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Fish Community Analysis Using Multidirectional ROV Video Surveys in the Northwestern Gulf of Mexico

Keegan J. Angerer

The University of Texas Rio Grande Valley

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FISH COMMUNITY ANALYSIS USING MULTIDIRECTIONAL ROV VIDEO SURVEYS IN THE NORTHWESTERN GULF OF MEXICO

A Thesis
by
KEEGAN J. ANGERER

Submitted in Partial Fulfillment of the

Requirements for the degree of

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The University of Texas Rio Grande Valley
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FISH COMMUNITY ANALYSIS USING MULTIDIRECTIONAL ROV VIDEO SURVEYS IN THE NORTHWESTERN GULF OF MEXICO

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COMMITTEE MEMBERS

Dr. Richard J. Kline
Chair of Committee

Dr. David W. Hicks
Committee Member

Dr. Erin E. Easton
Committee Member

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ABSTRACT

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In this study, ROV surveys with multidirectional video were used to analyze the fish communities associated with artificial reef patches in the Rio Grande Valley artificial reef 13.7 km off the coast of South Padre Island, TX. Nine configurations of reef patches consisting of varying combinations and densities of concrete pyramid and low-profile modules were surveyed. The highest species diversity was found at patches with large deployments of both pyramids and low-profile modules. Total Red Snapper *Lutjanus campechanus* abundance did not differ between configurations, but the highest abundances of juvenile Red Snapper were found at configurations with one pyramid and one low-profile module and at the largest low-profile only sites. Negative correlations between juvenile Red Snapper and both Grey Triggerfish *Balistes capriscus* and adult Red Snapper were identified. The results of this study indicate that artificial reefs with separate habitat areas composed of 1) large deployments of mid-profile structures for older juvenile and adult Red Snapper and Grey Triggerfish and 2) isolated patches of low-profile habitat or a single mid-profile structure with associated low-profile habitat for small juvenile Red Snapper will be the most effective for fisheries enhancement and supporting diverse fish assemblages.

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CHAPTER I

INTRODUCTION

Natural reef habitat in the Gulf of Mexico (GoM) is sparse and frequently degraded by human activity such as trawling and dredging (Wells et al. 2008). Natural structured habitat on the inner continental shelf of the northwestern GoM consists of relic shell reef, shell hash, relic submerged barrier islands, scattered rocky reefs, and relict coralgal reefs (Wells et al. 2009; Hicks et al. 2013). The northwestern GoM, from the Rio Grande to Pensacola, has 1.3 – 3.0% natural reef cover, much of which is low relief (< 1.5 m) (Parker et al. 1983). The GoM's most recreationally and commercially valued fishes, such as snapper (Lutjanidae), grouper (Serranidae), jack (Carangidae), and triggerfish (Balistidae) species, rely on structured habitats at critical points in their lives, particularly as juveniles and young adults and for spawning aggregations (Coleman et al. 2000; Gallaway et al. 2009; Heyman et al. 2019). Due to their specific life histories, these fishes are especially vulnerable to overfishing, and efforts to effectively manage their fisheries are ongoing (Heyman et al. 2019; Farmer et al. 2020; Stuntz et al. 2021). Red Snapper *Lutjanus campechanus* is the most economically valuable fish in the GoM with a robust recreational fishery and commercial landings of over three million kilograms in 2016 (SEDAR 52, 2018). The Red Snapper fishery endured collapse in the late 1980s and experienced landing reductions for both commercial and recreational fishermen throughout their long recovery process. Intense fishing pressure, lack of habitat availability, and high juvenile (age-0 through age-1) mortality due to predation and incidental bycatch in the shrimp fishery are factors inhibiting full recovery (Gallaway et al 2009; Shipp and Borton2009; Cowan et al. 2011). The latest report suggests that Red Snapper are not overfished and are not undergoing overfishing, though catch rates are still restricted (SEDAR 52, 2018).

To supplement limited natural reef and to enhance fishery stocks, artificial reefs have been deployed extensively throughout the GoM and are included in the fishery management plans of several states (Gallaway et al. 2009). Artificial reefs in the GoM include constructed pyramid reefs, decommissioned oil platforms, intentionally sunk ships, and many materials of opportunity, such as concrete culverts, highway dividers, and railroad ties. In contrast to predominately low-relief natural habitat in the GoM, artificial reefs there are generally characterized as mid (1.5 – 5m) or high (> 5 m) vertical relief. Oil rig jackets, standing platforms, and toppled platforms have vertical relief ranging from around 10 to over 60 m, sunken ships ranged from 5 to 9 m of relief, and the increasingly popular concrete pyramids have ~3 m of relief (Ajemian et al. 2015a). Many artificial reefs in the GoM consist of just one or a few types of material, such as sunken ships, toppled oil platforms, or 100s of identical concrete pyramid structures.

