts information could follow a similar format (drop down menus for type of organization, goals, cost ranges, and “ yes or no”

monitoring efforts exist) with areas to add addresses, agency names, personal contacts, phone numbers, email addresses, references, links to information sites, and any other information available. Clearly, with over 100 reefs created since Hurricane Katrina, there is enormous interest in better managing, enhancing, and restoring oyster reefs along the northern Gulf coast, and that these efforts support a diversity of ecosystem service related goals. This basic compilation of reef restoration efforts within the inshore zone, and the information in the following two chapters related to provision of ecosystem services of a subset of these identified reefs should be extremely useful to scientists and managers seeking to improve future efforts.

CHAPTER 3. DETERMINING SUCCESS OF REEF RESTORATION: A FIELD BASED REVIEW OF PAST PROJECTS WITH RESPECT TO CREATION MATERIAL

INTRODUCTION

In the last two decades, the recognition of the ecological value of oyster reefs beyond the context of a harvestable commodity, coupled with more than a century of oyster population decline, has led to an increase in the use of artificial reefs for restoration purposes (Grabowski and Peterson 2007, Volety et al. 2009, Beck et al. 2011). Deemed ecosystem engineers, the numerous ecosystem services oysters provide modify the surrounding environment (Wright and Jones 2006, Coen et al. 2007, Borsje et al. 2011). As filter feeders, oysters are well known for their positive influence on water quality and affect the turbidity, nutrient dynamics, and phytoplankton assemblages, along with aiding in carbon sequestration and denitrification (Dame et al. 1984, Coen et al. 2007, Grizzle et al. 2008). Their hard structure provides shoreline protection and erosion control (Meyer et al. 1997, Piazza et al. 2005) as well as habitat for mollusks, fish, decapods, and crustaceans (Meyer and Townsend 2000, Grabowski et al. 2005).

Global declines in oyster populations, and the subsequent loss of these ecosystem services, have been linked to destructive harvesting practices (Lenihan and Micheli 2000, Kirby 2004), changes in sedimentation regimes (Thomsen and McGlathery 2006), disease (Ford and Smolowitz 2007), hypoxia, (Lenihan and Peterson 1998) lack of hard substrate (Breitburg et al. 2000, Coen and Grizzle 2007) as well as erosion, coastal development and boat traffic (Coen and Grizzle 2007, Grabowski and Peterson 2007). Oysters are important as a harvestable commodity (Hargis Jr. et al. 1999, Lenihan and Micheli 2000), but it is the ecosystem services, lost through population declines, that artificial reef restoration efforts seek to regain.

To successfully restore ecosystem services, artificial oyster reef efforts inherently require the recruitment, survival, and maintenance of a viable oyster population. Under natural

conditions, the oysters themselves are the primary providers of the hard substrate required for their broadcast larvae to settle, grow, and build the populations needed to sustain themselves and their ecosystem services (O'Beirn et al. 2000, Nestlerode et al. 2007). Essentially, artificial reefs implemented to restore oyster populations attempt to (1) provide hard substrate to recruit oysters, provide habitat, and/or protect shorelines and (2) maintain viable oyster populations and, consequently, restore lost ecosystem services (Brumbaugh and Coen 2009, Powers et al. 2009b). The continual building of a reef, through recruitment and viable population maintenance, protects against the detrimental possibilities of sinking or sedimentation burial and the resulting loss of a reef and its associated ecosystem services (Coen and Luckenbach 2000, Powell and Klinck 2007, Powers et al. 2009b). Along with maintaining a reef's presence, an increase in oyster density results in increased ecosystem services. Reefs with greater quantities of oysters provide more structure for habitat and shoreline protection and higher densities of oysters result in increased water filtration (Breitburg et al. 2000, Grizzle et al. 2008). Additionally, as oysters become older and larger, capacities for water filtration, carbon sequestration, and larvae production increase, with the latter creating a possible cyclical return of higher recruitment densities (Mann 2000, Knights and Walters 2010).

The habitat provisions of restoration efforts lay the foundation for nekton to be used as a measure of artificial reef quality. Biodiversity, abundance, and relative nekton size can increase with the presence of oyster reefs (Wells 1961, Harding and Mann 2001, Tolley and Volety 2005, Humphries et al. 2011) as organisms seek refuge from predation, feeding habitat, and nesting grounds in the hard substrate and structure (Lenihan et al. 2001, Coen et al. 2007). Artificial reefs can mimic the nekton supporting habitat of historic reefs. Since it is possible for artificial reefs to support densities of common species (Meyer and Townsend 2000) similar to historic

reefs, historic reefs can be used as a relative baseline when assessing restoration reefs. The effect of substrate material and its structural complexity has been a recent area of interest for reef restoration practitioners (Baine 2001, Harding and Mann 2001, Gregalis et al. 2009) and may affect nekton use, but there is no current consensus on the best material choice for sustainably successful reefs.

Typical of many restoration activities, monitoring and long-term assessment of restoration success in artificial oyster reefs is often limited and inconsistent (Bohnsack and Sutherland 1985, Coen and Luckenbach 2000, Hackney 2000, Baine 2001, Johnson et al. 2009, Feary et al. 2011, Kennedy et al. 2011). Kennedy et al. (2011) found data to be dispersed, difficult to access, and widely varying in statistics and formats, which ultimately hindered evaluation of the success of specific oyster restoration activities and techniques, in Maryland and Virginia. Related areas of data paucity have been highlighted by others: quantitative data (Bohnsack and Sutherland 1985), post-construction monitoring (Carter et al. 1985), examination of effects by structures (e.g. jetties, pipelines, oil rigs) unintentionally mimicking reefs, (Feary et al. 2011), and defined long-term management goals linked to specific success criteria (Coen and Luckenbach 2000, Baine 2001). A plethora of recommendations for long-term monitoring techniques and standards accompany these studies, with a general consensus that reef population changes should be assessed over time. Specifically, a South Carolina Sea Grant Report defined oyster density, size frequency, associated fauna, reef size, reef architecture, landscape fragmentation, and water quality as choices for success determining metrics to be monitored, however no specific amount of time to continue monitoring is suggested (Coen et al. 2004). Given the amount of resources, time, and costs associated with reef restoration, it is critical to evaluate reef success in order to adapt future management so that the most efficient techniques

are used to meet goals. (Henderson and O'Neil 2003, Mann and Powell 2007, Brumbaugh and Coen 2009)

The northern Gulf of Mexico (GoM) is one region where few data exist on post-construction monitoring (Chapter 2). While the area's historic, naturally occurring oyster reefs are considered to be in fair condition, current populations in this region are estimated to remain at only 11-50% of their historical abundance (Beck et al. 2011), and restoration efforts are in place for the region's only native oyster, the eastern oyster *Crassostrea virginica* (Chapter 2). Understanding the outcome of these efforts, particularly whether material or design affect restoration outcomes, can aid future decisions and thereby improve future artificial oyster reef creation.

This study examined the outcome of inshore subtidal artificial oyster reefs created over the last 20 years along the northern shore of the Gulf of Mexico. Specifically, we examined oyster populations through the comparison of 1.) the provision of hard substrate and 2.) current live oyster population densities on three reef types (historic, shell material, rock material). Nekton assemblages were examined via comparisons of species abundance, richness, diversity, and environmental relationships between historic and artificial reefs for the GoM's two most common artificial reef materials: rock and shell.

METHODS

Study Area and Design

We surveyed artificial and historic reefs found in inshore waters of the northern Gulf of Mexico (GoM) from Texas to the panhandle of Florida (Figure 3.1). Historic reefs refer to oyster reefs that were either found on historic maps, or indicated as not created by local managers and oystermen. Artificial oyster reefs selected for sampling were reefs built for reef

restoration purposes and selected from a Gulf-wide list of inshore artificial reefs (Chapter 2). All reefs were subtidal, located in brackish, shallow (< 3.5 m) water, and a minimum of 100 m from the shoreline. Reefs varied in overall dimensions and configuration, but most were relatively low profile (< 20 cm) as are most reefs along the northern shore of the GOM. Reefs were grouped by location in one of 8 bays with some variations in harvesting pressure, distance from shore, exposure, and water quality. We were interested in difference between reef types (historic, shell, rock) as opposed to differences in reef success due to bay effects, and thus blocked all analyses by bay, with the assumption that reef creation would not have occurred in areas where water quality was not conducive to oyster growth. Because of the economic importance of oysters, few reefs are protected along the GOM, and so we were unable to control for harvest. A few bays contain reefs that are likely unharvested (Mobile Bay, Bay St. Louis, Barataria- Terrebonne, Vermilion Bay, Calacasieu) but all bay reefs in Florida, and Texas are likely harvested.

Initial design involved 21 reefs, located across 8 bays, stratified by reef type (7 historic, 7 shell, 7 rock). Historic (naturally occurring) reefs were viewed as control reefs. Shell reefs were created with loose oyster shell cultch, and rock reefs were created using limestone or concrete materials. Of the 14 artificial reefs originally selected, one shell reef was inaccessible during the sampling time frame due to the 2011 record floods in Louisiana. A second reef, originally designated as a shell reef, was reclassified as rock (R-SL) due to the discovery of concrete in samples, attributed to an adjacent train bridge destroyed by Hurricane Katrina (Table 3.1). Artificial reefs varied by age, based on date of installation as the original goal called for examining the effects of age on reef success. Age was not examined in this study, however reefs within our age range (3-20 years) should all be capable of meeting our basic success criteria. In

the sub-tropical climate along GoM, adult oysters can grow to colonize a reef in 2-3 years (Grabowski and Peterson, 2007) and as a sustainable resource, reefs can be expected to last at least 20 years. Oyster samples were obtained from a single visit to each reef during September and October of 2011.

Oyster Sampling

Reef material and oysters were sampled haphazardly by divers with five 0.25 m^2 quadrats, per reef site in fall 2011 (Oct-Nov). Reef sites were located by navigating close to coordinates using GPS units and then probing for hard bottom with a ten foot PVC pole. When three pole taps reached hard bottom during a boat speed of 1,000 rpm, the anchor was dropped. Buoys attached to a brick weight by a 4 m line were tossed haphazardly from the boat onto the submerged reef surface. Two divers sampled a 0.25 m^2 quadrat at each of the buoys. One diver held a bucket while the other laid a weighted quadrat. Substrate within the quadrat was removed to a 10cm depth using gloved hands and tent stakes (as pry bars), as best allowed by the artificial reef structure, and placed in the bucket. Holes in the buckets allowed water to drain as samples were brought to the boat. Once aboard, each sample was placed in a 3 mm mesh bag, labeled, and dipped overboard to wash mud and fine debris from the sample. Bags were placed on ice and transported to a cold room for storage until the contents were counted, weighed, and measured within one week.

Each sample was sorted into five categories: (1) shell hash, (2) gravel/concrete, (3) loose live oysters, (4) loose dead oysters, and (5) clusters. A cluster was defined as three or more adult oysters attached to one another, whether dead, live, or a combination. A volume was recorded for each of the five categories by measuring water displacement in a plastic tub (nearest 0.25 L). Total biomass was recorded for all loose live oysters and clusters containing >50% live oysters.

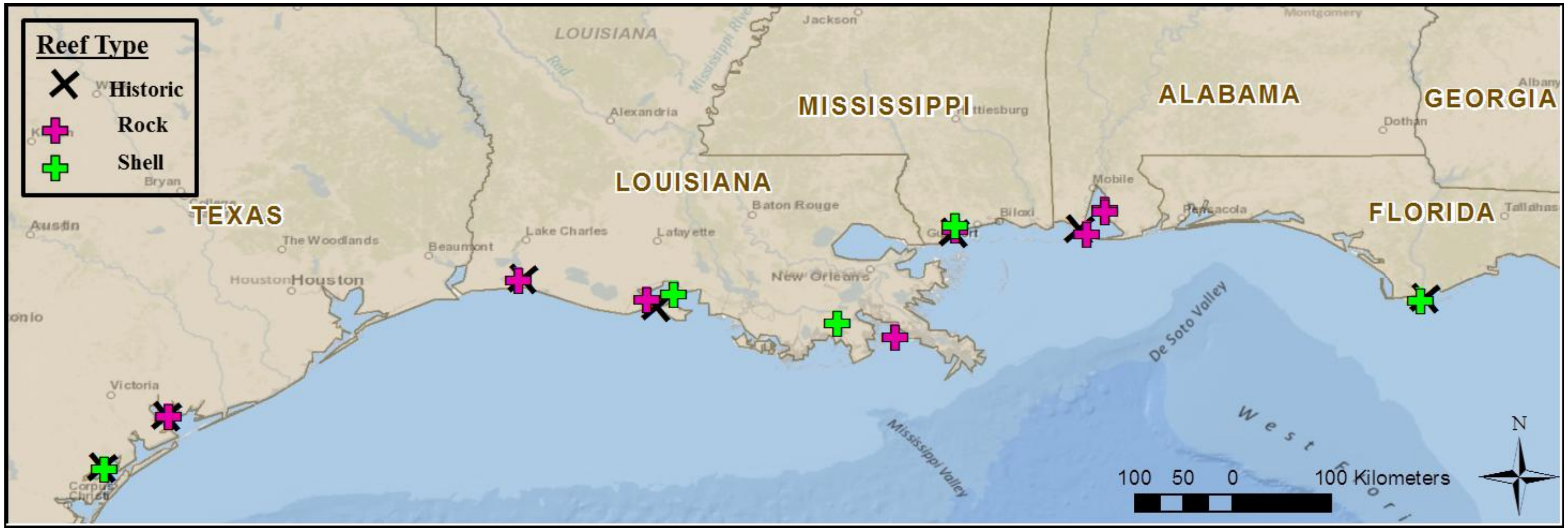


Figure 3.1 Map of northern Gulf of Mexico field study sites. Site abbreviations listed in Table 3.1.

Table 3.1 Reef classifications and locations: "original design" refers to original study design prior to sampling; "study design" refers to reefs actually sampled in this study. Changes from original design included reclassification of one reef due to conflicting substrate samples, and removal of one reef when unable to access it during the spring 2011 flood. Reef abbreviations read as the **M**aterial-**B**ay.

Original Design		Study Design							
Material	**Sampled?**	**Material**	**Installation**	**Reef Abbrev.**	**Reef Name**	**Bay**	**GPS**		**Water Depth (m)**
Historic	yes	Historic	historic	H-CB	Copano Bay Natural Reef	Copano Bay, TX	N28 08.150	W97 04.994	3.0
Historic	yes	Historic	historic	H-KL	Keller Bay Natural Reef	Keller/Lavaca Bay, TX	N28 36.646	W96 29.755	2.1
Historic	yes	Historic	historic	H-CL	Calcasieu Lake Natural Reef	Calcasieu Lake, LA	N29 51.804	W93 14.383	1.8
Historic	yes	Historic	historic	H-VB	Southwest Pass Natural Reef	Vermillion Bay, LA	N29 36.417	W92 01.160	1.2
Historic	yes	Historic	historic	H-SL	Bay St. Louis Natural Reef	Bay St. Louis, MS	N30 16.853	W89 18.120	3.7
Historic	yes	Historic	historic	H-MB	Mobile Bay Natural Reef	Mobile Bay, AL	N30 19.105	W88 09.158	1.8
Historic	yes	Historic	historic	H-AB	Apalachicola Bay Natural Reef	Apalachicola Bay, FL	N29 40.900	W84 00.034	2.1
Rock	yes	Rock	2005	R-KL	Alcoa Reef	Keller/Lavaca Bay, TX	N28 36.252	W96 29.260	3.0
Rock	yes	Rock	2007	R-CL	Calcasieu Oyster Reef 1	Calcasieu Lake, LA	N29 50.954	W93 17.029	2.1
Rock	yes	Rock	2006	R-VB	Redfish Point Reef	Vermillion Bay, LA	N29 40.678	W92 07.125	2.0
Rock	yes	Rock	2004	R-BT	Bay Ronqille Reef	Barataria/Terrebonne Bay, LA	N29 20.035	W89 50.702	1.8
Rock	yes	Rock	2000	R-MB3	Lynn Dent Boykin Reef	Mobile Bay, AL	N30 16.444	W88 05.799	2.6
Rock	yes	Rock	2001	R-MB2	Battles Wharf Reef	Mobile Bay, AL	N30 29.675	W87 55.903	3.0
Rock	yes	Rock	1996	R-MB1	Zundel's Landing	Mobile Bay, AL	N30 28.349	W87 55.574	1.5
Shell	*yes, but concrete	Rock	2005	R-SL	BSL Train Bridge Reef	Bay St. Louis, MS	N30 18.726	W89 18.015	1.8
Shell	yes	Shell	2008	S-CB	TNC Copano Bay Reef	Copano Bay, TX	N28 07.699	W97 04.087	3.0
Shell	yes	Shell	1997	S-BT	Bully Camp Reef	Barataria/Terrebone Bay, LA	N29 27.429	W90 22.668	1.7
Shell	yes	Shell	1991	S-VB	Cypremort Point Artifical Reef	Vermillion Bay, LA	N29 43.356	W91 52.361	2.3
Shell	yes	Shell	2009	S-SL	TNC Bay St. Louis Reef (2009)	Bay St. Louis, MS	N30 20.959	W89 17.624	1.7
Shell	yes	Shell	2006	S-AB	Dry Bar	Apalachicola Bay, FL	N29 40.045	W85 02.600	2.6
Shell	*no, access issues	~~Shell~~	~~1997~~	~~S-RI~~	~~Rabbit Island~~	~~Bayou Sale Bay, LA~~	~~N29 30.567~~	~~W91 33.867~~	~~2.1~~

Foreign substrates, including pieces of concrete, were included in oyster (dead, live, and cluster) volumes and masses when oysters were attached, due to the difficulty of separating the materials. Number of live and dead oysters, by size class, was counted for each sample. Six categories were used for counts: loose live seed-size (≥25 mm, < 75 mm), loose live market-size (≥75mm), loose dead seed-size (>25mm, < 75 mm), loose dead market-size (≥75mm), live spat (<25mm), and box shells. One loose dead oyster was defined as a single shell. Box shells were defined as dead adult oysters (≥25mm) still composed of two shells, open and essentially hollow. Total number of clusters was recorded, and then live seed-size, live market-size, and dead oysters were recorded for individual clusters. Mussel counts were estimated for each sample. Counts for each sample were converted from number per 0.25 m^2 and used in further analyses as densities per 1 m^2.

Two quadrat samples, as available, from each site were used for oyster size measurements. Up to 100 live adults (≥25mm) and up to 100 live spat (<25mm), as available, were randomly selected and measured (mm) within each sample. If less than 10 oysters were available for measurement, an additional quadrat was measured, when possible. Standard length measurements (umbo to distal edge, to the nearest mm) were taken with calipers. Sampling techniques are adapted from studies by Gregalis et al. (2008) and Powers et al. (2009b).

Next, we evaluated reefs as being either fully successful or partially successful. Fully successful referred to reefs that contained live oysters, such that live adult oyster density was > 0 oysters per m^2. Partially successful is defined as reefs that provide hard substrate above bay bottom (hard substrate volume > 0 per m^2). Partially successful reefs present potential reef habitat for nekton, shoreline protection, or oyster recruitment. Even though these criteria are admittedly low, they are a threshold between basic success and failure. If no hard substrate is

provided, the reef can no longer be considered functional; essentially a reef has "failed" and does not exist. The presence of live oysters is a defining point of an *oyster* reef. Reef success, in relation to oysters, typically includes measurements of reef vertical relief, and oyster density, recruitment, abundance, standard length, and biomass for both natural and artificial reefs (O'Beirn et al. 2000, Gregalis et al. 2008, Powers et al. 2009a). Increases in these metrics imply an increase in the ecosystem services they provide; we used these measurements to compare and rank reefs supporting live oysters.

Nekton Sampling

Nekton assemblages were sampled at each reef with a cast net, shrimp trawl, and gill nets to ensure the inclusion of all species and individuals. Two experimental monofilament gill nets (10 m long X 1 m high), each consisting of four 2.5 m long panels of 7.6, 10.2, 12.7, and 15.2 cm (3,4, 5, and 6 inch stretch measurements) mesh were set at each reef for a soak time of one hour. Each end of the net was attached to a cinderblock, so that nets were submerged and held in place; orange floats marked their location. One net was set at the reef edge; the second was set on the reef. Both were set perpendicular to the down-wind/current as best possible. Gill nets were left to soak for one hour, during which time the trawl and cast nets were used. Individuals cleared from gill net were identified to species, weighed, measured for standard length, and returned to the water. Gill net methods were adapted from Lenihan et al. (2001).

A 2.44 m (8 ft.) otter trawl was pulled for one minute adjacent to the reef edge and repeated for a second pull. After each pull, the net was cleared and large (>30 cm) individuals were weighed, measured, and released. Smaller specimens were bagged, euthanized on ice, and returned to the lab where they were identified, weighed, and measured for standard length. Otter trawl methods were adapted from Mann and Harding (1997).

Cast net (2.44 m diameter) throws were repeated seven times on the reef area from standing positions moving around the perimeter of the boat. Specimens were captured, bagged, euthanized on ice, and returned to the lab where they were identified, weighed, and measured for standard length (nearest mm). Any large (>300 mm) individuals were weighed, measured, and released.

Water Quality

Dissolved oxygen (%), temperature ($^{\circ}$C), and salinity (ppt) were recorded with a multiparameter YSI instrument for each site visit. A secchi disk measured water turbidity (cm depth). Chlorophyll a samples were collected in dark bottles, kept on ice, filtered within 48 hours and the filters kept on ice. Samples were sent to a separate lab where chlorophyll a concentration (μg $L^{-}1$) was determined (Appendix Table A.2).

Statistical Analyses of Oyster Populations

Counts of live oysters from loose and cluster subsets were combined within size class, so that seed-size, market-size, and adult live oyster categories were representative of all oysters on the reef, whether loose or in clusters. Counts and volumes of dead shells were not analyzed; it proved impossible to determine for shell reefs if dead shells represented an oyster fatality or a piece of planted shell cultch. Biomass was heavily skewed by the unavoidable inclusion of rock materials (e.g. rocks up 9.7 cm in diameter) in cluster formations and therefore biomass was removed from statistical analyses. Gravel volumes were only relevant to rock reefs and therefore not used in this material comparison study. Mussel densities were not considered for analyses due to inconsistent estimation techniques, and box shells were also removed from further analyses due to their infrequent occurrence.

Correlations between remaining variables (live spat density, live seed-size density, live

market-size density, live adult density, cluster density, cluster volume, loose live oyster volume, hash volume, and hard substrate volume), were examined using Spearman's Rho correlation analysis. Because cluster and loose live oyster volumes were strongly correlated (>0.80) with cluster and live adult densities, respectively, only the density categories were further analyzed. Additionally, due to a strong correlation (>0.80) between live seed-size density and live adult density, only the latter was used for further analyses. Reefs not classified as partially or fully successful were considered "failed" due to their lack of hard substrate and removed from further statistical analyzes. Successful reefs were then considered partially successful or fully successful, and analyzed in these 2 different, overlapping sets.

Partially successful reefs (contained hard substrate) were analyzed for differences between reef types in three hard substrate parameters: (1) cluster density, (2) hash volume, and (3) volume of all hard substrates (inclusive of any material from quadrat samples: hash, clusters, live and dead oysters, gravel, mussels). All three parameters were analyzed separately in a mixed model ANOVA (analysis of variance). The ANOVA model used reef type (historic, shell, rock) as the independent variable and general location (bay) as the random variable. Using bay location as the random variable created a block on the 8 bays, to control possible variation from differences in bay parameters, whether estimated (temperature, salinity, turbidity, etc.) or un-estimated (larval density, flow regime, etc.). Because all selected reefs were located in areas deemed suitable for reef restoration, we assumed that differences in construction technique and materials would override location effects in determining reef success.

Fully successful reefs (containing live adult oysters) were analyzed for differences between reef types in the 3 live oyster parameters. Densities of oysters in each category- spat (<25 mm), market-size (≥75 mm), and adult (≥25 mm; a combination of seed and market-size) – were

analyzed separately. We used the same mixed model ANOVA as we did with partially successful reefs.

Statistical analysis program SAS 9.3 (Proc Mixed) was used with the post-hoc Tukey-Kramer method to discern pairwise differences, when significant differences existed for the overall model. All parameters were log(x+1) transformed to help meet assumptions of normality and homogeneity of variance. Results where alpha=<0.05 were considered significant.

Statistical Analyses of Nekton Assemblages

To determine the effects of artificial reef material on nekton use, we analyzed each gear type separately. Abundance (CPUE), species counts (richness), and diversity (Shannon diversity index [*H'*]) of all reefs were analyzed separately in a mixed model ANOVA (Proc Mixed) with reef type (historic, shell, rock) as the independent variable and general location (bay) as the random variable.

Wilcoxon signed-rank tests were used to compare relative abundances of dominant species between paired reef types (shell and historic, rock and historic, shell and rock) in the same bays. We included any species representing $\geq$ 3% (Gauch 1982) of the abundance in each gear type. This approach allowed us to test for overall material effects, while controlling for date and site variability with the paired experimental design, via the pairing of reefs by sampling date within each bay. Paired tests were only performed when differing reef types existed in the same bay, and therefore, paired tests were performed on a different subset of reefs for each analysis. Three rock and shell reef pairs were available in three bays (Vermillion, Barataria-Terrebone, and St. Louis). Four shell and historic reef pairs were available in four bays (Copano, Vermillion, St. Louis, and Apalachicola). Seven rock and historic reef pairs were available in five bays (Keller, Calcasieu, Vermillion, St. Louis, and Mobile); three pairs used the same historic reef, because it

was paired with each of the three rock reefs in Mobile Bay, separately. Wilcoxon tests were run in SAS 9.3 and all test results where $p \leq 0.05$ were considered significant.

Canonical Correspondence Analysis (CCA) is a direct-gradient analysis that relates community variation patterns to environmental variation. We used CCA (CANOCO version 4.5) to relate nekton assemblage structure to the environmental variations in reef type (shell, rock, historic) and oyster reef provisions (adult oyster density, market-size oyster density, cluster density, hash volume, and hard substrate volume).

The CCA was performed separately on individual gear types, with the same dominant nekton species used in Wilcoxon signed rank tests. Spat density was not considered for inclusion as an oyster reef parameter in this analysis because the fall spat we measured was most likely not set when summer nekton sampling occurred. Water quality covariables (Appendix 2) were included (salinity, temperature, chlorophyll a concentration, Secchi disk depth, water depth, and percent dissolved oxygen). Forward selection was limited to K=4 environmental variables. All species were ln(x+1) transformed and canonical axes were tested for significance with 499 Monte Carlo simulations on the full model.

RESULTS

Oyster Populations

Of the 20 reefs sampled, 15 were fully successful (live adult oysters >0 oysters m^2), and those 15 plus two more reefs (total 17) were partially successful (hard substrate volume >0 liters per m^2), and the remaining three reefs were “failed” (Table 3.2).

Table 3.2 Success of individual reefs and associated criteria. Fully successful reefs contain live densities >0 oysters per m^2, and includes density size categories adult (≥25 mm), market-size (≥75 mm) - also included with adult, and spat (<25 mm). Partially successful reefs contain hard substrate volume >0 liters per m^2, and includes hard substrate (inclusive of any material from quadrat samples: hash, clusters, live and dead oysters, gravel, etc.), shell hash (fragmented shell), and cluster density (count of 1 = ≥3 oysters attached to one another, whether dead, live, or a combination) *Indicates fully successful reefs with only spat and no live adult oysters.

				Live Oysters = Fully Successful						**Substrate = Partially Successful**					
				Adult Density		**Market-size Density**		**Spat Density**		**Hard Substrate Vol.**		**Cluster Density**		**Shell Hash Vol.**	
Bay	**Reef**	**Material**	**Successful?**	**Mean (no. m^{-2})**	***SE***	**Mean (no. m^{-2})**	***SE***	**Mean (no. m^{-2})**	***SE***	**Mean (Liter m^{-2})**	***SE***	**Mean (no. m^{-2})**	***SE***	**Mean (Liter m^{-2})**	***SE***
Copano	H-CB	Historic	Fully	136	*60.9*	7.2	*2.9*	555.2	*180.6*	27.54	*3.4*	15.2	*8.6*	3.3	*1.0*
	S-CB	Shell	Fully	42.4	*26.9*	2.4	*1.6*	1.6	*1.6*	6.72	*3.3*	5.6	*3.5*	0.29	*0.1*
Keller/Lavaca	H-KL	Historic	Fully	175.2	*58.2*	46.4	*25.1*	52.8	*25.4*	18.96	*6.5*	19.2	*5.4*	0.49	*0.2*
	R-KL	Rock	Fully	304.8	*43.1*	16	*5.8*	87.2	*38.0*	40.11	*3.7*	42.4	*4.8*	0.29	*0.1*
Calcasieu	H-CL	Rock	Fully	95.2	*17.1*	8	*4.2*	13.6	*9.9*	10.55	*3.5*	6.4	*3.7*	0.19	*0.1*
	H-C	Historic	Partially	0	*0.0*	0	*0.0*	0	*0.0*	0.4	*0.4*	0	*0.0*	0	*0.0*
Vermillion	S-VB	Shell	Failed	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*
	R-VB	Rock	Fully	0.8	*0.8*	0.8	*0.8*	0	*0.0*	7.09	*3.0*	0	*0.0*	0	*0.0*
	H-VB	Historic	Fully	2.4	*1.6*	0	*0.0*	0	*0.0*	17.01	*2.3*	37.6	*5.7*	1.09	*0.4*
Barataria-Terrebon	S-BT	Shell	Fully	5.6	*2.4*	0	*0.0*	0	*0.0*	7.97	*2.5*	7.2	*1.5*	0.29	*0.1*
	R-BT	Rock	Partially	0	*0.0*	0	*0.0*	0	*0.0*	5.66	*1.9*	1.6	*1.6*	0.49	*0.2*
StLouis	R-SL	Rock	Fully	217	*91.5*	9	*7.7*	2.4	*2.4*	40.5	*9.2*	44.8	*12.2*	0.29	*0.1*
	S-SL	Shell	Failed	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*
	H-SL	Historic	Fully	4	*3.1*	0	*0.0*	0	*0.0*	19.39	*5.2*	2.4	*1.6*	2.2	*0.5*
Mobile	R-MB3	Rock	Fully	20.8	*1.5*	11.2	*2.0*	0	*0.0*	9.48	*1.3*	0.8	*0.8*	0	*0.0*
	R-MB1	Rock	*Fully	0	*0.0*	0	*0.0*	0.8	*0.8*	1.71	*1.1*	0	*0.0*	0.1	*0.1*
	R-MB2	Rock	*Fully	0	*0.0*	0	*0.0*	0.8	*0.8*	13	*3.5*	4	*1.8*	0.39	*0.2*
	H-MB	Historic	Fully	15.2	*8.3*	1.6	*1.0*	0	*0.0*	11.29	*2.4*	4	*2.2*	1.3	*0.3*
Apalachicola	S-AB	Shell	Failed	0		0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*
	H-AB	Historic	Fully	21.6	*10.6*	3.2	*2.3*	319.2	*94.2*	13.36	*4.5*	6.4	*3.0*	1.7	*0.7*

The three failed reefs (S-VB, S-SL, S-AB) lacked hard substrate above the mud-bottom, and being essentially non-existent, they were considered functionally extinct. All three of the failed reefs were artificial reefs created with shell material. Pole strikes on these reefs returned only "semi-hard" strikes, suggesting buried substrate.

Divers found no sign of reef S-VB, an old shell reef, listed by Louisiana Department of Wildlife and Fisheries, placed in 1991. Adult oyster shells and/or clam shells (all dead) were dug from the mud soft bay bottom by divers at S-SL and S-AB indicating burial of these newer shell reefs (2009, 2006).

Two reefs were considered only partially successful, with hard bottoms and no live oysters (R-BT and H-CL). Reef H-CL was a historic reef indicated on fishing maps in Calcasieu Lake, LA, and typically laced with crab traps, but primarily consisted of patches of clam shell, while R-BT was a reef created with limestone in 2004 in Barataria Bay, LA. The remaining 15 reefs were fully successful; all had live oysters, but two only had spat despite being 11 and 15 years old (R-MB2 and R-MB1).

The ANOVAs on the 15 fully successful reefs found spat density ($p=0.0016$) and adult density ($p=0.0459$) differed significantly between reef material. Specifically, adult density was significantly greater at rock ($p=0.0354$) than shell reefs, and historic reefs did not differ from the artificial reefs (Figure 3.2). Spat density was significantly greater at rock ($p=0.0077$) and historic ($p=0.0010$) reefs as compared to shell reefs (Figure 3.3). Market density did not differ between reef materials.

Seventeen reefs were considered at least partially successful by providing hard substrate for potential oyster settlement, shoreline protection, and nekton habitat. Material effects examined with ANOVAs in partially successful reefs showed significant differences in hash volume ($p=<0.0001$), hard substrate volume ($p=<0.0001$), and cluster density ($p=0.0430$). Hash volume was significantly greater at historic reefs than rock ($p=<0.0001$) and shell ($p=<0.0001$) reefs, which did not differ from one another (Fig. 3.4). Hard substrate volume was significantly higher at historic ($p=<0.0001$) and rock ($p=<0.0001$) reefs than shell reefs (Fig. 3.5). Cluster density was significantly higher at historic ($p=0.0409$) and rock ($p=0.0487$) reefs than shell reefs (Fig. 3.6).

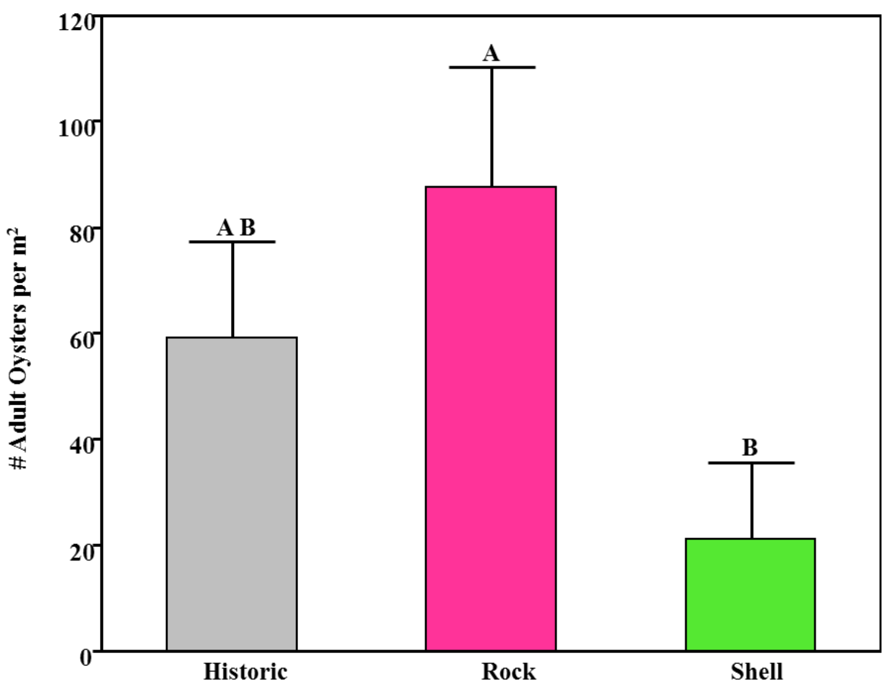


Figure 3.2 Densities (mean +1 SE) of live adult ($\geq$25 mm) oysters in three different types of fully successful reefs. Letters denote significant differences ($p\leq 0.05$,Tukey-Kramer)

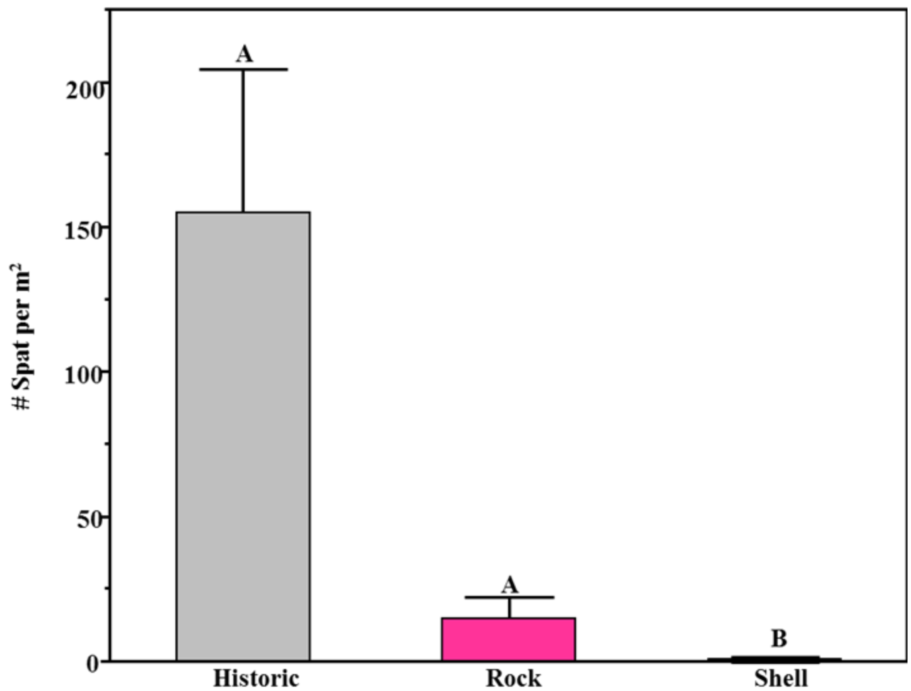


Figure 3.3 Densities (mean +1 SE) of oyster spat ($\geq$25 mm) in three different types of fully successful reefs. Letters denote significant differences ($p \leq 0.05$,Tukey-Kramer)

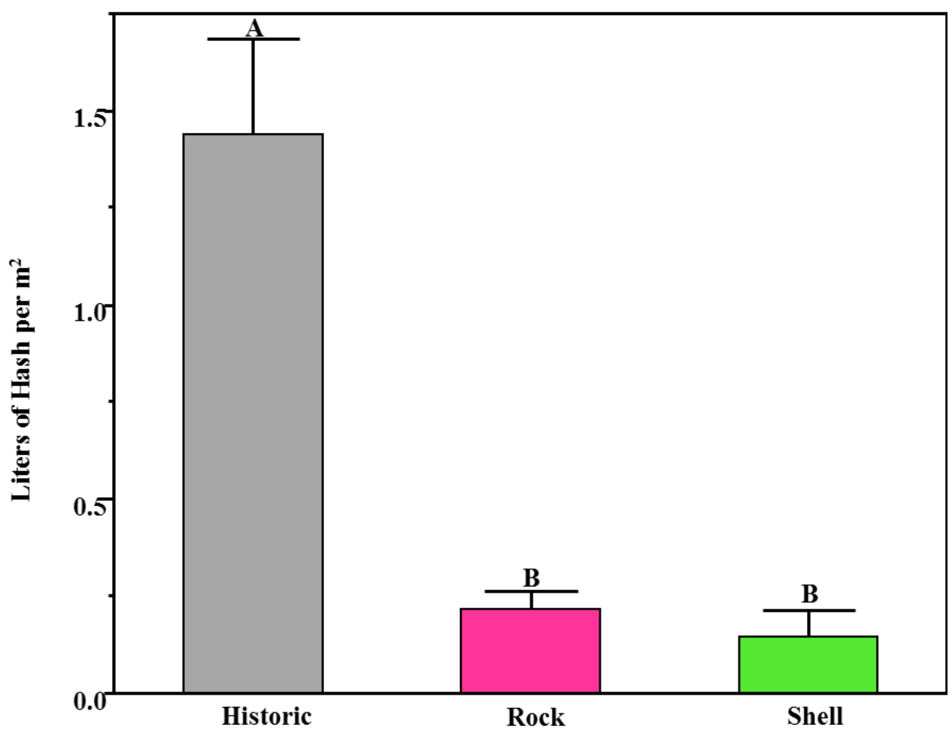


Figure 3.4 Volumes (mean +1 SE) of hash (broken shell) for three different types of partially successful reefs. Letters denote significant differences ($p \leq 0.05$,Tukey-Kramer)

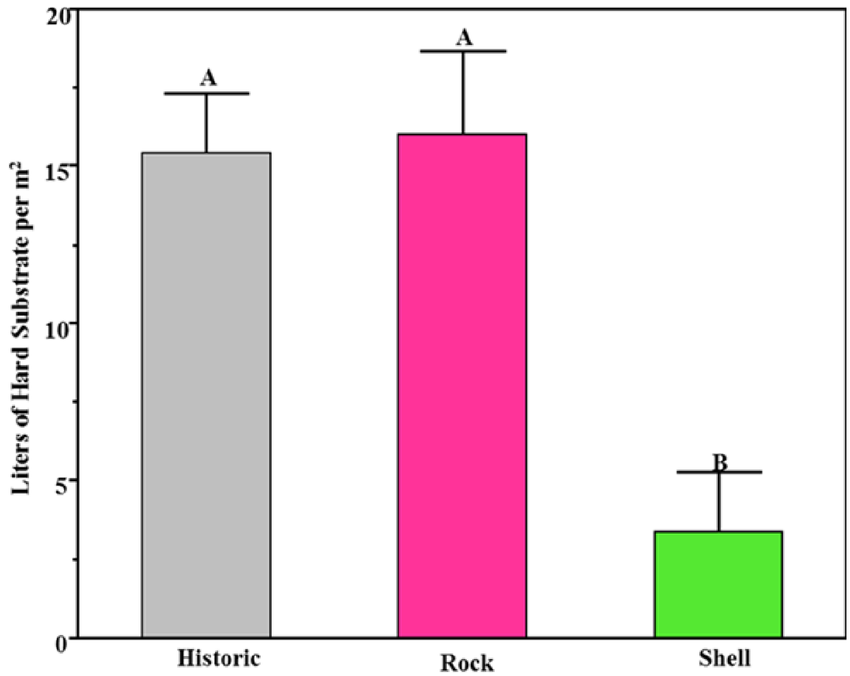


Figure 3.5 Volumes (mean +1 SE) of hard substrate for three different types of partially successful reefs. Letters denote significant differences ($p \leq 0.05$,Tukey-Kramer).