In artificial reef research there is a debate regarding if artificial reefs support increased production of fish, or if they instead attract fish from the surrounding area, increasing their vulnerability to fishing pressure (Pickering and Whitmarsh 1997). In the GoM this debate is frequently discussed in the context of Red Snapper management. For many reef-associated fish, including Red Snapper, mortality of juvenile fish is high and it has been theorized that protection in the form of available hard-bottom habitat is a limiting factor on population size. (Szedlmayer 2007; Gallaway et al. 2009). If this is the case, then increasing the available habitat (i.e., artificial reefs) for juveniles and adults would increase the overall production of Red Snapper. Other authors argue that hard-bottom habitat is not a limiting factor and artificial reefs in the GoM, at least for Red Snapper, serve as attractors rather than a means of increasing production (Bohnsack 1989; Cowan et al. 2011). In reality, attraction or production likely depends on artificial reef design, configuration, and the species in question.

To encourage production for a particular species, artificial reefs should supply suitable habitat for juvenile recruitment as well as adults (Brickhill et al. 2005). Exploited reef fish, such as grouper, triggerfish and snapper species, undergo ontogenetic shifts to habitats with higher structural complexity as they grow larger in size (Dahlgren and Eggleston 2000; Szedlmayer and Lee 2004). Juvenile Red Snapper settle first on bare substrate, shell, or other low-profile habitats, then move to increasingly complex habitats as they age (Szedlmayer and Lee 2004; Wells et al. 2008). Age-0 Red Snapper and other juvenile fish densities have been found to be highest at low-profile reefs that were isolated from more complex reefs (Mudrak and Szedlmayer 2012; Arney et al. 2017). Natural and artificial low-profile habitats like shell banks and limestone rubble also attract settlement age fish (Rooker et al. 2004; Dance et al. 2021). In contrast, oil and gas platforms function as large, high-profile and structurally complex artificial reefs that can attract older and larger fishes. For example, hydroacoustic and visual surveys at standing oil and gas platforms found large numbers of age-2 Red Snapper, and yielded total fish community counts between 10 and 30 thousand individuals (Wilson et al. 2006; Ajemian et al. 2015b). Because platforms house larger fish and an abundant and diverse set of predators (VERSAR, 2009), they may contribute to limiting the presence of juvenile fish in the surrounding area (Dance and Rooker 2019). At concrete block and shell artificial reefs off the coast of Alabama, Piko and Szedlmayer (2007) showed that sites where predators were excluded using cages exhibited significantly higher juvenile Red Snapper abundance than uncaged sites. Conspecific and interspecific competition may also contribute to the trend of reduced juvenile fish density at, or close to, large reefs. Presence of age-1 Red Snapper have limited the recruitment of age-0 Red Snapper at low-profile reefs (Workman 2002), and other studies have observed larger Red Snapper cannibalizing or aggressively defending complex habitats from smaller Red Snapper (Bailey et al. 2001; Mudrak and Szedlmayer 2012). Another common reef species, Grey Triggerfish *Balistes capriscus* can be abundant on GoM artificial reefs and are territorial (Simmons and Szedlmayer 2012). Further, they chase and attack Red Snapper, and removal of Grey Triggerfish from artificial reef sites resulted in a shift to smaller size classes of Red Snapper (Simmons and Szedlmayer 2018). Artificial reefs in the GoM are supplying primarily mid- and high-profile habitat, in contrast to much of the natural reef in the GoM which is frequently low-profile. Concrete pyramid-only habitats in particular are becoming increasingly common in the GoM and few artificial reef locations include purpose-built low-profile habitat. Jaxion-Harm and Szedlmayer (2015) found that a mixed reef design, with a variety of relief types in a reef complex, yielded a wide distribution of Red Snapper size classes, with smaller Red Snapper more frequent on small, isolated reefs, and larger Red Snapper more frequent on large reefs. It is possible that high density reef deployments of mid- to high-profile structure are lacking critical habitat for juvenile and intermediate stages of many reef-associated fishes.

Artificial reef designs and configurations are important determinants of fish assemblage. Froehlich and Kline (2015) found that at reefs consisting of concrete culverts in density categories of 1-30, 31-60, 71-120, and 121-190 culverts, the medium density category (71 - 120 culverts) was the most efficient for maximizing fish abundance per material placed. Artificial reef spacing is another important component of design. Artificial reef modules of 1 m^3 placed 12 – 50 m from a large reef had greater fish diversity and density when compared to reefs directly adjacent to the large reef (Belmaker et al. 2005). A similar trend was identified by Mudrak and Szedlmayer (2012) where diversity and recruitment at small cinderblock reefs was greater when placed 500 m from a larger cage reef compared to 15 m from the cage reef. Further, Jordan et al. (2005) showed that fish abundance and diversity increased at 1 m^3 concrete block modules spaced 25 m apart when compared to modules spaced 5 or 15 m apart. At modules placed 0.33 m apart (functionally a single, larger reef) there were more piscivorous species and larger individuals than the sites where each module was separated by 5 m or more. Similarly, Bohnsack et al. (1994) observed that arrays of eight identical reef modules exhibited higher diversity, abundance and biomass when compared to smaller reef arrays of one, two, and four of the same reef modules. However, diversity and abundance were higher at a total of eight modules spread across multiple small deployments (e.g four arrays with two modules each) when compared to eight modules in one array. Large reefs had higher biomass than small reefs due to the presence of large individuals. In comparison, the small reefs had higher fish density because of large numbers of small fish (Bohnsack et al. 1994). These findings are particularly relevant for management of Red Snapper because they indicate that different configurations of identical artificial reef structures can make habitat more or less suitable for juveniles or adults. For example, off the coast of Hawaii, Schroeder (1987) observed that juvenile recruitment rates increased as attractor (mesh cages) patch size and isolation increased. However, similar to results from Bohnsack et al. (1994), recruitment per unit area was reduced as attractor patch size increased. Hackradt et al. (2011) compared fish assemblages between artificial reef balls, pyramids, quadrilaterals, and cones, they found that at least 50% of fish species were attracted to a specific type of structure over the others. In summary, material type, spacing, density, and various combinations of high and low-profile artificial structures have differential effects, not just on individual species, but on different life stages of the same species. Artificial reefs are generally expensive to construct and deploy. Therefore, identifying optimal structure design and artificial reef configuration (defined here as the combination of the spatial arrangement and density of reef structures, and their distance from other natural or artificial reef habitats) is essential to effective and cost-efficient deployment of artificial reefs.

To determine the effects of artificial reef design and configuration, many studies employ visual survey methods to examine the fish community. Every survey method has its own advantages and biases, and differing conditions and objectives should determine the relative benefit of using one technique over another. Remotely operated vehicles (ROVs) outfitted with an array of video equipment are an increasingly common visual survey method. ROVs mitigate some of the disadvantages inherent in scuba-based surveys methods, such as underwater visual census (UVC), because ROVs are not limited by depth or bottom-time (Wetz et al. 2020). Additionally, ROVs serve as a platform for an assortment of equipment such as sonar, and positioning systems. These tools are useful for locating structure and tracking survey progress in low-visibility environments like the GoM. Attraction and avoidance are two common biases that occur depending on species and survey method. Many fish species avoid divers, particularly in heavily fished areas (Murphy and Jenkins 2010; Lindfield et al. 2014). A study by Wetz et al. (2020) in the Northern GoM found that diversity estimates from fish surveys performed with roving diver surveys were not significantly different from surveys performed using an ROV. However, abundance was significantly higher in roving diver surveys, and certain species were observed on only ROV surveys or only roving diver surveys. Further, snapper and jack species were encountered more frequently by ROV survey and exhibited attraction behavior towards the vehicle. Cryptic species are also less likely to be seen in ROV surveys (Andaloro et al. 2013;

Ajemian et al. 2015b). Low-visibility environments, continuous surveying, attraction to an ROV, and structurally complex survey areas make it extremely difficult to track fish without counting them multiple times. To compensate for this, researchers performing video surveys use a method called maximum minimum count or maxN (Willis and Babcock 2000). The maxN method takes a single abundance count when the maximum number of fish can be seen at a single point in time from a survey recording. Using maxN counts eliminates the risk of counting the same fish multiple times and provides a conservative abundance estimate. Most ROVs only have one or two cameras recording at once, generally oriented to record forward, back, or downwards (Andaloro et al. 2013; Ajemian et al. 2015b; Harvey et al. 2021). With just one or two cameras running during a survey there can be multiple “blind spots”, resulting in not counting any fish outside the field of view during a maxN count. If an ROV has sufficient size and power, blind spots can be mitigated by mounting many cameras in different directions, allowing for a greater continuous field of view during video surveys. Critically, ROV video-based surveys also have the advantage that they create a permanent record of the survey. While this can result in backlogs in video processing (Murphy and Jenkins 2010), it also allows for referencing the video as many times as needed, and the same video can be used for other research projects in the future.