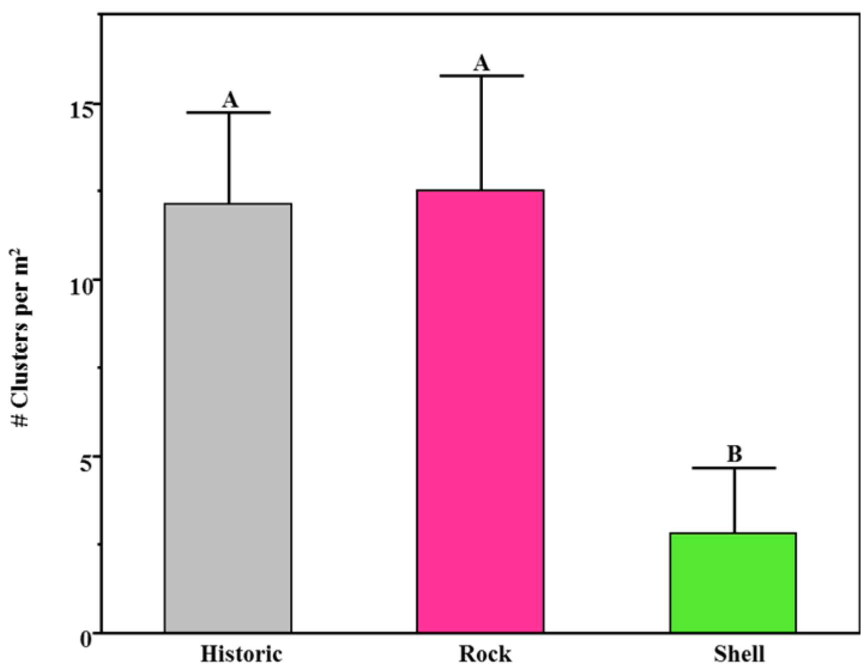


Figure 3.6 Volumes (mean +1 SE) of oyster clusters ($\geq$3 attached oysters, whether dead, live, or combination) for three different types of partially successful reefs. Letters denote significant differences ($p \leq 0.05$,Tukey-Kramer)

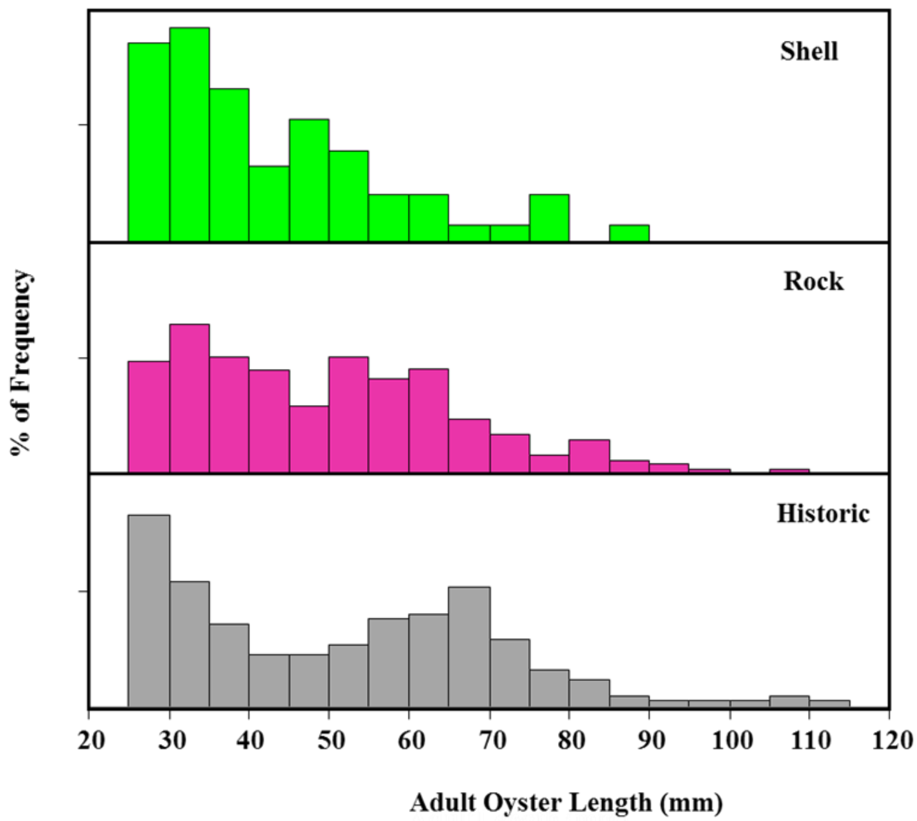


Figure 3.7 Adult length (mm) frequency distributions by reef type.

Nekton Assemblages

A total of 2081 nekton individuals of 42 species were collected. Gillnet catches included 217 individuals of 24 species, trawl catches included 815 individuals of 27 species, and castnet catches included 1055 individuals of 19 species (Appendix Table A.1). One individual cast (Reef R-SL) had an outlier quantity of 574 that was not used in further analyses; all other samples across gear types were included. In the ANOVA with all 20 reefs, no significant differences were found across all reef types and gear types, for nekton abundance, richness, or diversity.

Table 3.3 Mean ±1 SE abundance (CPUE), species counts (richness), diversity (Shannon-Wiener index), and ANOVA test results (p-value) for all reefs, separated by gear type.

	Historic			Rock			Shell			P-value
Gillnet (n=158)										
CPUE	1.38	±	*0.27*	1.53	±	*0.26*	0.98	±	*0.29*	0.0820
Richness	0.91	±	*0.16*	0.92	±	*0.14*	0.65	±	*0.16*	0.2427
Diversity (H')	0.33	±	*0.08*	0.31	±	*0.07*	0.17	±	*0.07*	0.2857
Castnet (n=559)										
CPUE	0.61	±	*0.11*	1.02	±	*0.22*	0.96	±	*0.22*	0.5373
Richness	0.30	±	*0.04*	0.37	±	*0.04*	0.34	±	*0.04*	0.8694
Diversity (H')	0.06	±	*0.02*	0.06	±	*0.02*	0.03	±	*0.01*	0.1442
Trawl (n=158)										
CPUE	5.88	±	*1.53*	5.42	±	*0.93*	3.75	±	*1.01*	0.4263
Richess	1.66	±	*0.26*	1.60	±	*0.24*	1.30	±	*0.21*	0.9837
Diversity (H')	0.58	±	*0.10*	0.55	±	*0.10*	0.41	±	*0.10*	0.6445

Table 3.4 Wilcoxon signed-rank test results comparing relative abundances of dominant species (≥3% abundance within gear type) between reef types paired by bay and sampling date. Each paired subset was analyzed separately: paired shell reefs and historic reefs (Shell/Historic), paired rock reefs and historic reefs (Rock/Historic), and paired shells reefs and rock reefs (Shell/Rock). Significant p-values (≤0.05) are in bold.

Gear	Species	Abbrev.	Shell/Historic	Rock/Historic	Shell/Rock
Gillnet	*A. felis*	AF	0.1484	0.1760	0.3750
	B. marinus	BM	0.9698	0.6204	0.6826
	B. patronus	BP	0.5547	0.1619	0.7188
	C. leucas	CL	0.5000	**0.0371**	**0.0078**
	C. nebulosus	CN	.	0.6250	0.1250
			(n=32)	(n=56)	(n=22)
Castnet	*A. felis*	AF	**0.0178**	0.1665	0.6250
	A. mitchilli	AM	0.4811	**0.0432**	0.0978
	B. marinus	BM	0.1250	0.5625	0.1250
	B. patronus	BP	1.0000	0.4195	**0.0459**
	F. aztecus	FA	0.6250	0.7500	0.3633
	M. martinica	MM	1.0000	**0.0156**	0.1250
			(n=112)	(n=195)	(n=83)
Trawl	*C. aernerius*	CA	0.3750	0.7266	**0.0469**
	F. aztecus	FA	0.1917	0.1858	0.1381
	L. xanthurus	LX	**0.0195**	0.7656	**0.0156**
	M. undulatus	MU	0.1563	0.1822	0.0527
	P. pugio	PP	0.5000	0.8047	.
			(n=32)	(n=56)	(n=22)

Using Wilcoxon signed rank tests, significant differences in dominant species abundance were found in each set of paired reefs in each gear type (Table 3.4). In paired historic and artificial reefs, all significant differences occurred when species abundances were greater at artificial reefs, whether shell or rock (Figures 3.7, 3.9, & 3.11). Abundance of *C. leucas*, caught in gillnets, was significantly greater (p=0.0371) at rock than historic reefs, and at shell than the paired historic reefs (0.0078). Abundance of *A. felis*, caught in castnets, was significantly greater (p=0.0178) at shell than historic reefs; abundances of *A. mitchilli* (p=0.0432) and *M. martinica* (p=0.0156) were significantly greater at rock reefs. In trawl catches, abundance of *L. xanthurus* was significantly greater (p=0.0195) at shell than historic reefs.

In paired rock and shell reefs, the abundance of *B. patronus*, caught in castnets, was significantly greater at rock reefs. Abundance of *L. xanthurus*, caught in trawl pulls, was significantly greater (p=0.0156) at shell than rock reefs, while abundance of *C. arenarius* was greater (p=0.0469) at rock than shell reefs. Wilcoxon signed rank paired tests were only used on reefs in the same bays, therefore affecting sample size used for each comparison. Pairs available by bay groupings allowed for 3 shell/rock pairings, 4 shell/historic pairings, and 7 rock/historic pairings. This smaller selection of reefs for Wilcoxon signed rank analyses is in contrast to the CCA and ANOVA results, which represent all (n=20) study reefs.

Within gillnet samples, forward selection of environmental variables for CCA analysis showed that cluster density (F=5.79, p=0.0001) and rock reef (F=2.48, p=0.0370) were statistically significant. The first 2 axes represented 91.1% of the species-environment relationship. Axis 1 was correlated most strongly with rock (0.46) and shell (-0.37) artificial reef materials. Axis 2 correlated positively with shell hash volume (0.31). The significant species, *C. leucas*, from Wilcoxon signed rank paired rock reef tests was associated positively with

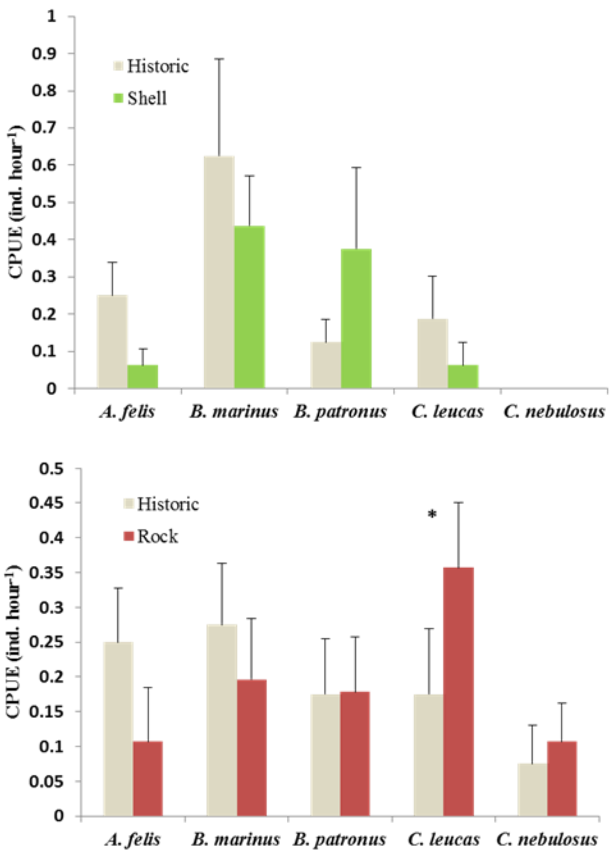
cluster density (Figures 3.7 & 3.8), and *B. marinus* was associated with shell reefs.

Within castnet samples, forward selection of environmental variables for CCA analysis showed that live adult oyster density (F=3.33, p=0.0100), hard substrate volume (F=2.93, p=0.0200) and historic reef (F=3.40, p=0.0060) were statistically significant. The first 2 axes represented 82.5% of the species-environment relationship. Direct axes correlations were not very strong, although Axis 1 correlated primarily with hard substrate volume (-0.25), and Axis 2 with live adult oyster density (-0.29) and shell reef (-0.23). The species *M. martinica*, which showed significance in Wilcoxon signed rank paired rock reef tests, was associated positively with hard substrate volume and adult oysters (Figures 3.9 & 3.10).

Within trawl samples, forward selection of environmental variables for CCA analysis showed that shell reef (F=7.15, p=0.0020) was statistically significant. The first 2 axes represented 91.4% of the species environment relationship. Axis 1 represented 73.8% itself, and was positively correlated with shell reef (0.47). Axis 2 was correlated with hard substrate volume (0.22). The species *L. xanthurus*, which showed significance in Wilcoxon signed paired shell reef tests, was associated positively with shell reefs (Figures 3.11 & 3.12).

Table 3.5 Inertia and eigenvalues of Canonical Correspondence Analyses (Figures 3.8, 3.10, & 3.12) by gear type.

Gear Type	**Total inertia**	**Eigenvalue**	**Canonical Eigenvalue**
Gillnet	2.219	1.706	0.257
Castnet	4.598	3.966	0.344
Trawl	1.668	1.327	0.175



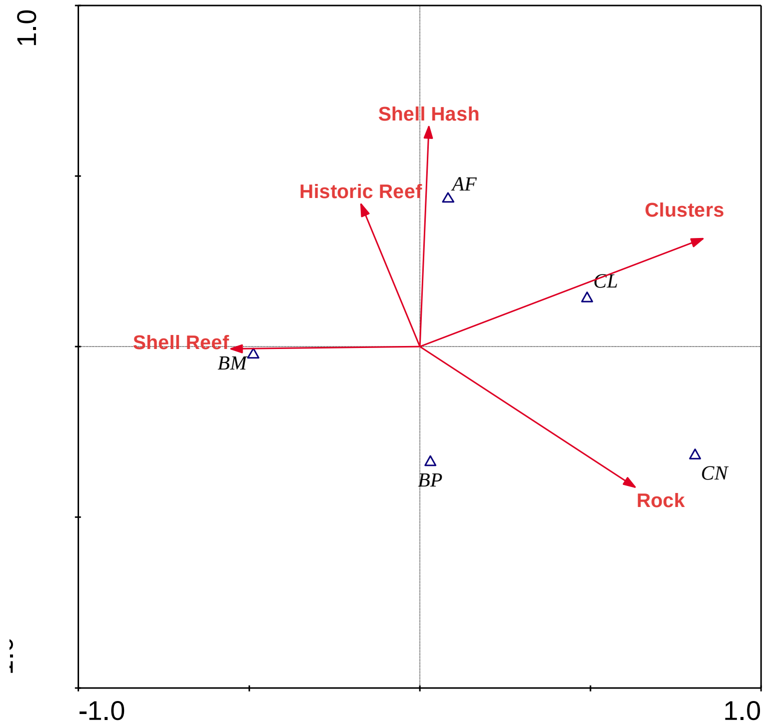
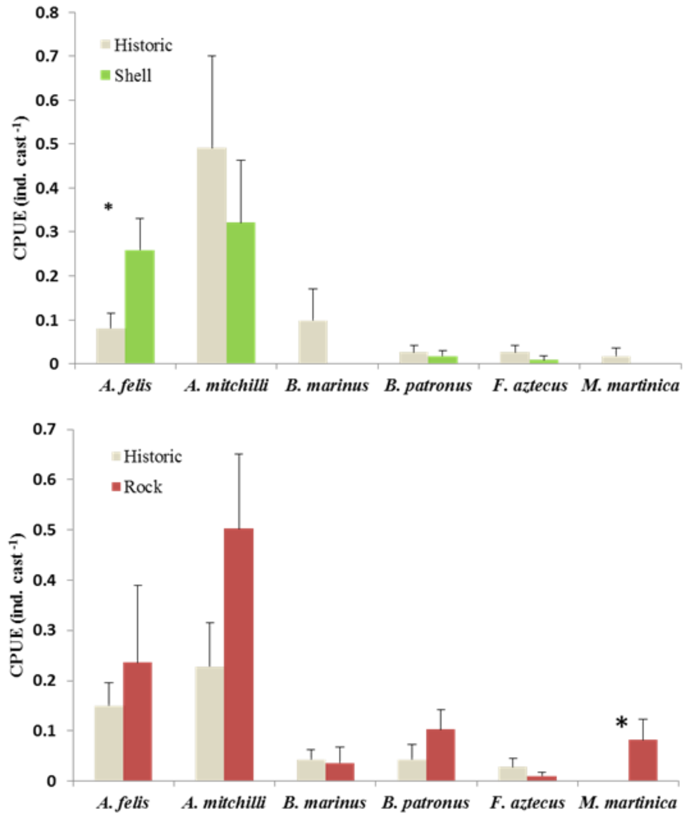


Figure 3.7 (left). Abundances (Catch Per Unit Effort mean+1 SE) of dominant nekton species (≥3% abundance) in gillnet gear type between shell and historic reefs, and rock and historic reefs. Significant differences (*) of $p \leq 0.05$ are from Wilcoxon signed rank tests using reefs paired by bay and sampling date.

Figure 3.8 (right). Association of dominant nekton species, with reef type (shell, hash, historic) and oyster reef (adult density, cluster density, hash volume, hard substrate volume) environmental characteristics from a canonical correspondence analysis (CCA) for gillnet catch. Species abbreviations are first letters of genus and specific epithet..



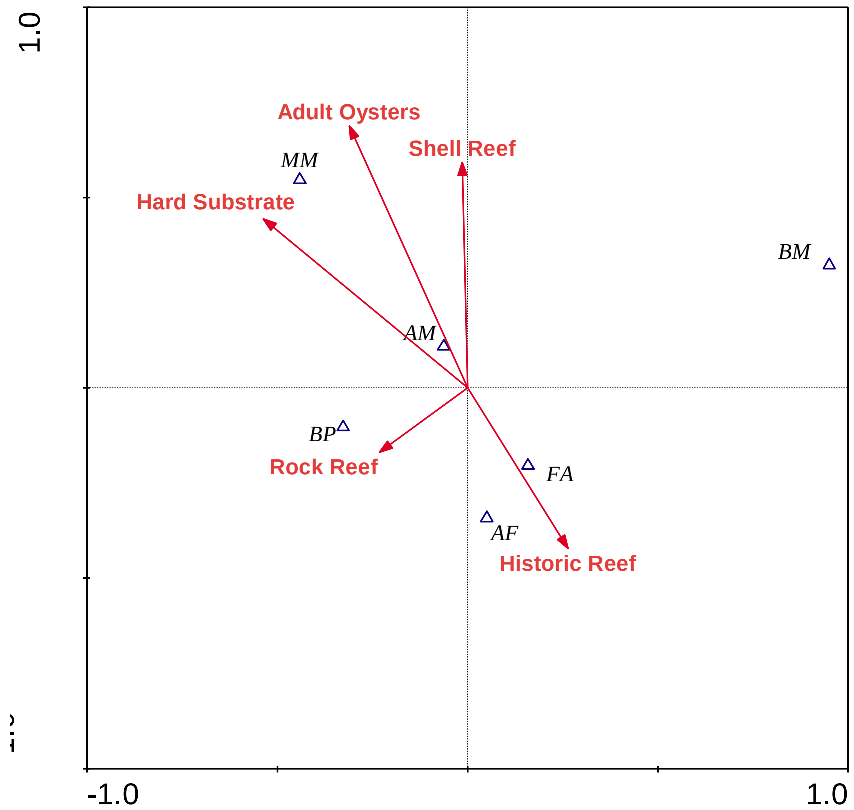
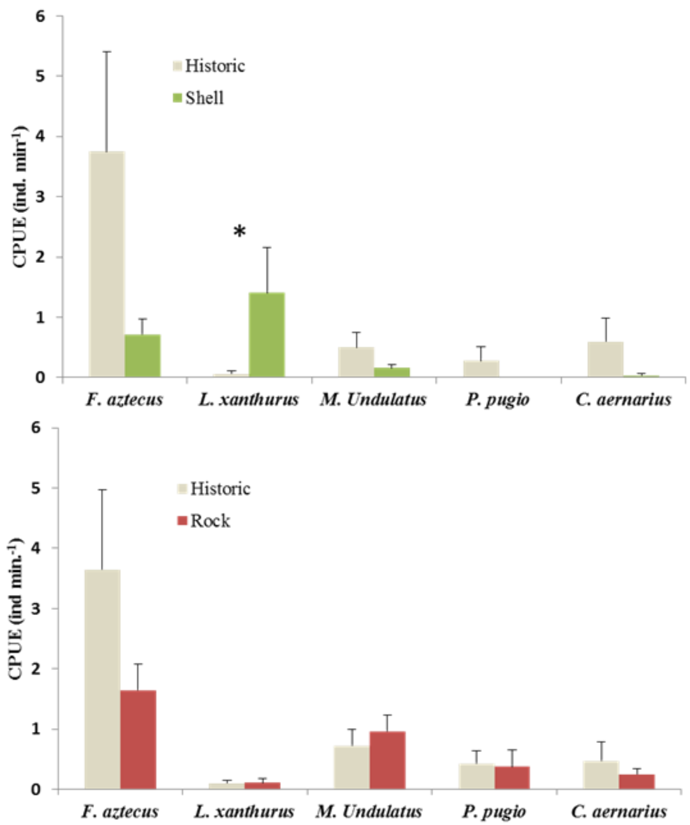


Figure 3.9 (left). Abundances (<u>C</u>atch <u>P</u>er <u>U</u>nit <u>E</u>ffort mean+1 SE) of dominant nekton species (≥3% abundance) in castnet gear type between shell and historic reefs, and rock and historic reefs. Significant differences (*) of p≤0.05 are from Wilcoxon signed rank tests using reefs paired by bay and sampling date.

Figure 3.10 (right). Association of dominant nekton species, with reef type (shell, hash, historic) and oyster reef (adult density, cluster density, hash volume, hard substrate volume) environmental characteristics from a canonical correspondence analysis (CCA) for castnet catch. Species abbreviations are first letters of genus and specific epithet.



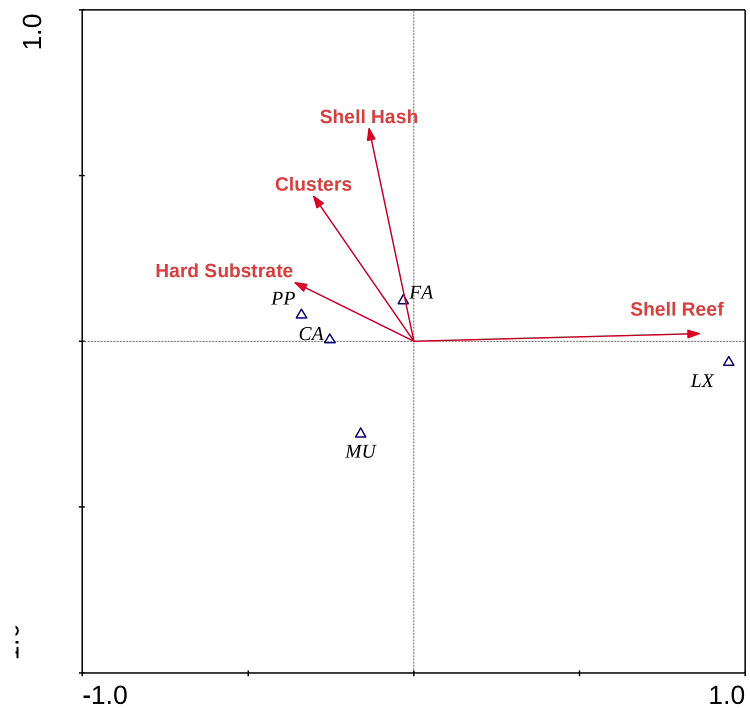


Figure 3.11 (left). Abundances (Catch Per Unit Effort mean+1 SE) of dominant nekton species (≥3% abundance) in trawl gear type between shell and historic reefs, and rock and historic reefs. Significant differences (*) of p≤0.05 are from Wilcoxon signed rank tests using reefs paired by bay and sampling date.