This study uses an ROV with five mounted cameras to perform multidirectional video surveys of the fish community at multiple configurations of prefabricated concrete low-profile and mid-profile artificial reef modules at the Rio Grande Valley reef (RGV reef) (Outer Continental Shelf Lease Block PS-1105). The results are used to investigate the effects on the fish assemblage resulting from differences in reef module density, and configuration of low- and mid-profile habitat. This information is then used to develop recommendations for optimal artificial reef design.

Objectives and Hypotheses

The objective of this study is to analyze differences in reef fish community assemblage and separately, adult and juvenile Red Snapper distribution and abundance among nine artificial reef patch configurations of different densities of low-profile (LP) modules, and mid-profile pyramids (PY), and combinations of both LP and PY (MX).

Specific hypotheses tested are:

1. LP Sites will have significantly different fish communities than PY or MX sites.
2. The fish communities at 1, 4 and 16 sized sites within the same module type (PY, LP or MX) will be significantly different from each other.
3. The highest species richness will be observed on intermediate density sites (4 PY, 4 LP, 4 MX).
4. Juvenile Red Snapper will have the greatest abundance on LP sites as compared to PY and MX sites.
5. Due to ontogenetic shifts during growth, Red Snapper will have the greatest average length at the densest sites with pyramids (16PY, and 16MX).
6. Mixed sites, 1MX, 4MX, and 16MX will have significantly more juvenile Red Snapper than their pyramid counterparts: 1PY, 4PY, 16PY.

CHAPTER II

METHODS

Study Site

This study was conducted in the northwestern GoM at the Rio Grande Valley (RGV) artificial reef (26.281287°, -97.060168°) (Figure 1). Sites were located in the Coastal Management Plan (CMP) experimental reef zone, a 1.37 km^2 subsection of the RGV reef (Figure 2). This zone consisted of 51 sites laid out in a randomized design with nine configurations of concrete pyramid and low-profile modules with five to six replicates of each configuration (Table 1) (Figure 2) . Sites were deployed in 2018 and each site is 50 × 50 m and separated from the nearest adjacent site by at least 100 m. Szedlmayer and Schroepfer (2005) and Topping and Szedlmayer (2011) found that Red Snapper, unless emigrating to a different location, stayed within <100 m of their home reef patch, suggesting that the 100 m separation of the experimental reef sites in this study should limit conspecific interaction between sites. The experimental reef zone was 13.7 km from the shore of South Padre Island and ranged from 17 to 20 m depth. The substrate around the study sites consisted of sand and mud. The pyramids were ~3 × 3 × 3 m and had embedded cinderblocks in their walls, creating many ~13.7 × 13.7 cm cavities in addition to one large triangular cavity (Figure 3). The low-profile modules provided ~0.5 m of vertical relief and are 1.8 × 1.8 m concrete squares with embedded cinderblocks and limestone (Figure 4). The entire RGV reef including the experimental reef zone were open to year-round fishing under Texas state saltwater regulations.

Table 1: The nine artificial reef configurations and number of replicates for each site type at the experimental reef area in the Rio Grande Valley reef. PY = Pyramid, MX = Mixed, LP = Low-Profile.

RGV Experimental Reef Area Site Types	# of Pyramids	# of Low-Profile Modules	Replicates
1PY	1	0	5
4PY	4	0	6
16PY	16	0	6
1MX	1	1	5
4MX	4	4	6
16MX	16	16	6
1LP	0	1	5
4LP	0	4	6
16LP	0	16	6

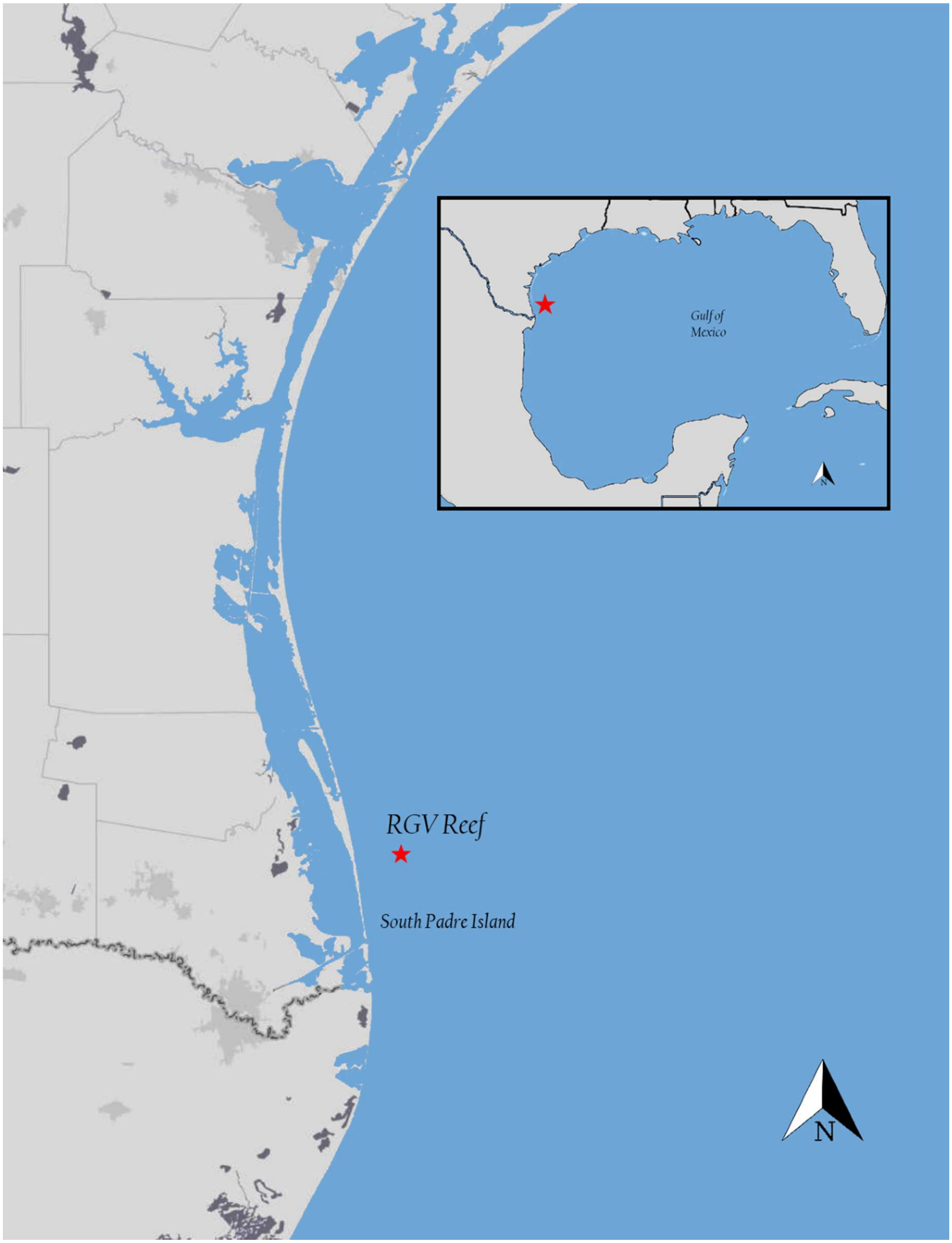


Figure 1: Rio Grande Valley artificial reef location 13.7 km from South Padre Island, TX

Figure 2: Deployment locations of habitat arrays in the experimental reef zone, part of the Rio Grande Valley reef. Low-profile modules are represented by blue squares, pyramids are represented by red triangles.