Figure 3.12 (right). Association of dominant nekton species, with reef type (shell, hash, historic) and oyster reef (adult density, cluster density, hash volume, hard substrate volume) environmental characteristics from a canonical correspondence analysis (CCA) for trawl catch. Species abbreviations are first letters of genus and specific epithet.

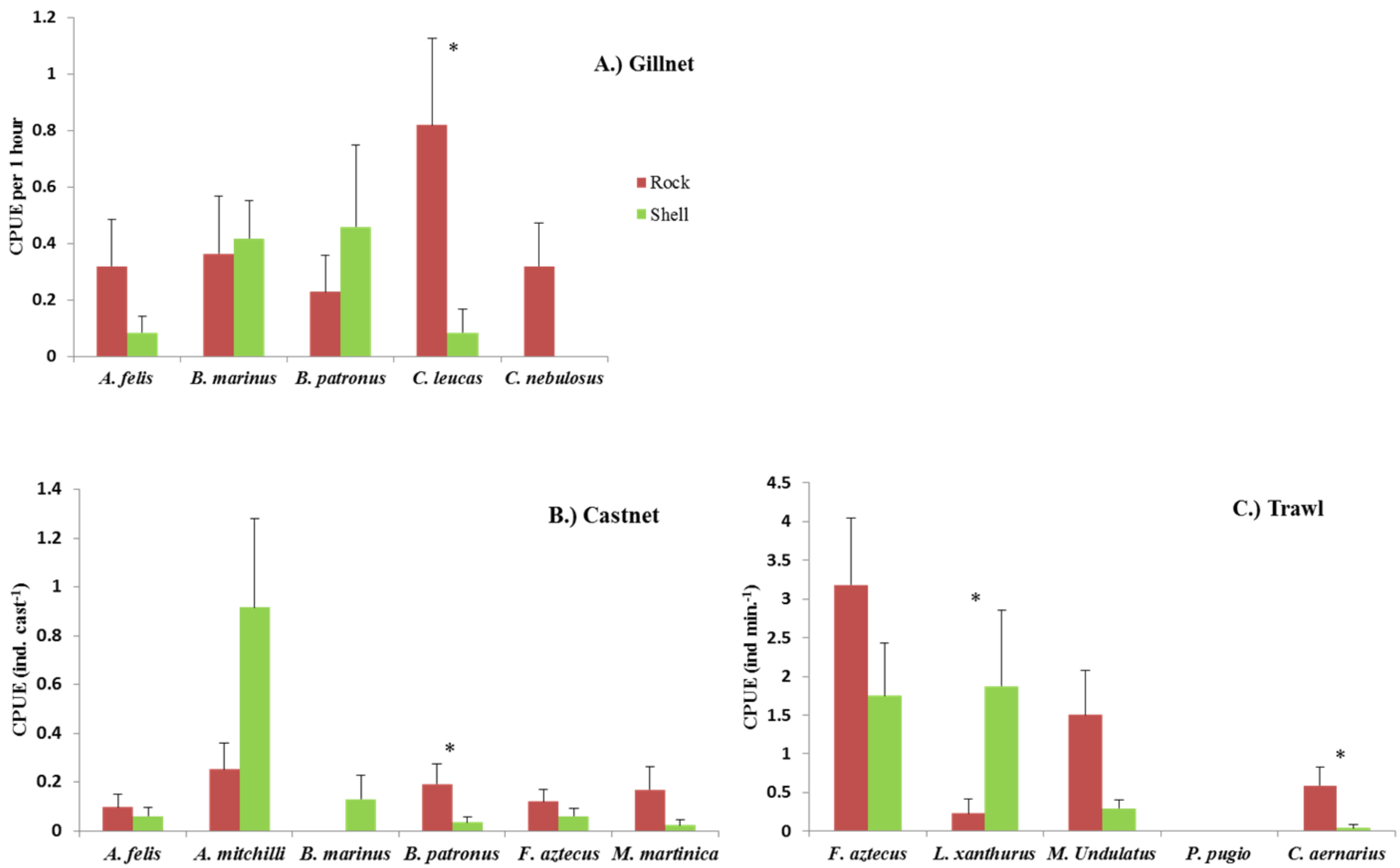


Figure 3.13 Abundances (Catch Per Unit Effort mean+1 SE) of dominant nekton species ($\geq$3% abundance) in A.) gillnet, B.) castnet, and C.) trawl gear types between rock and shell reefs. Significant differences (*) of $p\leq0.05$ are from Wilcoxon signed rank tests using reefs paired by bay and sampling date.

DISCUSSION

Artificial oyster reefs created with a base layer of what we call rock (limestone or concrete) materials consistently and significantly outperformed shell artificial reefs in our study. The reason(s) for the difference between materials is unclear, but clear disparities in reef success were evident. Three 3 (S-VB, S-SL, S-AB) of five shell reefs failed to provide hard substrate above bay bottom and were considered “failed”, as they were functionally extinct. These failed reefs were located in bays (Vermillion, St. Louis, Apalachicola) where other reefs, either historic or both rock and historic, were fully successful. This finding is in contrast to the evaluation of reef success in no-harvest sanctuaries by Powers et al. (2009) in North Carolina, where some sanctuaries contained all failed reefs, and suggests effects in our study from either reef design or small-scale location environmental differences.

Success Determinants

Placement specific location effects, working on a scale small enough to undermine our (statically blocked or paired) bay groupings, may be capable of failing a single reef within a bay where other reefs maintain live adult oyster populations, as a result of variations in flow regimes, protection via shoreline proximity, and other variables not considered. When viewed by bay, general trends are seen in total live adult density, where historic reefs and rock artificial reefs have similar relatively high (Keller Bay) or low (Vermillion Bay, Mobile Bay) densities, presumably as a result of their bay environment (Table 3.2). A noticeable break from the trend is Bay St. Louis in Mississippi where the rock reef adult live densities are far higher ($>200/m^2$) than the historic ($<10/m^2$). Site specific location effects may be a factor, considering the historic reef is located just outside the mouth of the bay and the rock reef just within, where it may be exposed to more Gulf offshore associated environmental variables such as stronger currents and a higher salinity. Additionally, the historic reef is commercially harvested while the rock reef

currently is not. Harvesting pressures not only remove larvae producing adults oysters from populations, but alter how the reef interacts with its environment, including fauna and flow, as a result of changes in reef structure (Breitburg et al. 2000).

Reef design choices, including materials, relief, layout, and structural complexity, can affect how a reef interacts with its environment. Higher reliefs are shown to increase recruitment and survival, specifically at their crest, presumably by providing oysters areas of higher flow velocity and consistently higher levels of dissolved oxygen (Lenihan 1999, Knights and Walters 2010). Increased flow supplies a higher quality of suspended food materials, increases resistance to disease and parasites, and can result in higher recruitment and growth (Lenihan 1999, Lenihan et al. 1999). Only one reef (R-KL) in our study is known to have been laid with stipulations for relief despite considerable recent attention examining its benefits along the Atlantic coast (Hargis Jr. et al. 1999, Coen and Luckenbach 2000, O'Beirn et al. 2000, Gregalis et al. 2008, Gregalis et al. 2009, Powers et al. 2009b). The rock reef was laid with plans stipulating relief to be 6-12 inches after limestone settled as part of mitigation processes with the company Alcoa (2006). Additionally, the layout of reef R-KL entails ridges of limestone with spaces of relatively open water between, for a ridge and swail effect visible through the water on GoogleEarth™. Reef R-KL is fully successful- supporting the highest mean live adult density of any reef in our study- and shares Keller Bay, TX with a historic reef (H-KL), also supporting high densities of live adults (Table 3.2). Both reefs also displayed high spat densities, suggesting that environmental conditions provided by location, reacted similarly with the historic and artificial reef. The rock reef's considerations of design, using limestone placed with high relief and a variable layout, definitely did not impede success. Considering design and relief for other study reefs proved difficult. Reports of relief, neither as initial design nor "as built" post-construction records, were

unavailable for all other reefs. Only 6 artificial reefs had records on area (0.15 – 15 acre range) and since quadrats were taken with no spatial specifications (samples taken an estimated 20-100 meters apart, depending on drifting conditions) variations throughout the reef may or may not have been reflected in our samples. Patchiness in a reef has not been shown to significantly affect reef habitat benefits, but patch size threshold is expected to occur at some point (Harwell et al. 2011).

Personal communications suggested shell material may have been spread further than originally planned to increase the reported acreage footprint on shell reef S-CB. Extremely low spat densities on this shell reef, S-CB, were strikingly different from the control reef (H-CB) in the same bay (Copano Bay, TX), which had the highest mean spat density of all 20 surveyed reefs. Again, factors attributing to such a phenomenon typically involve placement specific environmental variations, like flow regime, and/or design affects. The potentially detrimental effects of anoxic and hypoxic conditions on oyster settlement and recruitment (Baker and Mann 1992) could be present due to low flow and lack of mixing on the relatively deep (3m) reef. Conversely, an energetic environment could cause lightweight shell to be silted over, especially if the material is shifting in sand or mud and spread thin (Lukens and Selberg 2004) Even if not buried, coverings of sediment or bio-fouling organisms will negatively affect recruitment (Thomsen and McGlathery 2006).

Oysters were sampled over a 6 week period, and spat recruitments can vary temporally within this timeframe. Examining recruitment, in this study, on reefs in different bays can become difficult very quickly with this spread in collection dates. Some sites may have recruited earlier and quickly growing spat may have already reached adult lengths (>25mm). Spat examinations are also compounded by metapopulation connectivity and dynamics (Lipcius

et al. 2008), a large and small scale spatial consideration.

Materials used for reef construction, and their intrinsic properties, are inevitably linked to reef success. Our 3 failed shell reefs may not exist today due to a number of reasons, many of which are mentioned in grey literature like management plans. For example, the "Guidelines for Marine Artificial Reef Materials" by The Gulf and Atlantic States Marine Fisheries (Lukens and Selberg 2004), lists several "drawbacks" for shell. While peer reviewed literature is cited throughout the document, personal communications with managers also adds perspective and aids in the guidelines. The document states that a minimum profile of one and a half feet is needed to insure the permanence of a reef because lower profile reefs may result in shell material being buried by siltation. We do not know the original relief of our reefs, and if it affected their outcome. Additionally, caution is placed on shell reefs in moderate to high energy situations, especially if the substrate is shifting sand or mud and it is probable that our failed reefs succumbed to their loose and lightweight nature in energetic environments and became scattered by waves or silted over. Due to the concave shape of shell, the material most likely interacts differently with flow than other materials, and may catch and cup sediment in a way that can inhibit recruitment. Lukens and Selburg (2004) also state, without specific reasons, that it is important to time shell reef deployment with spat fall. We hypothesize timing is important for recruitment to occur before sediment and algal growth inhibit settlement, as seen by Thomsen and McGlathery (2006), and to begin building the reef to maintain relief. Lost relief, interstitial spaces, and functionality of shell may result from the fact that shell can 'hash' or break and compact, or shift in the bay, or also possibly in road transit to the site or during construction (Lukens and Selberg 2004, Powers et al. 2009b). Although shell reefs are preferred for trawling because they tend not to tear nets, it is highly likely that trawls negatively impact reefs as they

may further scatter and bury shell materials. As evidenced by the fully successful 15 year old shell reef S-BT, shell material may prove more successful in locations not subject to trawling and offering wave protection through shallow water (<2 m) and shoreline proximity.

Three fully successful rock reefs in Mobile Bay have maintained structure with their concrete materials, despite being 12-15 years old. The heavy, durable, typically bulky nature of concrete is better adapted to resist even hurricane forces in energetic environments; it has also been shown to last in seawater for at least 30 years (Lukens and Selberg 2004). Two of these reefs (R-MB1, R-MB2), however, were considered fully successful without any live adult oysters. This loophole of achieving full success by containing only spat, is a caveat to our very basic success standards. The reefs are marked with signs on pilings for recreational fishing and may provide nekton habitat in lieu of live oyster ecosystem services and, assumedly, the proper environmental conditions for oysters to grow. Reef MB-1 proved difficult to represent properly in our study, because the hard substrate it provided was a flat, molded, foundation-like slab of concrete that could not be collected for measurement. The design of the reef, however, provided considerably less refuge for nekton than clusters or other variable structures. Other rock artificial reefs were loose like shell, but composed of crushed limestone, with a weight and size heavy enough to resist and allow for flow over its surface (Turner et al. 1969), yet also capable of sinking if spread too thin. However, maintaining relief is possible if laid with considerations of settling effects, as displayed by the fully (and highly) successful 6 year old reef, R-KL.

Success Implications

When goals are not identified for oyster reef restoration, criteria and methods for determining success are not specifically directed. We therefore had to set our own criteria, and defined reefs as fully successful when there was evidence of a sustainable oyster population (live

oysters). Although general and minimal criteria, the presence of live oysters is a defining point of an oyster reef, but also implies sustainability. Adult oysters are preferable because their presence suggests reef materials and placement were appropriately chosen, and may restore ecosystem services associated with water filtration and act as a harvestable commodity, along with partially successful benefits. The ideal provision of long-term success is based on the assumption that oysters will settle, grow, and recruit more oysters, essentially maintaining a viable population and thus sustaining the reef and ecosystem services. Our criteria set a low threshold between basic success and failure, but also allowed for the consideration that a reef can still be functional, despite a lack of live oysters.

Partially successful reefs provided hard structure (in areas without natural hard structure) allowing for ecosystem services like spawning, feeding, and refuge habitat for nekton (Coen et al. 2007, Harwell et al. 2011, Humphries et al. 2011). The relatively lower diversity of nekton seen on shell reefs, as compared to rock and historic reefs (Table 3.4), could be a small reflection of the absence of hard structure habitat found in a majority (60%) of our shell reefs, but it was not significantly different. Paired comparisons of dominant species abundance between shell and historic reefs included only one fully successful shell reef (the other 3 being failed) in a set of 4, yet the two significant differences for this set appeared when shell reefs had higher abundances (species *L. xanthurus* and *A. felis*). The bottom feeding nature of these species, common names being spot croaker and hardhead catfish, may suggest they were using the mud bottom of failed reefs instead of actually attributing to greater reef use.

Oyster reef structural complexity, as inferred from cluster density, was similar between rock and historic reefs, and significantly lower at shell reefs. These differences were not reflected in nekton abundance, richness, or diversity in comparisons of all reefs within each gear

type. In theory, structurally complex habitats will elicit higher densities and greater diversity of organisms, but direct evidence of this assumption is not available for oyster reefs, and structure is particularly hard to define and measure (Diehl 1992, Humphries et al. 2011). Although variable because shells (3 or 20+, live or dead) and rock could be attached in a loose matrix providing interstitial space, or fused compactly providing minimal structure, our measures of cluster density provide the best indications of structure over any other parameter. This partially ambiguous measurement of structure, however, does not account for variations in area, relief, and spatial configuration of surrounding habitats, information which was not available for all study sites and therefore could not be included in analyses, despite indications of being important considerations in determining habitat value (Grabowski et al. 2005, Gregalis et al. 2009). Even with these misgivings, our lack of significant differences in assemblages is not uncommon considering the mobile nature of nekton, and is suggested as more a reflection of biophysical characteristics related to reef location (proximity to other reefs, shoreline, or bay opening, etc.) and temporal changes (salinity, temperature, dissolved oxygen, etc.) than a response to reef design (Shervette and Gelwick 2008, Gregalis et al. 2009).

Conclusions

Nine out of 13 artificial reefs examined were fully successful in creating reefs that may be sustainable over the long-term. Reefs created with shell were most likely to fail (60% of shell reefs failed) despite being suggested as a choice substrate for recruitment (Bartol et al. 1999, Barnes et al. 2008, Hall 2009) and evidence of sustainability (Powers et al. 2009b) Given the low level of information available on reef design and actual reef creation, it is difficult to state with certainty whether it is the reef material, or possible aspects of reef design or location that contributed to these failures. However, implications that a properly placed *and* well-designed

reef can lead to success in functionality and sustainability (Carter et al. 1985, Gregalis et al. 2008, Kennedy et al. 2011) are upheld by our findings. While the intrinsic properties of materials (e.g., density, durability) are unavoidable, they can be manipulated through design (e.g., high initial relief to control for sinking, shifting) and placement (e.g. wave protection via shoreline proximity) considerations. Although defining the specific successful combination of location conditions and reef type may be a difficult task, as suggested previously, pre-restoration monitoring of selected sites would be highly beneficial and cost effective.

Future artificial reef placements would benefit from preliminary *in-situ* small-scale assessments, much like Johnson et al. (2009), that can display recruitment, growth, and survival of oysters. If possible, the intended artificial reef material and design, as well as specific site location should be used for these assessments. It is important to keep in mind that although ideal, restoring populations in locations of historic occurrence may not be feasible due to environmental changes and oyster tolerance limitations (Powers et al. 2009b). It is economical and sensible to determine the feasibility of success before placing an artificial reef and "dumping" resources into untested waters.

CHAPTER 4. SUMMARY AND CONCLUSIONS

SUMMARY

While the creation of artificial oyster reefs is intended to restore the ecosystem service benefits provided by oysters and their biogenic reef structure, limited information exists on the actual outcomes of restoration projects, particularly beyond the first 2 years post-construction. The coordination of sharing or gathering knowledge related to reef restoration, specifically in terms of success or failure, does not currently exist across the northern Gulf of Mexico. The database of restoration projects created during the course of this study provides a baseline for tracking projects. While finding information for older projects, particularly pre-Katrina (2005) may be difficult, it is notable that more than a quarter of the projects reported (>100) were completed post-Katrina, indicating the significant on-going activities that should be generating valuable information.

Because data have not been made readily available for various reasons, a wealth of experience and knowledge is not available to help inform future projects, and to increase the odds for success. Furthermore, ecological restoration activities provide valuable opportunities to better understand the natural resources, and to help inform basic ecological knowledge regarding the factors that are important to (1) sustainability of living oyster reefs, and (2) provision of oyster reef ecosystem services.

Creation of a Gulf-wide database compiling information on reef restoration activities provides valuable insight to resource managers and agencies regarding the extent of activities within the northern Gulf of Mexico. While likely not a complete listing of all created reef sites, the key findings, are that (1) there are significant on-going activities, (2) there is little understanding of what has been done in terms of design and reef size, (3) material types used are

dominated by rock (48.6%), and shell (12.8%) based reefs, and (4) post-construction data are rarely available. As a result, it is difficult to determine if restoration activities are meeting goals, if set, or even basic criteria for success. Regardless of the measure of success, the outcome is often unknown because it is not sought. This suggests that initial efforts, and perceptions, of oyster reef restoration are currently viewed with greater importance than their actual outcomes and effects.

DESIGNING REEFS

In creating an artificial reef, many aspects of the planning and construction, important for successful outcomes, need to be considered. Despite their importance in meeting restoration goals, material choices are often driven by costs, availability, and ease of installation (Mann and Powell 2007, NOAA 2007). Additionally, maintaining a hard substrate above bay bottom and a relief above limiting anoxic conditions should always be a priority over maximizing surface area, but sometimes substantial and sustainable relief may not be an obvious priority. In the case of mitigations, grants, or other ventures where artificial reef requirements and/or success are measured by area covered, it is possible that spreading materials farther to meet the goals could jeopardize reef success. If money or materials, like shell (Mann and Powell 2007), are limited in an artificial reef project, but maximum area coverage is the goal, this situation could theoretically, and quite literally, spread a reef too thin. Reefs that are partially successful imply placement was chosen with proper consideration in design, at least enough to maintain hard substrate within their environment. If reefs are *only* partially successful, however, consideration of placement specific conditions required for oyster growth may not have been properly assessed. Monitoring information from past projects to aid such considerations is often not available and consequently, limits adaptive management.

After installation, monitoring reefs may not occur due to a number of legitimate difficulties presented by limited funding, obstacles to reef access (we required boats and divers), lack of clearly defined and measurable goals, and difficulties standardizing measurements. Even within this study, opportunities for divergent interpretations are possible, due to the complexities of oyster reefs and limitations in measurements. For example, cluster counts, used because volumes are not particularly representative of structure, are still highly variable because shells (3 or 20+, live or dead) and rock could be attached in such a way that they provide optimal interstitial space, or they could be fused compactly, providing minimal structure. The call for continued comparable monitoring on post-construction artificial reef efforts is standard rhetoric. Most likely, these calls are a result of frustrations by the apparent paucity and inconsistencies of monitoring data, and the associated limitations on its exigency to restoration progress via adaptive management (Bohnsack and Sutherland 1985, Coen and Luckenbach 2000, Hackney 2000, Baine 2001, Johnson et al. 2009, Feary et al. 2011, Kennedy et al. 2011)

Conclusions from this research suggest that pooling regional information in a timely and orderly fashion between all entities involved in artificial oyster reef restoration efforts, and using lessons learned from areas of success and failure to adapt future techniques is the clearest path to successful progress. Continuing with current practices without review, while awaiting the results and availability of new experimental designs, unfairly suggests current efforts are only a short-term solution. Diverting resources from their emphasis on creation to a review of outcomes may be difficult, and appear to impede restoration efforts, but if views are shifted from perceived progress to actual successful outcomes, this change of focus will most likely lead to more efficient use of resources. In particular, using restoration efforts to help further our scientific understanding would be an extremely beneficial use of resources.

FIELD EVALUATION OF RESTORATION EFFORTS

The field study portion of this research found some artificial oyster reef restoration efforts failed while others succeeded in providing basic structure and/or maintaining live oyster populations. While artificial reefs were examined by construction material, and rock reefs were found on average to provide greater densities of live oysters and volumes of hard substrate, design and placement-specific environmental variations that we failed to measure (i.e., hydrodynamics, relief) may be just as important in the determination of reef success. More detailed and site-specific data on the local environment, including daily salinity, temperature, turbidity information and local hydrology or current information would add significant knowledge to our understanding of the environmental parameters that define successful oyster reef establishment locations. Future reef restoration projects should include some measures of reef establishment success to allow scientists and managers better understanding of the hydrologic environment required for successful recruitment and oyster growth. Since the design and monitoring of reef restoration activities can be manipulated, some key questions for restoration ecologists and oyster biologists, are: (1) are there current thresholds for recruitment? (2) how might local hydrodynamics affect sedimentation on reefs? and (3) is there a minimum reef relief required to ensure initial oyster population establishment, and maintenance over the long-term? Many other questions could easily be explored if future projects acknowledge and plan for the need for longer term monitoring to not only account for the successful use of funds used, but to also improve future restoration efforts.

In evaluating the success of our reefs to support nekton use, we found no differences between historic reefs and either artificial reef material type in measures of abundance (CPUE),

species counts (richness), and diversity (H'), despite significantly different provisions of living oysters, hard substrate and structure. This finding can suggest that either any structure with interstitial space provides important habitat and supports nekton communities equally, as found in other research (Humphries and La Peyre 2010, Marenghi and Ozbay 2010, Scyphers et al. 2011) , or due to the nature of the gear types, there is variation in results attributable to variables like wind speed, wave energy, and season that may have masked any differences (Shervette and Gelwick 2008). Similar to monitoring to assess the sustainability of the reef, restoration projects have been, and should be used to better understand more explicitly what aspects of "structure" on oyster reefs are critical for nekton-habitat relationships. For example, (1) do oyster reefs with more adult living oysters support different communities of nekton? (2) do increasing interstitial spaces or sizes change the community supported by the reefs? (3) do reefs enhance production by enhancing or aggregating food resources? Similar to above, there are multiple questions that should be answered, and can be designed into reef creation projects, but would require monitoring, and detailed project design information.

Along the northern shore of the GoM, significant restoration activities involving creation and enhancement of artificial oyster reefs are on-going. This work presents the first attempt to compile a list of these efforts, and highlights a lack of project tracking, along with the loss of potentially valuable information that could help inform future restoration projects. This information could also further our ecological understanding of how oyster reefs function, which variables influence long-term reef sustainability, and which factors are important in determining the contribution and provision of other ecosystem services. Clearly, better project tracking, and the inclusion of monitoring protocols are critical.

BEST MANAGEMENT PRACTICES

Artificial reef activities would benefit from the use best management practices (BMP). With the information gained from this project, basic guidelines necessary to improve reef success have become clear, some suggestions are presented below.

Ideally artificial oyster reef projects would (1.) pre-restoration, do research on reef location and design, (2.) use *in-situ* pre-construction tests, (3.) construct reefs in locations with designs researched and tested, (4.) monitor for live adult oysters, over five plus years (5.) adapt management on the current reef as needed by enhancing or changing the material and/or reef design, and (6.) share information with the artificial reef community.

The first responsible step in reef creation would be to 1.) choose sites for artificial oyster reef restoration activities with considerations of past projects. Specifically, site selection would consider results from projects in the same geographic region and with similar site-specific environmental stressors, when available. Special attention should be paid to the seasonal and annual water quality fluctuations, wave energy, current bay substrate, availability of larvae, and location susceptibility to catastrophic events (hurricanes, floods, oil spills).

To best ensure an area is capable of maintaining live oyster populations, specifically in the context of the intended reef's design, it is suggested that (2.) pre-construction *in-situ* studies, at the proposed reef, be conducted a year or more in advance, whenever possible. These 'test runs' can be done with prototypes mimicking the reef's intended design –with special attention to materials, relief, and structural complexity. While area covered, or layout of the reef may not be testable with preliminary studies, the studies will at the very least safeguard against large installations at sites unsuitable for oysters and/or some aspects of the reef design.

After confirmation that the reef design can be successful in the location chosen for restoration, (3.) reefs can be constructed with the intended design. The considerations of design elements as well as environmental variables through pre-construction research and test studies, should be used to inform the construction process. Shifting, sinking, and scattering of materials may occur during or after construction, but manipulations to the design based on pre-construction research and monitoring, should be made to safeguard against these issues. A typical example of this often involves relief; loose material (shell or limestone) reef construction plans can stipulate materials be set with a relief higher than intended, so that a specific relief will be maintained even after materials settle.

After construction, (4.) monitoring will aid in determining success of a reef and/or if manipulations need to be made to improve the reef. Monitoring varies based on goals, and the lack of comparable monitoring has been highlighted as an issue. We suggest that because nekton assemblage data can be labor intensive and often inconclusive, monitoring efforts should focus on live adult oysters, particularly because live oysters imply reef sustainability and water quality improvements. Live oyster metrics, in their most basic form, should be taken so that they may be presented as density counts per a set amount of area. Divers may need to be used for monitoring, but due to the sessile natures of oysters, sampling can be a quick event. Timelines for monitoring, when it does occur, are typically only 1-2 years; a bare minimum amount of time, used to confirm initial recruitment and growth. However, if reefs are being installed as a sustainable restoration endeavor, monitoring of the reef's presence and provisions should continue for longer. Our suggestion is that after the initial 1-2 years, a one-time sampling event "check-up" should occur, every five years if possible. If the reefs are indeed sustainable, defining an end date for monitoring can be difficult, and ideally monitoring would continue

indefinitely unless the reef fails at some point. Other basic parameters to measure would involve maintenance of reef relief, and water quality to help explain any success, or lack of success, and inform managers who may need to design other projects, or engage in adaptive management.

As the reef ages, (5.) adaptive management should be used to improve, or simply ensure, basic success of the restoration efforts of the current project. For example, if a reef appears to be losing relief, making it more prone to sedimentation, and consequently affecting, or threatening to affect oyster recruitment and growth, some corrections can be made to reef design, material used, and additional materials added to ensure the reef is not lost entirely.

Lastly, through the use of (6.) knowledge and data gained from the efforts absolutely need to be tracked and shared with the oyster managers, biologistics, and the artificial reef community in general. As many details as possible, such as those tracked or attempted to be located in Chapter 2, Appendix 1 are critical for moving forward in artificial oyster restoration. It is not clear who should be responsible for this, whether this should be a requirement of permits, a federal or a state agency requirement, or whether this would be a role for a nonprofit organization, but it is absolutely essential that we document the activities more thoroughly. Because permitting of reefs may fall under a variety of different authorities (Nix 2011), one concrete step forward would be to develop a specific, state or federal level permit for artificial oyster reef deployment which would have a mechanism for the tracking of reef information, and monitoring of these reefs. At a minimum, this database should require, as stated previously, items such as location, name, material, date of creation, design, as-built information, monitoring parameters, monitoring data, funding, and goals of project.

It is only through this collection, and subsequent dispersal, of information relating to artificial reef restoration efforts that progress will be seen and endeavors will thrive.

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APPENDIX

Table A.1 Database of inshore artificial reefs in the northern Gulf of Mexico and their locations, physical attributes, and parties involved & associated efforts. This information is best viewed, searched, and sorted in an Excel file. The original Excel file may be requested from the lab of Megan La Peyre in the School of Renewable Natural Resources.

SiteID State Lat Long Material Structure/Materials Date Built Water Body/Location Local Site Name Donor/Partner Size Web Info Relief Type Depth Monitored Total Cost Reason Built (fish habitat, shoreline, oyster restoration, etc.) Date/Month Notes

LA-1 Louisiana 29° 58' 20.09" 93° 17' 45.92" Rock limestone 2007 Lake Calcasieu Finfish Reef 1 Cheniere Energy www.wlf.louisiana.gov/news/29402 0.0 0 Jun-07 Dates- months shown are at times place holders for the format and no month was given this are indicated with a * in the notes

LA-2 Louisiana 29° 50' 58.3" 93° 17' 1.39" Rock limestone 2007 Lake Calcasieu Oyster Reef 1 Cheniere Energy www.wlf.louisiana.gov/news/29402 0.0 0 Jun-07 *

LA-3 Louisiana 29° 50' 57.91" 93° 16' 54.30" Rock limestone 2007 Lake Calcasieu Oyster Reef 2 Cheniere Energy www.wlf.louisiana.gov/news/29402 0.0 0 Jun-07 *

LA-4 Louisiana 29° 51' 1.91" 93° 16' 58.44" Rock limestone 2007 Lake Calcasieu Oyster Reef 3 Cheniere Energy www.wlf.louisiana.gov/news/29402 0.0 0 Jun-07 *

LA-5 Louisiana 30° 2' 58.09" 93° 18' 20.85" Rock limestone 2007 Lake Calcasieu Turner's Bay Island Coastal Conservation Association 1.5 acres www.ccalouisiana.com 5-6 feet Mar-07

LA-6 Louisiana 29° 43' 19.99" 91° 52' 22.01" Shell shell 1991 Vermillion Bay Cypremort Point LDWF 12 feet Sep-91

LA-7 Louisiana 29° 39' 38.27" 92° 7' 56.93" Shell shell 2006 Vermillion Bay Prien Point - Shoreline Protection Louisiana Wetlands Association www.oyster-restoration.org/research.php Start-up Program Mar-06

LA-8 Louisiana 29° 40' 37.02" 92° 7' 4.98" Shell shell 1991 Vermillion Bay Redfish Pointe 1 LDWF 12 feet Sep-91

LA-9	Louisiana	29° 40' 39.88"	92° 7' 5.95"	Rock	limestone	2006	Vermillion Bay	Redfish Pointe 2	Coastal Conservation Association	www.ccalouisiana.com	12 feet		Sep-06
LA-10	Louisiana	29° 25' 10.02"	91° 42' 27"	Shell	shell	1997	Cote Blanche Bay	Nickel Reef	LDWF		12 feet		Jun-97
LA-11	Louisiana	29° 25' 37.02"	91° 42' 27"	Shell	shell	1997	Cote Blanche Bay	Rabbit Island 1	LDWF		12 feet		Jun-97
LA-12	Louisiana	29° 30' 34.02"	91° 33' 52.02"	Shell	shell	1997	Cote Blanche Bay	Rabbit Island 2	LDWF		12 feet		Jun-97
LA-13	Louisiana	29° 3' 33.59"	90° 43' 25.79"	Rock	limestone	2002	Lake Pelto	Bird Island	Coastal Conservation Association	www.ccalouisiana.com	12 feet		Mar-02
LA-14	Louisiana	29° 3' 34.63"	90° 43' 21.36"	Rock	limestone	2002	Lake Pelto	Bird Island II	NOAA Disaster Grant & CCA		12 feet		Jun-02
LA-15	Louisiana	29° 6' 26.64"	90° 38' 8.59"	Rock	limestone	2002	Timbalier Bay	Point Mast	NOAA Disaster Grant & CCA	www.ccalouisiana.com	12 feet		Jun-02
LA-16	Louisiana	29° 27' 28.01"	90° 22' 40.98"	Shell	shell	1997	Point Aux Chenes	Bully Camp 1	LDWF		12 feet		Aug-97
LA-17	Louisiana	29° 27' 28.01"	90° 22' 40.98"	Shell	shell	1997	Point Aux Chenes	Bully Camp 2	LDWF		12 feet		Aug-97
LA-18	Louisiana	30° 5' 1.68"	90° 12' 5.76"	Rock	reef balls	2003	Lake Pontchartrain	H-1 South Shore	Lake Pontchartrain Basin Foundation	www.saveourlake.org/fishing.php	7-10 feet	$59,975/3 a	Aug-03
LA-19	Louisiana	30° 5' 2.04"	90° 12' 34.92"	Rock	reef balls	2003	Lake Pontchartrain	H-3 South Shore	Lake Pontchartrain Basin Foundation	www.saveourlake.org/fishing.php	7-10 feet	$59,975/3 b	Oct-03

LA-20 Louisiana 30° 5' 16.44" 90° 12' 20.16" Rock reef balls 2003 Lake Pontchartrain H-4 South Shore Lake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 7-10 feet $59,975/3 c Sep-03

LA-21 Louisiana 30° 3' 31.25" 89° 59' 36.49" Rock limestone rubble 2001 Lake Pontchartrain L-1 Lake Front AirportLake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 13-15 feet $59,000.00 Jul-01

LA-22 Louisiana 30° 7' 27.30" 90° 4' 42.17" Rock reef balls Lake Pontchartrain Orleans Site Lake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 15 feet

LA-23 Louisiana 30° 16' 17.76" 90° 3' 45.18" Rock reef balls 2004 Lake Pontchartrain N-1 North Shore Lake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 7-10 feet $13,100.00 Jan-04

LA-24 Louisiana 30° 13' 27.37" 89° 56' 50.28" Rock reef balls 2009 Lake Pontchartrain St. Tammany (east) Lake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 15 feet Apr-09

LA-25 Louisiana 30° 18' 20.88" 90° 9' 0.0" Rock reef balls 2009 Lake Pontchartrain St. Tammany (west) Lake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 15 feet Apr-09

LA-26 Louisiana 30° 8' 4.63" 90° 19' 2.89" Rock reef balls 2009 Lake Pontchartrain St. Charles Lake Pontchartrain Basin Foundation www.saveourlake.org/fishing.php 15 feet May-09

LA-27 Louisiana 29° 20' 0.60" 89° 50' 35.23" Rock limestone 2004 Barataria Bay Bay Ronquille Recreational Fisheries Research Institute 12 feet Jul-04

LA-28 Louisiana 29° 36' 42.71" 92° 3' 10.74" MixedShell Oystercrete 2009 Vermillion Bay TNC Vermillion Bay Oystercrete The Nature Conservancy Jul-09

LA-29 Louisiana 29° 40' 33.42" 89° 31' 38.11"Rock reef block 2009 Lake Fortuna St. Bernard Marsh Project The Nature Conservancy 1.65 mi Grand Isle and St. Bernard Marsh Shorline Protection Project - Jul-09

LA-30 Louisiana 29° 45' 39.82" 89° 26' 36.29" Rock reef block 2009 Lake Eloi St. Bernard Marsh Project The
Nature Conservancy .067 mi Grand Isle and St. Bernard Marsh Shorline Protection
Project - Jul-09

LA-31 Louisiana 29°14'58.58" 90°56'25.16" Shell shell Sister Lake 3H

LA-32 Louisiana 29°13'54.48" 90°57'38.63 Shell shell Sister Lake 3L

LA-33 Louisiana 29°15'40.40 90°54'17.25 Shell shell Sister Lake 6H

LA-34 Louisiana 29°15'23.42 90°54'0.55" Shell shell Sister Lake 6L

LA-35 Louisiana 29°13'3.53" 90°55'18.40" Shell shell Sister Lake 7H

LA-36 Louisiana 29°12'44.36" 90°56'5.28" Shell shell Sister Lake 7L

LA-37 Louisiana 29°14' 1.8558"90° 0' 29.6244" Rock reef block 2010 Caminada Bay St. Bernard Marsh Project
The Nature Conservancy .23 mi Grand Isle and St. Bernard Marsh Shorline
Protection Project - Mar-10

LA-38 Louisiana 29°13' 51.0996"90° 0' 54.4674" 90° 0' 54.4674" Rock reef block 2010 Caminada Bay St.
Bernard Marsh Project The Nature Conservancy 0.63 mi Grand Isle and St.
Bernard Marsh Shorline Protection Project - Mar-10

LA-39 Louisiana 29°15'35.65" 89°58'20.77" Rock reef block 2010 Bay Des Ilettes St. Bernard Marsh Project
The Nature Conservancy 0.8 mi Grand Isle and St. Bernard Marsh Shorline
Protection Project - Mar-10

LA-40 Louisiana 29° 18' 26.98" 89° 56' 01.01" Rock limestone 2011 Barataria Bay Independence Island CCA &
LDWF 50 acres www.ccalouisiana.com $250,000 CCA Building Consevation Habitat Program
Jun-11

MS-1 Mississippi 30° 17' 53.41" 89° 19' 48" Rock limestone Bay St. Louis- Mouth American Legion Launch
7 ft

MS-2 Mississippi 30° 18' 6.37" 89° 19' 36.30" MixedShell oyster shell/limestone Bay St. Louis- Mouth American
Legion Pier 3 ft

MS-3 Mississippi 30° 18' 42.41" 89° 18' 0.54" Rock crushed concrete Bay St. Louis- Mouth Bay St. Louis Train
Bridge 5 ft

MS-4 Mississippi 30° 19' 30.18" 88° 43' 4.33" Rock limestone/crushed concrete Mississippi Sound Bellefontaine
5 ft

MS-5 Mississippi 30° 23' 9.71" 88° 50' 50.93" Rock crushed concrete Biloxi Bay Biloxi Channel East
6 ft

MS-6 Mississippi 30° 23' 28.39" 88° 52' 58.73" Shell oyster shell Biloxi Bay Biloxi Harbor
1 ft

MS-7 Mississippi 30° 23' 14.21" 88° 58' 13.26" Shell oyster shell Mississippi Sound Broadway Harbor
4 ft

MS-8 Mississippi 30° 20' 12.59" 89° 19' 32.41" Rock crushed concrete Bay St. Louis Cedar Point
5 ft

MS-9 Mississippi 30° 21' 35.10" 89° 6' 30.71" Rock limestone Mississippi Sound Charles Walker Pier
0 ft

MS-10 Mississippi 30° 22' 23.81" 89° 2' 32.21" Rock limestone/crushed concrete Mississippi Sound Courthouse
Rd. 3 ft

MS-11 Mississippi 30° 22' 33.60" 88° 49' 55.45" MixedShell oyster shell/limestone Biloxi Bay Deer Island North
5 ft

M2-12	Mississippi	30° 22' 34.57"	88° 52' 15.31"	Rock	crushed concrete	5 ft	Mississippi Sound	Deer Island South Barge
MS-13	Mississippi	30° 25' 21.28"	88° 53' 28.14"	Shell	oyster shell	2 ft	Back Bay of Biloxi	D'Iberville Marina
MS-14	Mississippi	30° 25' 23.16"	88° 53' 39.77"	Rock	limestone	2 ft	Back Bay of Biloxi	C'Iberville Bridge
MS-15	Mississippi	30° 19' 32.27"	89° 11' 42.43"	Rock	limestone	2 ft	Mississippi Sound	Emerald Street
MS-16	Mississippi	30° 25' 15.24"	88° 51' 34.13"	Shell	oyster shell	6 ft	Back Bay of Biloxi	Fort Bayou
MS-17	Mississippi	30° 21' 10.37"	89° 7' 1.45"	Rock	limestone	5 ft	Mississippi Sound	Fournier Ave.
MS-18	Mississippi	30° 25' 20.82"	88° 54' 35.10"	Rock	limestone	1 ft	Back Bay of Biloxi	Goat Island
MS-19	Mississippi	30° 20' 50.03"	88° 40' 15.31"	Rock	crushed concrete	6 ft	Mississippi Sound	Graveline
MS-20	Mississippi	30° 21' 32.83"	88° 45' 52.45"	MixedShell	oyster shell/limestone	0 ft	Mississippi Sound	Gulf Park Estates Pier
M2-21	Mississippi	30° 21' 31.75"	88° 46' 3.54"	Shell	oyster shell	3 ft	Mississippi Sound	Gulf Park Estates
MS-22	Mississippi	30° 22' 13.08"	89° 3' 34.99"	Rock	limestone	3 ft	Mississippi Sound	Hewes Ave.
MS-23	Mississippi	30° 19' 22.37"	89° 12' 24.01"	Rock	limestone	3 ft	Mississippi Sound	Japonica Drive

MS-24 Mississippi 30°20'38.32" 89° 8'49.38" Rock limestone Mississippi Sound Jeff Davis Ave. Pier
0 ft

MS-25 Mississippi 30° 23' 12.30" 88° 51' 37.62" Shell oyster shell Biloxi Bay Joe Thornton Hull
4 ft

MS-26 Mississippi 30° 21' 24.67" 88° 50' 22.13" Rock limestone/crushed concrete 2008 Mississippi Sound Katrina Key
7 ft

MS-27 Mississippi 30° 25' 13.37" 88° 55' 22.01" Rock limestone Back Bay of Biloxi Keesler Harbor
1 ft

MS-28 Mississippi 30° 21' 46.33" 88° 52' 54.37" Rock crushed concrete Mississippi Sound Keesler Rubble
10 ft

MS-29 Mississippi 30° 22' 5.41" 89° 4' 11.53" Rock limestone Mississippi Sound Kelly Ave.
2 ft

MS-30 Mississippi 30° 23' 28.57" 88° 52' 21" Shell oyster shell Biloxi Bay Kuhn St. Pier
1 ft

MS-31 Mississippi 30° 19' 4.08" 89° 13' 21.83" Rock limestone Mississippi Sound Lang Ave.
2 ft

MS-32 Mississippi 30° 22' 59.88" 89° 00' 12.06" Rock limestone 2007 Mississippi Sound Legacy Towers
2577.3 m^2 2 ft 2007 replenished

MS-33 Mississippi 30° 20' 34.98" 89° 7' 54.91" Rock limestone/crushed concrete Mississippi Sound Long Beach
East- coordinates bit dif from Fulford 464 m^2 7 ft

MS-34 Mississippi 30° 20' 30.48" 89° 8' 33.07" Shell oyster shell Mississippi Sound Long Beach Jetty
2 ft

MS-35 Mississippi 30° 20' 34.33" 89° 8' 24.79" Rock limestone/crushed concrete Mississippi Sound Long Beach
Pier 3 ft

MS-36 Mississippi 30° 20' 6.29" 89° 17' 14.64" MixedShell limestone/oyster shell Bay St. Louis Mellini Point
4 ft

MS-37 Mississippi 30° 17' 3.01" 89° 21' 28.19" Rock limestone Mississippi Sound Monroe Street
7 ft

MS-38 Mississippi 30° 21' 33.84" 89° 5' 0.24" MixedShell oyster shell/limestone Mississippi Sound Moses Pier
4 ft