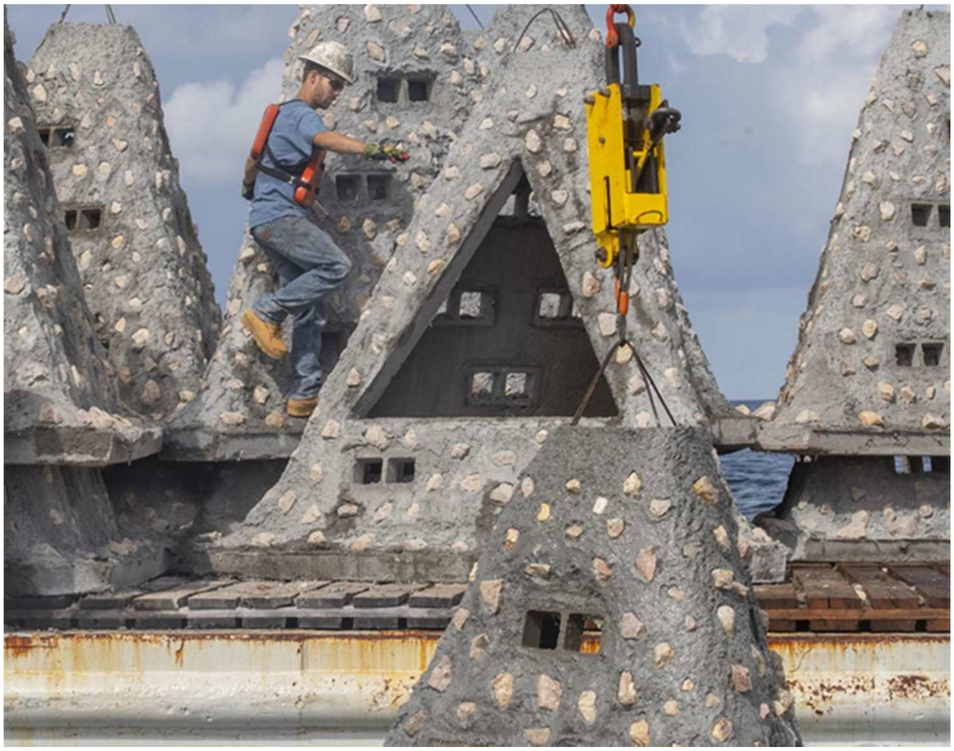


Figure 3: Concrete reefing pyramids used in the experimental reef area in the Rio Grande Valley artificial reef. ~3 m of vertical relief

Figure 4: Concrete low-profile modules used in the experimental reef area in the Rio Grande Valley artificial reef. ~0.5 m of vertical relief

ROV Video Sampling

An Outland 2000 ROV (Outland Technology, Slidell, Louisiana, United States) equipped with GoPro Hero 9 and Hero 5 cameras (GoPro, San Mateo, California, United States) was used to survey the fish communities. GoPro cameras were mounted in five positions so that video could be taken forward, back, left, right, and downward simultaneously. For all cameras, video was recorded in wide mode at 60 frames per second (fps) and 2.7k resolution. Each of the 51 sites was visited once across five sampling events between July and October of 2021. For each dive, the ROV was deployed near the center coordinates of the survey site. Once in the water, forward-looking sonar (Tritech Gemini 720is, Tritech International, Westhill, Aberdeenshire, Scotland) and a positioning system (Tritech MicronNav) were used to locate the reef sites. The ROV was flown towards the base of the pyramid or low-profile module and then was moved to at least one other side of the module as it collected multidirectional video. To locate fish obscured by the structure at low-profile modules, the ROV was flown above the modules so that small fish would be captured on the downward-facing camera. For sites with more than one unit, the first three low-profile modules and three pyramids encountered were surveyed.

Videos were time synced using the automatic audio time syncing function on Adobe Premiere Pro v22 (Adobe, San Jose, California, United States) video editing software. If the videos were still out of sync after automatic time syncing, then peaks in the audio waveforms between recordings were matched manually. After time syncing, the videos were arranged in a grid so that all videos could be observed simultaneously (Figure 5). A single modified maxN abundance count was determined for each unique fish species for each survey. To obtain this count, an observer continuously monitored the video recordings in grid format and marked the video frame where the most fish were visible across all five camera feeds. Then, from the marked time point, the number of fish was counted by viewing the same frame in full screen for each camera and counting all the individuals for that species. The total maxN count was determined by summing the counts from each individual camera at that time point for each species. If directionality of movement was apparent, as with schools of Pinfish *Lagodon rhomboides* moving across the view of one camera, then those fish were counted continuously until they had passed. Two separate counts were conducted for Red Snapper, one for juveniles, as determined by size (< ~175mm) and coloration, and one for adults.

To measure visibility, the forward-looking sonar recordings and the forward camera video were time synced. Using the sonar recordings and distance measuring tool in the Tritech Genesis software, visibility was measured as the distance from the sonar head to a low-profile or pyramid at the point in time when that structure became discernable on the forward camera. Pyramids were larger and visible from a further distance than low-profile modules. To correct for this, a linear regression was run between visibility measurements of low-profile modules and pyramids at mixed sites. With the resulting equation, visibility measurements at low-profile only sites were put in as the x value in the regression equation. Visibility at mixed sites used only the visibility measurements from the pyramid structures.