MS-39 Mississippi 30° 22' 49.87" 89° 00' 59.65" Rock limestone 2007 Mississippi Sound Naval Hospital
1774.8 m^2 3 ft 2007 replenished

MS-40 Mississippi 30° 16' 10.20" 89° 22' 20.39" Rock limestone Mississippi Sound Oak Street
11 ft

MS-41 Mississippi 30° 24' 19.33" 88° 50' 3.05" Shell oyster shell Biloxi Bay Ocena Springs Community Pier
2 ft

MS-42 Mississippi 30° 24' 13.86" 88° 49' 48.61" Rock limestone Biloxi Bay Ocean Springs Pier
1 ft

MS-43 Mississippi 30° 24' 8.35" 88° 49' 28.49" Rock limestone Biloxi Bay Ocean Springs Harbor Pier
0 ft

MS-44 Mississippi 30° 24 28.91 88° 50' 41.03" Rock limestone Back Bay of Biloxi Old Highway 90 Bridge East
9 ft

MS-45 Mississippi 30° 24' 10.08" 88° 51' 4.21" Rock limestone Back Bay of Biloxi Old Highway 90 Bridge West
5 ft

MS-46 Mississippi 30° 20' 2.69" 88° 32' 13.81" Rock crushed concrete Mississippi Sound Pascagoula Front
Beach 6 ft

MS-47 Mississippi 30° 20' 26.09" 88° 32' 2.65" Rock crushed concrete Mississippi Sound Pascagoula Municipal
Pier 3 ft

MS-48	Mississippi	30° 22' 48.72"	88° 34' 7.86"	Rock	limestone		Marsh Lake-closest	Pascagoula River 1			1 ft
MS-49	Mississippi	30° 24' 28.80"	88° 36' 53.75"	Rock	limestone		Big Lake- closest	Pascagoula River 3			1 ft
MS-50	Mississippi	30° 24' 9.97"	88° 36' 27.54"	Rock	limestone		Big Lake	Pascagoula River 4			1 ft
MS-51	Mississippi	30° 21' 52.31"	88° 35' 59.57"	Rock	crushed concrete		RailRoad Corner- closest	Pascagoula River West Mouth			1 ft
MS-52	Mississippi	30° 18' 36.29"	89° 14' 58.38"	Rock	limestone		Mississippi Sound	Pass Christian Harbor Pier	292 acres	Rebuilding_MS_Oyster_Reef	1 ft
MS-53	Mississippi	30° 17' 23.10"	88° 35' 17.09"	Rock	crushed concrete		Mississippi Sound	Round Island Jetty			5 ft
MS-54	Mississippi	30° 25' 7.07"	88° 51' 20.59"	MixedShell	limestone/oyster shell	2004	Back Bay of Biloxi	Spoil Island North			5 ft
MS-55	Mississippi	30° 24' 49.57"	88° 51' 34.63"	Rock	limestone		Back Bay of Biloxi	Spoil Island South			1 ft
MS-56	Mississippi	30° 16' 22.80"	89° 22' 9.59"	Rock	limestone		Mississippi Sound	St. Claire			8 ft
MS-57	Mississippi	30° 16' 20.71"	89° 18' 54.07"	Rock	limestone/crushed concrete	19xx	Mississippi Sound	Square Handkerchief Key			7 ft
MS-58	Mississippi	30° 22' 33.89"	89° 2' 7.91"	Rock	limestone		Mississippi Sound	Tegarden			2 ft
MS-59	Mississippi	30° 21' 58.79"	89° 4' 35.51"	Rock	limestone		Mississippi Sound	Thornton Ave.			2 ft

MS-60 Mississippi 30° 21' 33.55" 89° 5' 10.50" Rock crushed concrete Mississippi Sound Urie Pier North
0 ft

MS-61 Mississippi 30°21'30.53" 89° 5'9.97" Rock crushed concrete Mississippi Sound Urie Pier South
0 ft

MS-62 Mississippi 30° 20' 49.92" 89° 8' 1.14" Shell oyster shell Mississippi Sound USM- coordinates slightly different from Fulford 4039 m^2 3 ft

MS-63 Mississippi 30° 22' 17.87" 89° 3' 8.21" Rock limestone Mississippi Sound VA Hospital
2 ft

MS-64 Mississippi 30° 19' 38.39" 89° 11' 15.83" Rock crushed concrete Mississippi Sound Walmart
3 ft

MS-65 Mississippi 30° 16' 50.27" 88° 21' 53.21" Rock limestone Mississippi Sound Waveland Pier
16 ft

MS-66 Mississippi 30° 16' 50.81" 89° 21' 52.92" Rock crushed concrete Mississippi Sound Waveland Rubble
7 ft

MS-67 Mississippi 30° 22' 52.32" 88° 55' 34.32" Shell oyster shelll Mississippi Sound Whitehouse
5 ft

MS-68 Mississippi 30° 21' 45.79" 89° 18' 46.91" Shell oyster shell 2004 St. Louis Bay St. Louis Bay
http://gulfmex.org/crp/3006.html 4 ft

MS-69 Mississippi 30° 21' 51.55" 88° 49' 12.71" Shell Oyster shell 2010 Back Bay of Biloxi Deer Island Restoration Project 3 ft

MS-70 Mississippi Rock Limestone 2009 Mississippi Sound Pass Marianne Reef 283 acres-a
Rebuilding_MS_Oyster_Reefs

MS-71 Mississippi Shell oyster shell 2009 Mississippi Sound St. Joe's Reef 283 acres-b
Rebuilding_MS_Oyster_Reefs

MS-72 Mississippi 30° 18' 51.5406" 89° 17' 56.4714" Shell shell 2007 St. Louis Bay TNC- Mike Murphy Contact
5 ft

MS-73 Mississippi 30° 20' 27.1674" 89° 17' 8.5914" Shell shell 2009 St. Louis Bay TNC- Mike Murphy Contact
5 ft

MS-74 Mississippi 30° 24' 47.34" 88° 51' 19.9224" Unknown unknown 2004 Back Bay of Biloxi TNC- Mike Murphy Contact little known on this reef 6 ft

AL-1A Alabama 30° 16' 12" 88° 5' 24" MixedShell limestone marl base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 8 ft 1-Jan-04 Dates- months shown are at times place holders for the format and no month was given this are indicated with a * in the notes

AL-1B Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 1 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...low 8 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-1C Alabama Same as above Same as above MixedShell concrete rubble base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 2 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...high 8 ft yes, see lit. $18,600 Restoration Habitat 100 cm high

AL-1D Alabama Same as above Same as above MixedShell concrete rubble base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 3 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...high 8 ft yes, see lit. $18,600 Restoration Habitat 100 cm high

AL-1E Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 4 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...high 8 ft yes, see lit. $20,292 Restoration Habitat 100 cm high

AL-1F Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 5 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...high 8 ft yes, see lit. $20,292 Restoration Habitat 100 cm high

AL-1G Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 6 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...low 8 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-1H Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 7LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...low 8 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-1I Alabama Same as above Same as above MixedShell limestone marl base, topped byoyster shell 2004 Mobile Bay (Intra Coastal Waterway) Sand Reef 8 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs...low 8 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-2A Alabama 30° 15' 36" 87° 51' 36" MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank Dauphin Island Sea Lab 7 ft yes, see lit. 1-Jan-04

AL-2B Alabama Same as above Same as above MixedShell concrete rubble base, topped by oyster shell 2004 Bon Secor Bay Shellbank 1 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... high 7 ft yes, see lit. $18,600 Restoration Habitat 100 cm high

AL-2C Alabama Same as above Same as above MixedShell concrete rubble base, topped by oyster shell 2004 Bon Secor Bay Shellbank 2 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... high 7 ft yes, see lit. $18,600 Restoration Habitat 100 cm high

AL-2D Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank 3 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 7 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-2E Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank 4 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 7 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-2F Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank 5 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 7 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-2G Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank 6 Hr Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... high 7 ft yes, see lit. $20,292 Restoration Habitat 100 cm high

AL-2H Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank 7 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 7 ft yes, see lit. $2,068 Restoration Habitat 10 cm high

AL-2I Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell 2004 Bon Secor Bay Shellbank 8 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... high 7 ft yes, see lit. $20,292 Restoration Habitat 100 cm high

AL-3 Alabama 30° 24' 31.86" 88° 3' 59.33" MixedShell concrete/ oyster cultch 1998 Mobile Bay Denton Reef 290,000 m2 low 12 ft Est. of Oyster reef and Fishing Reef 21-Jun-98 *

AL-4 Alabama 30° 36' 1.19" 87° 55' 3.61" MixedShell concrete/ oyster shell 1992 Mobile Bay Dell Williamson Reef 4,800 m2 low 7 ft Fishing Reef Only 15-Jun-92 *

AL-5 Alabama 30° 28' 41.99" 87° 55' 36.01" Rock concrete 1996 Mobile Bay Zundel's Landing 15000 m2 low 1 ft Fishing Reef Only 19-Jun-96 *

AL-6 Alabama 30° 19' 42.31" 87° 49' 49.80" MixedShell concrete/ oyster shell 1996 Bon Secour Bay Fish River Reef 60,000 m2 low 7 ft Est. of Oyster reef and Fishing Reef 19-Jun-96 *

AL-7 Alabama 30° 15' 42.95" 87° 51' 40.93" MixedShell concrete/ oyster shell 1996 Bon Secour Bay Shellbank Reef 34,500 m2 low 8 ft Est. of Oyster reef and Fishing Reef 19-Jun-96 *

AL-8 Alabama 30° 16' 23.41" 88° 5' 46.21" Rock concrete/ rubble 2000 Little Dauphin Island Lynn Dent Boykin Reef 28070 m2 low 8 ft Est. of Oyster reef and Fishing Reef 23-Jun-00 *

AL-9 Alabama 30° 31' 38.53" 88° 2' 52.62" MixedShell concrete/ rubble/ oyster cultch 2000 Mobile Bay Bender- Austal Reef 15500 m2 low 8 ft Est. of Oyster reef and Fishing Reef 23-Jun-00 *

AL-10 Alabama 30° 27' 27.61" 87° 55' 56.39" MixedShell concrete/ rubble/ oyster cultch 2001 Mobile Bay P. Grey Cane, Jr. Reef 20750 m2 low 8 ft Est. of Oyster reef and Fishing Reef 24-Jun-01 *

AL-11 Alabama 30° 39' 45" 88° 1' 30" Rock concrete/ rubble 2000 Mobile Bay Choctaw Pass Reef 10,000 m2 high 1 ft Fishing Reef Only 23-Jun-00 *

AL-12	Alabama	30° 29' 38.04"	87° 55' 55.09"	Rock	concrete/ rubble	2001	Mobile Bay	Battles Wharf Reef	6,550 m2	low	5 ft	Fishing Reef Only	24-Jun-01	*
AL-13	Alabama	30° 35' 16.15"	87° 57' 0.11"	Mixed	barge/ shrimpboat/ concrete	2007	Mobile Bay	Upper Bay Barge Reef/Buddy Beiser Reef	5,000	low	10 ft	Fishing Reef Only	1-Oct-07	
AL-14	Alabama	30° 37' 57.90"	88° 3' 7.13"	Rock	concrete/ rubble	2001	Mobile Bay	Brookley Hole Reef	15,000 m2	high	5 ft	Fishing Reef Only	24-Jun-01	*
AL-15	Alabama	30° 18' 19.91"	88° 16' 23.62"	Mixed	shrimpboat/ concrete/ rubble	2002	Mississippi Sound	Shrimpboat Reef	12,500 m2	low	9 ft	Fishing Reef Only	25-Jun-02	*
AL-16	Alabama	30° 14' 0.13"	88° 1' 13.55"	Unknown			Fort Morgan	Ft. Morgan Barge			13 ft			
AL-17	Alabama	30° 17' 33.65"	87° 31' 57.61"	Rock	concrete/ rubble	2005	Perdido Bay	Bayou St. John Reef	24,000 m2	high	7 ft	Fishing Reef Only	1-Sep-05	
AL-18	Alabama	30°15'15.01"	88° 3'7.20"	Mixed	limestone/ gas production platforms	2003	Mobile Bay	ExxonMobil 76A-AUX	1,000 m2	low	14 ft	Fishing Reef Only	1-Jun-03	
AL-19	Alabama	30° 17' 48.12"	88° 2' 48.87"	Mixed	limestone/ gas production platforms	2003	Mobile Bay	ExxonMobil 62A-AA	1,000 m2	low	14 ft	Fishing Reef Only	1-Jun-03	
AL-20	Alabama	30° 17' 30.66"	87° 59' 44.34"	Mixed	limestone/ gas production platforms	2003	Mobile Bay	ExxonMobil 63AB	1,000 m2	low	12 ft	Fishing Reef Only	1-Jun-03	
AL-21	Alabama	30° 16' 49.37"	87° 58' 4.80"	Mixed	limestone/ gas production platforms	2003	Mobile Bay	Legacy Platform	1,000 m2	low	12 ft	Fishing Reef Only	1-Jun-03	
AL-22	Alabama	30° 16' 50.23"	87° 59' 6.25"	Mixed	limestone/ gas production platforms	2003	Mobile Bay	Legacy Satellite 615-1	1,000 m2	low	12 ft	Fishing Reef Only	1-Jun-03	
AL-23	Alabama	30° 16' 0.73"	87° 58' 25.75"	Mixed	limestone/ gas production platforms	2003	Mobile Bay	Legacy Satellite 615-3	1,000 m2	low	13 ft	Fishing Reef Only	1-Jun-03	

AL-24 Alabama 30° 17' 17.09" 87° 57' 19.55" Mixed limestone/ gas production platforms 2003 Mobile Bay Legacy
Satellite 615-4 1,000 m2 low 12 ft Fishing Reef Only 1-Jun-03

AL-25 Alabama 30° 24' 38.99" 88° 4' 1.81" Shell mature oysters added to reef 2003 Mobile Alabama Shellfish
Restoration & Crab Trap Recovery 12 ft year 2003

AL-26 Alabama 30° 15' 8.21" 88° 4' 57.47" Rock concrete breakwaters-fringing 2004 Dauphin Island Habitat
Restoration in the Saw Grass Point Salt Marsh 1 ft 1-Jun-04

AL-28 Alabama 30°19'26.16" 87°30'40.08" Rock Concrete/rubble/ brigde span 2007 Ross Point Reef
25,000 m2 high 13 ft Fishing Reef Only 1-Apr-07

AL-29 Alabama 30°18'10.02" 87°29'24.24" Rock concrete/red clay brick/rubble2007 Ono Island Reef
56,800 m2 high 7 ft Fishing Reef Only 1-May-07

AL-30 Alabama 30°23'13.80" 87°53'6.66" Mixed Steel Barge/ shrimp boat hull/ rubble 2007 Upper Wreck Reef
5000 m2 low 6 ft Fishing Reef Only 1-Oct-07

AL-31 Alabama 30°21'28.39" 88°15'11.62" Unknown 2001 Portersville Bay Pilings New Reef
3 ft 24-Jun-01 GIS data file

AL-32 Alabama 30°20'58.83" 88°13'51.54" Unknown 2001 Portersville Bay Existing Hard Reef Oyster
Bed 36.52 ac 5 ft 24-Jun-01 *

AL-33 Alabama 30°20'50.53" 88°12'27.74" Unknown 2001 Portersville Bay Middle Ground Oyster Bed
36.39 ac 4 ft 24-Jun-01 *

AL-34 Alabama 30°18'37.71" 88° 9'30.50" Unknown 1995 Mississippi Sound Half Moon Reef
19.9 ac 5 ft 18-Jun-95 *

AL-35 Alabama 30°18'11.92 88° 8'24.17" Unknown 1995 Mississippi Sound Cedar Point Reef
2009.2 ac 4 ft 18-Jun-95 *

AL-36 Alabama 30°16'38.22" 88° 7'25.21" Unknown 1995 Bayou Aloe Peavy Island Reef 256.5
ac 3 ft 18-Jun-95 *

AL-37 Alabama 30°15'41.36" 88° 6'17.30" Unknown 1995 Dauphin Island Bay Dauphine Island Reef
521.8 ac 4 ft 18-Jun-95 *

AL-38 Alabama 30°19'26.14" 88° 7'43.11" Unknown 1995 Mobile Bay Single Cedar 12.1 ac
6 ft 18-Jun-95 *

AL-39 Alabama 30°19'36.67" 88° 7'25.74" Unknown 1995 Mobile Bay Buoy Reef "D" 25.2 ac
8 ft 18-Jun-95 *

AL-40 Alabama 30°19'26.14" 88° 6'41.52" Unknown 1995 Mobile Bay Buoy Reef "A" 212.4
ac 10 ft 18-Jun-95 *

AL-41 Alabama 30°19'55.10" 88° 7'11.52" Unknown 1995 Mobile Bay Buoy Reef "C" 12.4 ac
8 ft 18-Jun-95 *

AL-42 Alabama 30°19'59.84" 88° 6'59.42" Unknown 1995 Mobile Bay Buoy Reef "B" 33.9 ac
8 ft 18-Jun-95 *

AL-43 Alabama 30°20'16.68" 88° 6'43.62" Unknown 1995 Mobile Bay Buoy Reef "E" 18.7 ac
8 ft 18-Jun-95 *

AL-44 Alabama 30°20'33.52" 88° 6'34.15" Unknown 1995 Mobile Bay Kings Bayou Reef 66.8 ac
8 ft 18-Jun-95 *

AL-45A Alabama 30°18'36.00" 88° 6'36.00" MixedShell concrete rubble base, topped by oyster shell Mobile
Bay Cedar Point Reef area A 1 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster
Reefs... high 10 ft $18,600 Restoration Habitat 100 cm high

AL-45B Alabama Same as above Same as above MixedShell concrete rubble base, topped by oyster shell Mobile
Bay Cedar Point Reef area A 2 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster
Reefs... high 10 ft $18,600 Restoration Habitat 100 cm high

AL-45C Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell Mobile
Bay Cedar Point Reef area A 3 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster
Reefs... low 10 ft $2,068 Restoration Habitat 10 cm high

AL-45D Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell Mobile Bay Cedar Point Reef area A 4 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 10 ft $2,068 Restoration Habitat 10 cm high

AL-45E Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell Mobile Bay Cedar Point Reef area A 5 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... high 10 ft $20,292 Restoration Habitat 100 cm high

AL-45F Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell Mobile Bay Cedar Point Reef area A 6 HR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... high 10 ft $20,292 Restoration Habitat 100 cm high

AL-45G Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell Mobile Bay Cedar Point Reef area A 7 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 10 ft $2,068 Restoration Habitat 10 cm high

AL-45H Alabama Same as above Same as above MixedShell limestone marl base, topped by oyster shell Mobile Bay Cedar Point Reef area A 8 LR Dauphin Island Sea Lab 25x25 m 2008 Power, Gregalis Restoration of Oyster Reefs... low 10 ft $2,068 Restoration Habitat 10 cm high

AL-47 Alabama 30°20'41.58" 88° 7'24.05" MixedShell reef block, reef balls, bagged oyster shell 2010 Mobile Bay Mobile Port TNC, Dauphin Island Sea Lab 2250 m low 1 ft yes $2,132,866/2 Shore stablization and restoration 1-Apr-10 *. monitored

AL-48 Alabama 30°20'19.87" 88°15'12.19" MixedShell reef block, reef balls, bagged oyster shell 2010 Portersville Bay Coffee Island TNC, Dauphin Island Sea Lab 2250 m low 1 ft yes $2,132,866/2 Shore stablization and restoration 1-Apr-10 *. Monitored

FL-1 Florida 29° 55' 12" 84° 14' 8.09" Rock concrete bridge deck spans 1991 Wakulla County Rotary Reef Bridge North 17 ft Jan-91 Dates- months shown are at times place holders for the format and no month was given this are indicated with a * in the notes

FL-2 Florida 29° 55' 2.75" 84° 14' 10.61" Rock concrete bridge deck spans 1991 Wakulla County Rotary Reef Bridge Center 17 ft Jan-91

FL-3	Florida	29° 54' 55.98"	84° 14' 15.36"	Rock	concrete bridge deck spans	1991	Wakulla County	Rotary Reef Bridge South	17 ft	Jan-91
FL-4	Florida	29° 59' 58.67"	84° 9' 12.89"	Rock	concrete culverts	1988	Wakulla County	St. Marks Reef (3)	16 ft	Jun-88
FL-5	Florida	29° 59' 55.75"	84° 9' 15.73"	Rock	concrete culverts	1988	Wakulla County	St. Marks Reef (2)	16 ft	Jun-88
FL-6	Florida	29° 59' 54.53"	84° 9' 17.28"	Rock	concrete culverts	1988	Wakulla County	St. Marks Reef (1)	16 ft	Jun-88
FL-7	Florida	29° 55' 6.35"	84° 14' 11.15"	Rock	concrete culverts	1988	Wakulla County	Rotary Reef (5)	17 ft	Jun-88
FL-8	Florida	29° 54' 55.15"	84° 14' 14.03"	Metal	airplane DC3	1988	Wakulla County	Rotary Reef (3)	17 ft	May-88
FL-9	Florida	29° 59' 56.94"	84° 9' 15.91"	Other	tires	1964	Wakulla County	St. Marks Reef Tires	16 ft	Dec-64
FL-10	Florida	29° 54' 1.80"	84° 14' 10.79"	Other	tires (2500)	1964	Wakulla County	Rotary Reef Tires	18 ft	Dec-64
FL-11	Florida	29° 39' 52.02"	83° 37' 44.76"	Rock	modules concrete cubes (112)	1998	Taylor County	Steinhatchee Reef	19 ft	Jun-98
FL-12	Florida	29° 47' 4.56"	83° 37' 13.73"	Rock	concrete culverts	1993	Taylor County	Birdrack #2	5 ft	May-93
FL-13	Florida	29° 50' 5.46"	83° 38' 44.52"	Rock	concrete culverts	1993	Taylor County	Birdrack #1	4 ft	May-93
FL-14	Florida	29° 43' 26.29"	83° 34' 28.38"	Rock	concrete culverts	1993	Taylor County	Birdrack #3	2 ft	May-93