Red Snapper total length (TL) was measured using the forward-looking sonar. Points in the video when Red Snapper were broadside to the ROV were identified. Then that same time point was viewed in the sonar recordings. Red Snapper oriented at a broadside angle to the ROV, and which could be identified on the sonar, were measured with the measuring tool in Genesis. Low-profile modules were covered in varying amounts of sediment, so the amount of structure exposed at each low-profile module during the surveys was qualitatively estimated by analyzing the proportion of cinderblocks exposed from the sediment. Estimations were deemed to be accurate given that the low-profile modules are square and symmetrical.

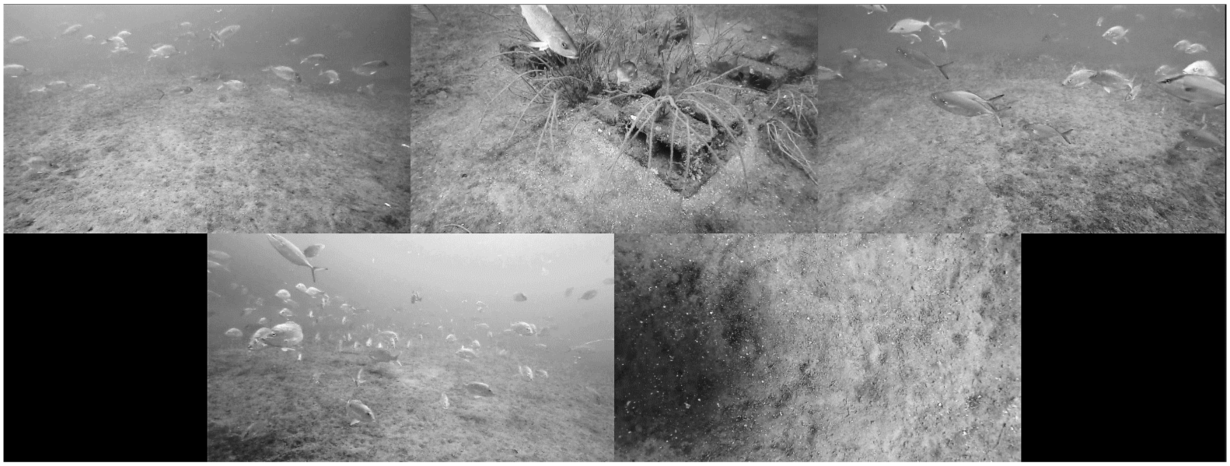


Figure 5: View of survey videos after arranging into a grid. Left camera is on the top left, forward camera top center, right camera top right, back camera bottom left, and downward camera bottom right.

Statistical Analyses

Abundance of adult and juvenile Red Snapper, Grey Triggerfish, and total Red Snapper were all tested for differences between site types using separate one-way ANCOVAs with visibility as a covariate. Natural log transformations were applied to the count data to improve conformity to the assumptions of ANCOVA (Cochran 1957), based on Kolmogorov-Smirnov (1933) normality tests, Levene's (1960) tests, and boxplots. Scatterplots were used to determine if there was a linear relationship between visibility and the abundance counts. Post-hoc analyses were performed based on estimated marginal means. Species richness, Red Snapper length, and percentage exposure of low-profile module structure all violated the assumptions of ANCOVA. A Kruskal-Wallis (1952) test was used instead for these metrics. Post-hoc testing was conducted using the Dunn method (1964). A Spearman's (1904) rank-order correlation was used to examine the relationship between adult Red Snapper abundance and juvenile Red Snapper abundance, as well as the relationship between Grey Triggerfish abundance and adult and juvenile Red Snapper abundance. All univariate statistics were performed using SPSS v27 (IBM, Chicago, Illinois, United States).

Fish community analyses were performed using PRIMER-E and PERMANOVA+ v7 software (Quest Research, Auckland, New Zealand). A square root transformation was applied to the fish community data to reduce the effect of extremely abundant species. Then a Bray-Curtis (1957) similarity matrix was built and a PERMANOVA test, with visibility as a covariate, was run to determine if there were differences between the overall fish community between sites. SIMPER analysis was used to examine which species drove the dissimilarity between site types. Finally, a bootstrapped metric, multidimensional scaling (mMDS) plot was created to visually support the results of the PERMANOVA (Clarke and Gorley 2015). For all post-hoc tests with multiple comparisons, the Benjamini-Hochberg method (1995) was used to control for the false discovery rate.