FL-15 Florida 29° 40' 1.02" 83° 37' 31.55" Rock concrete culverts 1993 Taylor County Steinhatchee Reef
19 ft May-93

FL-16 Florida 29° 40' 0.30" 83° 37' 42.13" Rock concrete culverts 1992 Taylor County Steinhatchee Reef
19 ft Jun-92

FL-17 Florida 29° 40' 1.09" 83° 37' 39.83" Metal steel scrap 1990 Taylor County Steinhatchee Reef
19 ft Apr-90

FL-18 Florida 29° 39' 28.80" 83° 37' 35.40" Metal steel scrap 1965 Taylor County Steinhatchee Reef
22 ft Dec-65

FL-19 Florida 29° 49' 52.07" 84° 30' 20.95" Rock concrete rubble 2000 Franklin County Florida Gas Transmission
Reef (B) 17 ft Jan-00

FL-21 Florida 29° 54' 28.44" 85° 27' 50.33" Rock concrete precast structures 1999 Bay County Unnamed
17 ft Dec-99

FL-22 Florida 29° 54' 5.76" 85° 27' 34.13" Rock modules concrete reefballs 1997 Bay County Captain Toms Reef
18 ft Oct-97

FL-23 Florida 30° 27' 54" 87° 6' 2.99" Shell clam, oyster shell 2005 Santa Rosa County Boathouse Lumps
4 ft Mar-05*.Restoration

FL-24 Florida 30° 25' 31.19" 87° 1' 24.60" Shell clam, oyster shell 2005 Santa Rosa County White Point Reef
12 ft Mar-05*.Restoration

FL-25 Florida 30° 29' 18.60" 87° 1' 14.41" Shell clam, oyster shell 2005 Santa Rosa County Blackwater Bay Reef
8 ft Mar-05*.Restoration

FL-26 Florida 30° 26' 17.99" 86° 58' 10.20" Shell oyster shell 2005 Santa Rosa County Half Moon Reef
8 ft Mar-05*.Restoration

FL-27 Florida 30° 26' 17.99" 86° 58' 10.20" Shell clam, oyster shell 2006 Walton County Alligator Point Bar
Aug-06 *.Restoration

FL-28 Florida 30° 16' 23.99" 85° 49' 36.01" Shell clam, oyster shell 2006 Bay County Mid-bay Reef
6 ft Mar-06*.Restoration

FL-29 Florida 30° 16' 41.99" 85° 47' 33.0" Shell clam, oyster shell 2006 Bay County Doyle Point
3 ft Mar-06*.Restoration

FL-30 Florida 30° 15' 33.01" 85° 47' 4.81" Shell clam, oyster shell 2006 Bay County Breakfast Point Bar
7ft Mar-06*.Restoration

FL-31 Florida 30° 1' 50.99" 85° 29' 24.0" Shell clam, oyster shell 2006 Bay County Strange Point Bar
2 ft Mar-06*.Restoration

FL-32 Florida 30° 1' 27.01" 85° 28' 22.80" Shell clam, oyster shell 2006 Bay County Baker Point Bar
4 ft Mar-06*.Restoration

FL-33 Florida 29° 42' 0.0" 85° 8' 21.01" Shell oysters 2006 Franklin County Bayou Flats
6 ft Jun-06 *.Restoration

FL-34 Florida 29° 41' 57.01" 85° 7' 48.00" Shell clam, oyster shell 2006 Franklin County Paradise Flats
5 ft Mar-06

FL-35 Florida 29° 40' 0.01" 85° 3' 33.00" Shell oyster shell 2006 Franklin County Dry Bar
6 ft Mar-06*

FL-36 Florida 29° 41' 13.20" 85° 2' 17.41" Shell oyster shell 2006 Franklin County Green Point Plant Site
6 ft Mar-06*

FL-37 Florida 29° 41' 30.01" 84° 58' 14.99" Shell oysters 2006 Franklin County Hagen's Flats
5 ft Jun-06 *Restoration

FL-38 Florida 29° 40' 17.40" 84° 53' 30.59" Shell clam, oyster shell 2006 Franklin County Hotel Bar/ Pelican Bar
6 ft Mar-06*

FL-39 Florida 29° 43' 30.0" 84° 52' 0.01" Shell oysters 2006 Franklin County Cat Point Bar
6 ft Mar-06*Restoration

FL-40 Florida 29° 43' 30.0" 84° 50' 6.0" Shell oyster shell 2006 Franklin County Porter's Bar
9 ft Mar-06*

FL-41 Florida 29° 42' 0.0" 84° 49' 9.01" Shell oysters 2006 Franklin County Platform Bar
16 ft Jun-06 *.Restoration

FL-42 Florida 29° 24' 0.0" 83° 13' 59.99" Shell oysters 2005 Dixie County Shired Reef 1 ft
Mar-05*.Restoration

FL-43 Florida 29° 22' 59.99" 83° 12' 18.00" Shell oysters 2005 Dixie County Coon Island 0 ft
Mar-05*.Restoration

FL-44 Florida 29° 21' 25.20" 83° 11' 4.81" Shell oysters 2005 Dixie County Bumble Bee 0 ft
Mar-05*.Restoration

FL-45 Florida 29°55'7.23" 85°24'30.18" Rock lime stone, concrete fish pyramid Bay County Cole Turner Memorial Reef Mexico Beach Artificial Reef Association MBARA 21 ft Memorial/ habitat

FL-46 Florida 29°55'2.16" 85°24'26.22" Rock lime stone, concrete fish pyramid 2010 Bay County Steve Mason Memorial Reef Mexico Beach Artificial Reef Association MBARA 21 ft Memorial/ habitat Sep-10

FL-47 Florida 29°54'57.18" 85°24'22.38" Rock lime stone, concrete fish pyramid Bay County Fantasy Properties' Reef Mexico Beach Artificial Reef Association MBARA 22 ft Memorial/ habitat

FL-48 Florida 29°54'53.22" 85°24'17.88" Rock lime stone, concrete fish pyramid Bay County Roy Crowe Memorial Reef Mexico Beach Artificial Reef Association MBARA 22 ft Memorial/ habitat

FL-49 Florida 29°54'24.72" 85°24'19.32" Rock 5 reef balls Bay County Amberjack Reef Mexico Beach Artificial Reef Association MBARA 25 ft Habitat

FL-50 Florida 29°54'22.91" 85°24'20.72" Rock 5 reef balls Bay County Cobia Reef Mexico Beach Artificial Reef Association MBARA 25 ft Habitat

FL-51 Florida 29°54'23.28" 85°24'16.32" Rock 5 reef balls Bay County Grouper Reef Mexico Beach Artificial Reef Association MBARA 24 ft Habitat

FL-52 Florida 28°47'24.00" 83° 3'30.00" Mixed Lincoln logs, culverts,boulders,bridge material 2007 Citrus County Fish Haven #1 Cirtus County FL Aquatics 29 ft Dec-07

FL-53 Florida 28°54'54.00" 82°52'18.00" Mixed Lincoln logs, culverts,boulders,bridge material Citrus County Fish Haven #2 Cirtus County FL Aquatics 9 ft

FL-54 Florida 28°55'18.00 82°52'30.00" Mixed Lincoln logs, culverts,boulders,bridge material Citrus County Fish Haven #3 Cirtus County FL Aquatics 10 ft

FL-55 Florida 25°58'0.00" 81°48'36.90" Metal barge Collier CountyBen's Barge Sea Grant Collier-environment-artificialreefs 28 ft

FL-56 Florida 25°51'26.46" 81°41'29.34" Metal crane/ ship wreck Collier CountyCape Ramano Crane Sea Grant Collier-environment-artificialreefs 5.5 1 ft

FL-57 Florida 25°54'26.64 81°45'17.28" Mixed dredge pipe, pilings and culverts Collier CountyCaxambas 1.5 Mile IW01 Sea Grant Collier-environment-artificialreefs 5.0 14 ft

FL-59 Florida 26°13'31.08" 81°52'10.26" Rock bridge debris Collier CountyClam Pass 3 Mile - bridge 01 Sea Grant Collier-environment-artificialreefs 6.0 20 ft

FL-60 Florida 26°13'23.40" 81°52'3.06" Rock bridge debris Collier CountyClam Pass 3 Mile - bridge 02 Sea Grant Collier-environment-artificialreefs 6.0 19 ft

FL-61 Florida 26°13'26.70" 81°52'13.74" Rock concrete debris Collier CountyClam Pass 3 Mile - C&D1 Sea Grant Collier-environment-artificialreefs 12.0 20 ft

FL-62 Florida 26°13'23.23" 81°52'11.17" Rock concrete debris Collier CountyClam Pass 3 Mile - C&D2 Sea Grant Collier-environment-artificialreefs 10.0 20 ft

FL-63 Florida 26°13'35.28" 81°52'12.72" Mixed culverts, junction box, manhole risers Collier CountyClam Pass 3 Mile - junction boxes-1 Sea Grant Collier-environment-artificialreefs 10.0 20 ft

FL-64 Florida 26°13'35.08" 81°52'12.73" Mixed culverts, junction box, manhole risers Collier CountyClam Pass 3 Mile - junction boxes-2 Sea Grant Collier-environment-artificialreefs 10.0 20 ft

FL-65 Florida 26°13'34.32" 81°52'4.44" Rock 1800 concrete railroad ties Collier CountyClam Pass 3 Mile - railroad ties Sea Grant Collier-environment-artificialreefs 10.0 19 ft

FL-66 Florida 26°10'12.72" 81°54'21.06" Rock culverts Collier CountyDoctors Pass 5 Mile Sea Grant Collier-environment-artificialreefs 3.0 20 ft

FL-67 Florida 26°10'16.11" 81°54'2.08" Rock Culvert concrete rubble Collier CountyDoctors Pass 4.5 Mile-1 Sea Grant Collier-environment-artificialreefs 10.0 28 ft

FL-68 Florida 26°10'14.46" 81°54'2.58" Rock Culvert concrete rubble Collier CountyDoctors Pass 4.5 Mile-2 Sea Grant Collier-environment-artificialreefs 10.0 28 ft

FL-69 Florida 26° 5'39.12" 81°53'42.18" Rock CONCRETE CULVERTS Collier CountyGordon Pass 4.5 mile - culverts Sea Grant Collier-environment-artificialreefs 5.0 28 ft

FL-70 Florida 26° 5'47.40" 81°53'19.68" Rock CONCRETE BRIDGE RUBBLE Collier CountyGordon Pass 4.5 mile - rubble-1 Sea Grant Collier-environment-artificialreefs 4.0 28 ft

FL-71 Florida 26° 5'38.88" 81°53'42.54" Rock CONCRETE RUBBLE Collier CountyGordon Pass 4.5 mile - rubble-2 Sea Grant Collier-environment-artificialreefs 28 ft

FL-72 Florida 25°55'40.98" 81°48'13.80" Metal barge Collier CountyJohn D Sea Grant Collier-environment-artificialreefs 27 ft

FL-73 Florida 26° 2'2.04" 81°49'47.22" Rock limestone boulders Collier CountyKeewaydin 3 Mile - B1 Sea Grant Collier-environment-artificialreefs 8.0 21 ft

FL-74 Florida 26° 2'6.54" 81°49'51.12" Rock limestone boulders Collier CountyKeewaydin 3 Mile - B2 Sea Grant Collier-environment-artificialreefs 9.0 21 ft

FL-75 Florida 26° 2'10.14" 81°49'53.94" Rock limestone boulders Collier CountyKeewaydin 3 Mile - B3 Sea Grant Collier-environment-artificialreefs 12.0 21 ft

FL-76 Florida 26° 2'13.56" 81°49'58.14" Rock limestone boulders Collier CountyKeewaydin 3 Mile - B4 Sea Grant Collier-environment-artificialreefs 10.0 22 ft

FL-77 Florida 26° 2'5.40" 81°49'51.00" Rock concrete debris Collier CountyKeewaydin 3 Mile - C&D1 Sea Grant Collier-environment-artificialreefs 10.0 22 ft

FL-78 Florida 26° 2'11.04" 81°49'51.54" Rock concrete debris Collier CountyKeewaydin 3 Mile - Gannet Reef Sea Grant Collier-environment-artificialreefs 10.0 21 ft

FL-79 Florida 26° 2'7.50" 81°49'57.00" Rock concrete debris Collier CountyKeewaydin 3 Mile - Houla Dog Sea Grant Collier-environment-artificialreefs 12.0 22 ft

FL-80 Florida 26° 2'0.66" 81°49'57.00" Rock 34 4' x 6' culverts Collier CountyKeewaydin 3 Mile - Jeff Klein Sea Grant Collier-environment-artificialreefs 4.0 22 ft

FL-81 Florida 25°55'24.96" 81°45'47.64" Mixed concrete rubble, tires Collier CountyMarco 1.75 Mile - Deltona 02Sea Grant Collier-environment-artificialreefs 3.0 14 ft

FL-82 Florida 25°55'25.56" 81°46'14.34" Rock CONCRETE RUBBLE Collier CountyMarco 2 Mile - 02 Sea Grant Collier-environment-artificialreefs 17 ft

FL-83 Florida 26° 8'59.34" 81°48'41.40" Rock limestone boulders Collier CountyMitigation Reef Sea Grant Collier-environment-artificialreefs 5.0 0 ft

FL-84 Florida 26° 8'1.56" 81°50'37.50" Rock concrete debris and culverts Collier CountyNaples Pier - 01 Sea Grant Collier-environment-artificialreefs 8.0 15 ft

FL-85 Florida 25°58'36.30" 81°47'42.36" Metal barge Collier CountyPass Barge Sea Grant Collier-environment-artificialreefs 22 ft

FL-86?? Florida 26 5.395 81 50.616 Unknown Natural Hole Collier CountySparky Lee Hole Sea Grant Collier-environment-artificialreefs 27 ft

FL-87 Florida 26°18'27.48" 81°52'18.54" Rock 18 40' concrete telephone poles Collier CountyWiggins Pass 3 Mile - Annie's Reef Sea Grant Collier-environment-artificialreefs 10.0 21 ft

FL-88 Florida 26°18'27.48" 81°52'24.54" Rock 16 40' concrete telephone poles Collier County Wiggins Pass 3 Mile - CRRT 01 Sea Grant Collier-environment-artificialreefs 10.0 22 ft

FL-89 Florida 26°18'17.58" 81°52'25.86" Rock 20' culvert Collier County Wiggins Pass 3 Mile - ECA Culvert Sea Grant Collier-environment-artificialreefs 22 ft

FL-90 Florida 26°18'22.56" 81°52'21.60" Mixed concrete w/ steel I beams Collier County Wiggins Pass 3 Mile - ECA Reef Sea Grant Collier-environment-artificialreefs 12.0 22 ft

FL-91 Florida 26°18'19.44" 81°52'25.56" Rock concrete debris Collier County Wiggins Pass 3 Mile - Roughskin Spurdog Sea Grant Collier-environment-artificialreefs 10.0 22 ft

FL-92 Florida 30°19'44.28" 87°10'52.26" Rock 270 tons of concrete materials 2011 Escambia County Capt. Bob Quarles Reef Escambia.fl.us 13.0 0 ft Feb-11

FL-93 Florida 30°20'45.96" 87° 3'9.54" Rock Concrete "Eco-system Reef" modeules (under construction) 2011 Escambia County PensBchParkEastSnorkelReef Escambia.fl.us 14.0 0 ft Apr-11

FL-94 Florida 27°51'27.58" 82°33'13.53" Mixed four barges, concrete pilings and slabs 1987 Hillsborough County Ted Adams Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 100ydsX400yds EPC_Art._Reef_Program 0 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Mar-87

FL-95 Florida 27°44'53.40 82°30'55.20" Rock concrete pilings, slabs, culverts 1987 Hillsborough County Bahia Beach Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 200yds X 400 yds EPC_Art._Reef_Program 20 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Sep-87

FL-96 Florida 27°53'21.60" 82°28'48.00" Rock concrete pilings, slabs, culverts 1987 Hillsborough County Ballast Point Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County (4 reefs) 100 ft X 200 ft EPC_Art._Reef_Program 0 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Dec-87

FL-97 Florida 27°39'47.40" 82°34'44.40" Rock Concrete pilings, bridge docking, rubble 1990 Hillsborough County Port Manatee Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 400 yds X 400 yds

EPC_Art._Reef_Program 20 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Oct-90

FL-98 Florida 27°51'24.60" 82°33'16.20" Rock 10 concrete pyramids, 1 reef ball 1991 Hillsborough County Picnic Island Pier Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 75 ft X 50 ft EPC_Art._Reef_Program 0 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Jul-91

FL-99 Florida 27°57'48.59" 82°36'51.60" Rock concrete pilings 1991 Hillsborough County Courtney Camp Bell Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 400 yds X 200 yds EPC_Art._Reef_Program 15 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Jul-91

FL-100 Florida 27°54'42.00" 82°33'15.00" Rock concrete pilings,bridge supports 1991 Hillsborough County Howard Frankland Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 400 yds X 200 yds EPC_Art._Reef_Program 17 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Dec-91

FL-101 Florida 27°35'0.00" 82°44'36.00" Rock concrete bridge, pyramids, pipe 1999 Hillsborough County Egmont Key Reef Sportfishing Restoration, Environmental Protection commission Hillsborough County 400 yds X 400 yds EPC_Art._Reef_Program 20 ft Art. Reef Program- increase habitat diversity and hard substrate, provide fishing opportunities for sport fishing. Jun-99

FL-102 Florida 26°43'2.28" 82° 9'38.52" Rock Novak Culverts 2002 Lee County BOK Lee County Art. Reef 6 ft Monitored by County Mar-02

FL-103 Florida 26°45'45.87" 82° 9'29.23" Rock Culverts 2005 Lee County CH1 Lee County Art. Reef 19 ft Monitored by County May-05

FL-104 Florida 26°45'46.62" 82° 9'22.80" Rock Culverts 2005 Lee County CULV1A Lee County Art. Reef 20 ft Monitored by County May-05

FL-105 Florida 26°45'45.24" 82° 9'21.31" Rock Culverts 2005 Lee County CULV1B Lee County Art. Reef 21 ft Monitored by County May-05

FL-106	Florida	26°45'43.74"	82° 9'27.96"	Rock	Culverts	2005	Lee County	CULV3A	Lee County Art. Reef	20 ft	Monitored by County	May-05
FL-107	Florida	26°45'42.72"	82° 9'29.52"	Rock	Culverts	2005	Lee County	CULV3B	Lee County Art. Reef	20 ft	Monitored by County	May-05
FL-108	Florida	26°45'43.18"	82° 9'29.38"	Rock	Culverts	2005	Lee County	CULV4A	Lee County Art. Reef	20 ft	Monitored by County	May-05
FL-109	Florida	26°45'42.00"	82° 9'31.20"	Rock	Culverts	2005	Lee County	CULV4B	Lee County Art. Reef	19 ft	Monitored by County	May-05
FL-110	Florida	26°45'43.80"	82° 9'33.60"	Rock	Culverts	2005	Lee County	CULV5A	Lee County Art. Reef	19 ft	Monitored by County	May-05
FL-111	Florida	26°45'43.20"	82° 9'36.00"	Rock	Culverts	2005	Lee County	CULV5B	Lee County Art. Reef	19 ft	Monitored by County	May-05
FL-112	Florida	26°45'45.00"	82° 9'35.40"	Rock	Culverts	2005	Lee County	CULV5C	Lee County Art. Reef	18 ft	Monitored by County	May-05
FL-113	Florida	26°45'45.30"	82° 9'22.80"	Rock	Pyramidal concrete boxes	2005	Lee County	GARBN1	Lee County Art. Reef	20 ft	Monitored by County	May-05
FL-114	Florida	26°45'44.22"	82° 9'29.40"	Rock	Pyramidal concrete boxes	2005	Lee County	GARBN3	Lee County Art. Reef	19 ft	Monitored by County	May-05
FL-115	Florida	26°45'42.60"	82° 9'30.60"	Rock	Pyramidal concrete boxes	2005	Lee County	GARBN4	Lee County Art. Reef	20 ft	Monitored by County	May-05
FL-116	Florida	26°45'42.07	82° 9'33.77"	Rock	Pyramidal concrete boxes	2005	Lee County	GARBN5	Lee County Art. Reef	19 ft	Monitored by County	May-05
FL-117	Florida	26°45'46.74"	82° 9'21.24"	Metal	Pyramidal steel pipes	2005	Lee County	STPIP1	Lee County Art. Reef	20 ft	Monitored by County	May-05

FL-118 Florida 26°45'47.40" 82° 9'27.84" Metal Pyramidal steel pipes 2005 Lee County STPIP3
Lee County Art. Reef 18 ft Monitored by County May-05

FL-119 Florida 26°45'41.40" 82° 9'30.60" Metal Pyramidal steel pipes 2005 Lee County STPIP4
Lee County Art. Reef 20 ft Monitored by County May-05

FL-120 Florida 26°45'44.40" 82° 9'34.20" Metal Pyramidal steel pipes 2005 Lee County STPIP5
Lee County Art. Reef 18 ft Monitored by County May-05

FL-121 Florida 26°22'58.80" 82° 1'6.60" Other Piling Cutoffs 2006 Lee County SC1 Lee County
Art. Reef 24 ft Monitored by County Feb-06

FL-122 Florida 26°22'56.22" 82° 1'8.64" Other Piling Cutoffs 2006 Lee County SC2 Lee County
Art. Reef 24 ft Monitored by County Jun-06

FL-123 Florida 26°22'50.16" 82° 1'14.88" Mixed pile caps, steel road bed 2007 Lee County SC3
Lee County Art. Reef 24 ft Monitored by County Aug-07

FL-124 Florida 26°22'51.60" 82° 1'10.14" Other road bed 2007 Lee County SC4 Lee County
Art. Reef 24 ft Monitored by County Sep-07

FL-125 Florida 26°22'51.84" 82° 1'6.54" Other road bed 2007 Lee County SC5 Lee County
Art. Reef 25 ft Monitored by County Nov-07

FL-126 Florida 26°22'51.00" 82° 1'9.24" Mixed road bed/ pilings 2007 Lee County SC6 Lee
County Art. Reef 25 ft Monitored by County Nov-07

FL-128 Florida 26°22'55.57" 82° 1'7.62" Other Piling Cutoffs 2006 Lee County SC8 Lee County
Art. Reef 24 ft Monitored by County Jul-06

FL-129 Florida 26°22'54.06" 82° 1'7.50" Other Piling Cutoffs 2006 Lee County SC9 Lee County
Art. Reef 24 ft Monitored by County Sep-06

FL-130 Florida 26°22'58.80" 82° 1'4.92" Other Piling Cutoffs 2006 Lee County SC10 Lee County
Art. Reef 24 ft Monitored by County Sep-06

FL-131	Florida	26°23'1.80"	82° 1'10.44"	Other	Piling Cutoffs	2007	Lee County	SC11	Lee County Art. Reef	24 ft	Monitored by County	Apr-07
FL-132	Florida	26°22'50.10"	82° 1'15.48"	Other	Pile caps/pilings	2007	Lee County	SC12	Lee County Art. Reef	24 ft	Monitored by County	Jul-07
FL-134	Florida	26°22'52.20"	82° 1'16.20"	Other	Pilings	2007	Lee County	SC14	Lee County Art. Reef	24 ft	Monitored by County	Aug-07
FL-135	Florida	26°22'50.52"	82° 1'14.16"	Metal	Guardrails	2007	Lee County	SC15	Lee County Art. Reef	24 ft	Monitored by County	Sep-07
FL-137	Florida	26°22'52.56"	82° 1'12.48"	Other	Road Bed	2007	Lee County	SC17	Lee County Art. Reef	24 ft	Monitored by County	Sep-07
FL-138	Florida	26°22'54.72"	82° 1'15.00"	Mixed	Guardrails, Pilings	2007	Lee County	SC18	Lee County Art. Reef	24 ft	Monitored by County	Sep-07
FL-139	Florida	26°22'51.96"	82° 1'3.18"	Other	Road Bed	2007	Lee County	SC19	Lee County Art. Reef	25 ft	Monitored by County	Nov-07
FL-141	Florida	26°22'54.18"	82° 1'13.14"	Other	Road Bed	2007	Lee County	SC21	Lee County Art. Reef	24 ft	Monitored by County	Nov-07
FL-143	Florida	26°22'56.04"	82° 1'13.14"	Mixed	Pile Caps/ Pilings	2007	Lee County	SC23	Lee County Art. Reef	24 ft	Monitored by County	Nov-07
FL-144	Florida	26°22'56.64"	82° 1'14.88"	Mixed	Pile Caps/ Pilings	2007	Lee County	SC24	Lee County Art. Reef	24 ft	Monitored by County	Dec-07
FL-145	Florida	26°22'55.92"	82° 1'12.30"	Mixed	Pile Caps/ Pilings	2007	Lee County	SC25	Lee County Art. Reef	24 ft	Monitored by County	Dec-07
FL-146	Florida	26°22'53.64"	82° 1'11.70"	Other	Pile Caps	2007	Lee County	SC26	Lee County Art. Reef	24 ft	Monitored by County	Dec-07

Fl-147 Florida 26°22'59.40" 82° 1'14.40" Other Pilings 2007 Lee County SC27 Lee County Art. Reef
24 ft Monitored by County Dec-07

FL-148 Florida 26°23'1.86" 82° 1'15.36" Mixed Pile Caps/ Pilings 2007 Lee County SC28 Lee
County Art. Reef 24 ft Monitored by County Dec-07

FL-149 Florida 26°22'58.56" 82° 1'12.18" Mixed Pile Caps/ Pilings 2008 Lee County SC29 Lee
County Art. Reef 24 ft Monitored by County Jan-08

FL-150 Florida 26°45'33.00" 82°11'10.50" Metal Wreck 1988 Lee County D1 Lee County Art. Reef
11 ft Monitored by County Feb-88

FL-151 Florida 26°20'43.20" 81°56'57.00" Metal Steel Dumpster 1986 Lee County GH01 Lee
County Art. Reef 28 ft Monitored by County Sep-86

FL-152 Florida 26°20'43.80" 81°57'7.20" Metal Steel Dumpster 1986 Lee County GH02 Lee
County Art. Reef 27 ft Monitored by County Sep-86

FL-153 Florida 26°20'49.80" 81°57'4.20" Metal Steel Dumpster 1986 Lee County GH03 Lee
County Art. Reef 26 ft Monitored by County Sep-86

FL-154 Florida 26°20'49.80" 81°56'54.60" Metal Steel Dumpster 1986 Lee County GH04 Lee
County Art. Reef 27 ft Monitored by County Sep-86

FL-155 Florida 26°20'51.00" 81°57'3.00" Metal Steel Dumpster 1986 Lee County GH05 Lee
County Art. Reef 27 ft Monitored by County Sep-86

FL-156 Florida 26°20'39.00" 81°56'51.30" Metal Barge 1986 Lee County GH1 Lee County Art. Reef
27 ft Monitored by County Sep-86

FL-157 Florida 26°20'52.68" 81°57'10.68" Metal Barge 1986 Lee County GH2 Lee County Art. Reef
26 ft Monitored by County Sep-86

FL-158 Florida 26°20'53.70" 81°57'9.72" Other Shrimp Nets, Outriggers 1986 Lee County GH3
Lee County Art. Reef 26 ft Monitored by County Sep-86

FL-159 Florida 26°20'51.60" 81°57'8.10" Metal Cement Mixer Drum 1986 Lee County GH4 Lee County Art. Reef 26 ft Monitored by County Sep-86

FL-160 Florida 26°20'54.60" 81°57'27.12" Rock Limestone rock 1994 Lee County GH5 Lee County Art. Reef 27 ft Monitored by County May-94

FL-161 Florida 26°20'30.60" 81°57'23.34" Rock Culverts 1995 Lee County GH6 Lee County Art. Reef 27 ft Monitored by County May-95

FL-162 Florida 26°20'44.58" 81°57'11.40" Metal Steel Vessel 1997 Lee County GH7 Lee County Art. Reef 27 ft Monitored by County Apr-97

FL-163 Florida 26°22'59.28" 81°55'39.90" Mixed Barge, Pilings 1981 Lee County M.A.Y 1 Lee County Art. Reef 21 ft Monitored by County Jun-81

FL-164 Florida 26°22'43.92" 81°55'22.98" Rock Bridge Rubble 1981 Lee County M.A.Y 2 Lee County Art. Reef 20 ft Monitored by County Jun-81

FL-165 Florida 26°22'20.04" 81°55'2.10" Rock Rubble 1981 Lee County M.A.Y 3 Lee County Art. Reef 20 ft Monitored by County Jun-81

FL-166 Florida 26°22'20.52" 81°55'0.54" Rock Rubble 1981 Lee County M.A.Y 4 Lee County Art. Reef 20 ft Monitored by County Jun-81

FL-167 Florida 26°22'41.52" 81°55'5.22" Rock Concrete Boxes 1999 Lee County M.A.Y 5 Lee County Art. Reef 20 ft Monitored by County Mar-99

FL-168 Florida 26°24'56.82" 82° 3'9.66" Rock Concrete Rubble 1977 Lee County SANIB1 Lee County Art. Reef 18 ft Monitored by County Jun-77

FL-169 Florida 30°24'42.01" 86°30'40.79" Other 12 PREFAB PLASTIC RESIN CONES LOCATED IN CHOCTAWHATCHEE BAY. 1987 OKALOOSA BAY CONES (BAY) okaloosa.fl.us 11 21 ft Sport Fishing Habitat Dec-87

FL-170 Florida 27°55'28.44" 82°51'13.26" Unknown Pinellas County pinellascounty_reef 18 ft

FL-171 Florida 27°53'25.08" 82°51'14.34" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-172 Florida 27°53'30.90" 82°51'13.08" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-173 Florida 27°53'36.60" 82°51'12.00" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-174 Florida 27°53'41.22" 82°51'11.28" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-175 Florida 27°53'47.22" 82°51'11.46" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-176 Florida 27°54'9.60" 82°51'5.40" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-177 Florida 27°54'13.80" 82°51'4.20" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-178 Florida 27°54'16.80" 82°51'3.00" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-179 Florida 27°56'48.60" 82°50'24.60" Unknown 2006 Pinellas County North Shore Mitigation Reefs
(IMR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a
completion date not reflective of individual reefs

FL-180 Florida 27°56'55.80" 82°50'24.60" Unknown 2006 Pinellas County North Shore Mitigation Reefs (IMR) pinellascounty_reef 1 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-181 Florida 27°57'0.00" 82°50'20.40" Unknown 2006 Pinellas County North Shore Mitigation Reefs (IMR) pinellascounty_reef 1 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-182 Florida 27°57'6.60" 82°50'18.00" Unknown 2006 Pinellas County North Shore Mitigation Reefs (IMR) pinellascounty_reef 2 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-183 Florida 27°57'13.80" 82°50'14.40" Unknown 2006 Pinellas County North Shore Mitigation Reefs (IMR) pinellascounty_reef 1 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-184 Florida 27°57'19.80" 82°50'14.40" Unknown 2006 Pinellas County North Shore Mitigation Reefs (IMR) pinellascounty_reef 5 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-185 Florida 27°57'25.20" 82°50'14.40" Unknown 2006 Pinellas County North Shore Mitigation Reefs (IMR) pinellascounty_reef 7 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-186 Florida 27°52'15.60" 82°51'17.40" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-187 Florida 27°52'12.00" 82°51'18.00" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 1 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-188 Florida 27°52'6.00" 82°51'14.40" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-189 Florida 27°51'59.40" 82°51'15.60" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 1 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-190 Florida 27°51'55.20" 82°51'15.60" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 1 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-191 Florida 27°51'51.60" 82°51'16.20" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 4 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-192 Florida 27°51'46.20" 82°51'16.80" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 6 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-193 Florida 27°51'43.80" 82°51'15.60" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 5 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-194 Florida 27°51'40.20" 82°51'13.80" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 2 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-195 Florida 27°51'36.00" 82°51'13.80" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 5ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-196 Florida 27°51'15.00" 82°51'58.80" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 16 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-197 Florida 27°50'45.00" 82°50'48.00" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-198 Florida 27°50'25.20" 82°50'25.20" Unknown 2006 Pinellas County South Shore Mitagation Reefs(MIR) pinellascounty_reef 0 ft Diving habitat/recreational Apr-06 Date used is a completion date not reflective of individual reefs

FL-199 Florida 26°54'48.00" 82° 7'37.20" Other Tires 2007 Charlotte County Old Tire Reef-1 Charlotte County Art. Reefs 8 ft Fish Habitat/Rec. Fishing 2007 As of 2007

FL-200 Florida 26°50'39.00" 82° 5'19.02" Rock Concrete Culverts 2007 Charlotte County Old Tire Reef-2 Charlotte County Art. Reefs 13 ft 2007

FL-201 Florida 26°50'59.34" 82° 5'19.02" Rock 12' reef balls, concrete modules 2007 Charlotte County Charlotte Harbor Reef-1 Charlotte County Art. Reefs 13 ft 2007

FL-202 Florida 26°50'59.34" 82° 5'17.76" Rock 12' reef balls, concrete modules 2007 Charlotte County Charlotte Harbor Reef-2 Charlotte County Art. Reefs 13 ft 2007

FL-203 Florida 26°51'30.12" 82° 5'19.08" Rock 12' reef balls, concrete modules 2007 Charlotte County Charlotte Harbor Reef-3 Charlotte County Art. Reefs 13 ft 2007

FL-204 Florida 26°51'30.12" 82° 5'17.76" Rock 12' reef balls, concrete modules,culverts 2007 Charlotte County Charlotte Harbor Reef-4 Charlotte County Art. Reefs 13 ft 2007

FL-206 Florida 26°54'42.00" 82°21'48.00" Rock Bridge rubble 2007 Charlotte County Englewood Fish Haven Charlotte County Art. Reefs 22 ft 2007

FL-207 Florida 27°22'4.50" 82°34'28.62" Mixed Concrete, FPL insulators, reef balls Sarasota Bay, Sarasota County Hart's Family Sarasota.gov 10 ft

FL-208 Florida 27°20'12.02" 82°34'33.20" Rock Concrete rubble Sarasota Bay, Sarasota County O.D. Miller Sarasota.gov 4 ft

FL-209 Florida 27°19'42.54" 82°33'50.94" Mixed Concrete, FPL insulators, reef balls Sarasota Bay, Sarasota County Pop Jantzen Sarasota.gov 0 ft

FL-210 Florida 27°19'43.62" 82°33'27.12" Mixed Concrete, FPL insulators Sarasota Bay, Sarasota County Jim Evans Sarasota.gov 3 ft

FL-211 Florida 27°18'51.72" 82°34'17.52" Mixed Concrete, FPL insulators Sarasota Bay, Sarasota County
Bully Powers Sarasota.gov 2 ft

FL-212 Florida 27°18'41.88" 82°32'32.22" Mixed Concrete, FPL insulators Sarasota Bay, Sarasota County
Rose Coker Sarasota.gov 2 ft

FL-213 Florida 27°22'22.80" 82°35'31.50" Mixed Rocks, Boulders, reef balls Sarasota Bay, Sarasota County
Jonnie Walker Sarasota.gov 12 ft

FL-214 Florida 27°21'4.80" 82°35'52.98" Rock Reef balls Sarasota Bay, Sarasota County Sportfishing
Anglers Club Sarasota.gov 4 ft

FL-215 Florida 27° 6'11.22" 82°27'51.42" Rock Limestone boulders Sarasota County .62 at 152- Venice
Inlet Sarasota.gov 1 ft

FL-216 Florida 27° 6'2.40" 82°27'50.16" Rock Limestone boulders Sarasota County .77 at 156- Venice
Inlet Sarasota.gov 3 ft

FL-217 Florida 27° 5'52.14" 82°27'44.46" Rock Limestone boulders Sarasota County .96 at 155- Venice
Inlet Sarasota.gov 0 ft

FL-218 Florida 27° 5'45.36" 82°27'41.34" Rock Limestone boulders Sarasota County 1.08 at 156- Venice
Inlet Sarasota.gov 0 ft

FL-219 Florida 27° 3'54.96" 82°26'59.88" Rock Limestone boulders Sarasota County 3.02 at 159- Venice
Inlet Sarasota.gov 0 ft

FL-220 Florida 29°49'52.08" 84°30'14.94" Rock Concrete rubble Saint George Sound, Franklin County
Florida Gas Transmission Reef Florida Gas Transmission Company oarreefs.org 16 ft

FL-221 Florida 29°53'36.30" 84° 7'40.14" Rock Modules/ concrete fish haven Apalachee Bay, Wakullai County
OAR-2K Reef 25 ft 30 TOWERS & 12 FISH HAVENS IN A 50
METER PENTAGON SHAPE

FL-222 Florida 29°57'3.18" 84° 4'49.02" Rock Modules/ concrete cubes (108) Apalachee Bay, Wakullai County Dog Ballard Phase 3 20 ft 108 - 1 METER SQUARE CUBES PLACED IN A TIGHT SQUARE,

FL-223 Florida 29°58'9.60" 84° 7'55.20" Rock Modules/ concrete cubes (24) Apalachee Bay, Wakullai County Wakulla #1 Big Bend Reef 19 ft 24 PRE-FABRICATED CUBES ONE METER ON A SIDE-50M SPACED HEXAGON

FL-224 Florida 29°58'8.40" 84° 8'22.62" Rock Modules/ concrete cubes (96) Apalachee Bay, Wakullai County Wakulla #2 Big Bend Reef 19 ft 96 PRE-FABRICATED CUBES ONE METER ON A SIDE-50M SPACED HEXAGON

FL-225 Florida 29°57'3.06 84° 4'51.12" Rock Concrete culverts Apalachee Bay, Wakullai County Dog Ballard Phase 1 20 ft 253 TONS OF CONCRETE CULVERTS.

FL-226 Florida 29°57'6.72" 84° 4'49.14" Rock Concrete poles Apalachee Bay, Wakullai County Dog Ballard Phase 2 20 ft NON-GRANT PROJECT, LARGE CONCRETE POLES

TX-1 Texas 28° 7' 41.34" 97° 4' 4.58" Shell oysters 2009 Copano Bay TNC Copano Bay Reef 6 ft

TX-2 Texas 28° 36' 14.46" 96° 29' 13.31" Rock limestone 2005 Lavaca Bay Alcoa Reef 10.9 acres 6-12 inches 2 ft

TX-3 Texas 29 32' 26.20 94 52' 42.11 Rock limestone rock 2000 Galveston Bay Reef Pad 1 7 ft

TX-4 Texas 29 32' 28.98 94 53' 1.17 Rock limestone rock 2000 Galveston Bay Reef Pad 2 6 ft

TX-5 Texas 29 32' 22.82 94 52' 59.47 Rock limestone rock 2000 Galveston Bay Reef Pad 3 6ft

TX-6 Texas 29 32' 20.47 94 52' 51.29 Rock limestone rock 2000 Galveston Bay Reef Pad 4 7ft

TX-7	Texas	29 32' 2.87	94 54' 1.95	Rock	limestone rock	2000	Galveston Bay	Reef Pad 5	7ft	
TX-8	Texas	29 32' 55.61	94 54' 57.56	Rock	limestone rock	2000	Galveston Bay	Reef Pad 6	7ft	
TX-9	Texas	29 32' 55.61	94 54' 57.56	Rock	limestone rock	2000	Galveston Bay	Reef Pad 7	7 ft	
TX-10	Texas	29 33' 11.19	94 55' 1.74	Rock	limestone rock	2000	Galveston Bay	Reef Pad 8	6 ft	
TX-11	Texas	29 30' 52.43	94 52' 6.94	Rock	limestone rock	2000	Galveston Bay	Reef Pad 9	6ft	
TX-12	Texas	29 31' 13.63	94 52' 21.18	Rock	limestone rock	2000	Galveston Bay	Reef Pad 10	6ft	
Tx-13	Texas	29 32' 18.94	94 52' 59.35	Rock	limestone rock	2000	Galveston Bay	Reef Pad 11	6 ft	
TX-14	Texas	29 32' 18.94	94 53' 9.50	Rock	limestone rock	2000	Galveston Bay	Reef Pad 12	6 ft	
TX-15	Texas	29 32' 18.83	94 52' 29.96	Rock	limestone rock	2000	Galveston Bay	Reef Pad 13	7 ft	
TX-16	Texas	29 36' 4.66	94 50' 40.76	Rock	limestone rock	2000	Galveston Bay	Reef Pad 14 Tern Reef (south)	4 ft	
TX-17	Texas	29 36' 12.21	94 50' 34.61	Rock	limestone rock	2000	Galveston Bay	Reef Pad 15 Tern Reef (north)	4 ft	Enhanced with domes in 2012
TX-18	Texas	29 30' 14.54	94 47' 36.86	Rock	limestone rock, reef domes	2000	Galveston Bay	Reef Pad 16 Gas Pipe Reef	3 ft	Texas Parks and Wildife and Galveston Bay Foundation

TX-19 Texas 29 30' 50.69 94 39' 53.18 Rock limestone rock 2000 Galveston Bay Reef Pad 17 Stevenson Reef (south)
2 ft

TX-20 Texas 29 30' 54.98 94 39' 50.38 Rock limestone rock, reef domes 2000 Galveston Bay Reef Pad 18 Stevenson Reef (North) Texas Parks and Wildife and Galveston Bay Foundation 2 ft
Enhanced with domes in 2012

TX-22 Texas 28°34'34.41" 96°13'35.86" Rock Limestone rock Matagorda Bay Half Moon Reef
2 ft 1 ft

Table A.2 Water quality of individual reefs, acquired over 4 samplings from April to August 2011.

		Depth (ft)	Salinity (ppt)		Temp (°C)		Dissolved Oxygen (%)		Chl a (ug/L)		Secchi (cm)	
Bay	**Reef**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Apalachicola	S-AB	8.5	22	30	28.1	30.8	84.3	113.4	3.56	9.94	86	113
	H-AB	7	19	26	27.9	30.8	80.8	111.1	1.67	9.09	37	117
Barataria-Terrebone	S-BT	5.5	8	16	29.5	32.5	70.3	113.3	14.82	26.14	42	52
	R-BT	6	3	14	29.1	33.5	115.4	121.5	16.07	33.22	37	49
Calcasieu	H-CL	7	14	21	23	31.8	82	107.5	9.98	12.14	14	61
	H-C	6	14	18	24.1	31.8	84.1	98.9	14.73	19.4	30	58
Copano	H-CB	10	15	28	21.9	31.4	86.6	96.3	1.08	3.85	32	91
	S-CB	10	16	28	21.8	30.8	88.2	99.4	2.12	4.17	39	95
Keller/Lavaca	H-KL	7	24	31	22.8	32.9	91.5	105.9	0.28	8.28	44	83
	R-KL	10	18	32	22.3	32.3	80.9	97.1	2.34	16.81	43	94
Mobile	R-MB3	8.5	7	14	26	32	86.1	97	3.94	15.03	65	79
	R-MB1	5	7	17	27	31.7	87.7	102	3.95	13.37	46	71
	R-MB2	10	14	19	25	30.8	76.3	105.5	1.67	14.3	57	109
	H-MB	6	11	21	24.6	31	72.1	93.4	4.48	11.49	28	67
StLouis	R-SL	6	2	17	24.4	33.4	87.2	126.8	10.21	22.02	30	71
	S-SL	5.5	3	15	24.5	33.3	68.7	107.1	3.07	13.03	41	61
	H-SL	12	1	17	23.8	33	87.8	110.8	5.77	24.96	40	71
Vermillion	S-VB	7.5	0	12	28.5	31.7	71.4	97.3	7.38	21.75	9	57
	R-VB	6.5	2	29	25.4	33.2	86.6	116	3.85	38.43	12	36
	H-VB	4	1	15	26.5	33	82.1	97.6	2.17	16.38	13	40

VITA

Jessica Nicole Furlong is from Iowa.