CHAPTER III

RESULTS

Throughout the entirety of the study, 4400 individual fish were counted, and 33 species were identified (Table 2). Red Snapper were the predominant species, composing 48.19% of the total fish abundance followed by Pinfish (16.95%), Grey Triggerfish (12.05%), Atlantic Spadefish *Chaetodipterus faber* (6.59%), and Blue Runner *Caranx crysos* (4.64%). Mean survey duration was 4 minutes and 13 seconds ± 22 seconds, and a mean of 6.08 ± 0.58 red snapper were measured at each site. Camera malfunctions occurred on one 4MX site, one 16MX site, and one 4PY site so they were excluded from the study. The proportion of exposed low-profile structure was significantly different between site types (Kruskal-Wallis: $H_5 = 39.30$, $P < 0.001$). Low-profile structures at 1LP and 4LP sites were significantly more buried than 4MX, 16MX and 16LP sites (all $P < 0.006$) (Figure 6). Three 1LP and three 4LP sites could not be located at all and the modules were presumed completely buried. One 4LP site only had one module remaining and was considered a 1LP site when reporting means. Due to multiple missing sites and missing modules, data collected from 1LP and 4LP site types were excluded from all fish community statistical analyses, except for correlations.

Table 2. Total fish abundance by species from ROV video surveys at Pyramid (PY), Low-profile (LP), and Mixed (MX) sites in the experimental reef area at the RGV reef in the Gulf of Mexico. Collected between July and October 2022.

Scientific name	**Common Name**	**1MX**	**4MX**	**16MX**	**1PY**	**4PY**	**16PY**	**1LP**	**4LP**	**16LP**	**Total**
Lutjanus campechanus	Adult Red Snapper	155	246	200	167	247	332	3	13	27	1390
Lutjanus campechanus	Juvenile Red Snapper	164	64	19	80	40	16	37	147	164	731
Lagodon rhomboides	Pinfish	8	0	150	207	6	13	40	76	246	746
Balistes capriscus	Grey Triggerfish	23	51	151	43	65	129	7	12	49	530
Chaetodipterus faber	Atlantic Spadefish	65	39	52	12	38	84	0	0	0	290
Caranx crysos	Blue Runner	26	8	13	140	2	15	0	0	0	204
Haemulon aurolineatum	Tomtate Grunt	13	11	8	4	26	9	0	10	1	82
Seriola dumerili	Greater Amberjack	6	3	31	27	5	9	0	0	0	81
Pareques acuminatas	Cubbyu	9	21	15	2	6	9	0	0	5	67
Archosargus probatocephalus	Sheepshead	0	6	11	0	6	19	0	0	1	43
Orthopristis chrysoptera	Pigfish	1	2	5	7	0	15	1	1	7	39
Rypticus maculatus	White-Spotted Soapfish	4	6	3	2	6	2	0	0	4	27
Lutjanus griseus	Gray Snapper	8	2	14	1	2	9	0	0	0	36
Gobiidae Spp.	Goby Spp.	0	0	21	0	0	0	0	0	0	21
Unidentifiable Juvenile	Unidentifiable Juvenile	0	3	16	0	0	0	0	0	1	20
Carangoides bartholomaei	Yellow Jack	0	1	9	1	5	1	0	0	0	17
Chromis Spp.	*Chromis* Spp.	0	0	17	0	0	0	0	0	0	17
Decapterus punctatus	Round Scad	0	0	0	9	0	0	0	0	0	9
Scorpaena plumieri	Spotted Scorpionfish	1	2	1	0	1	0	0	0	2	7
Chaetodon ocellatus	Spotfin Butterflyfish	0	0	3	0	0	2	0	0	0	5
Lutjanus synagris	Lane Snapper	0	2	2	0	0	0	1	0	0	5
Stegastes leucostictus	Beaugregory	0	2	2	0	0	0	0	0	0	4
Sphoeroides spengleri	Bandtail Puffer	0	1	2	0	1	0	0	0	0	4
Scomberomorus Spp.	Mackerel Spp	0	0	0	0	0	4	0	0	0	4
Serranus subligarius	Belted Sandfish	1	1	0	0	0	0	0	2	1	5
Priacanthus arenatus	Bigeye	0	0	0	0	0	0	1	1	2	4
Aluterus monoceros	Unicorn Leatherjacket Filefish	0	0	0	2	0	0	0	0	0	2
Chilomycterus schoepfii	Striped Burrfish	0	0	0	0	0	0	0	0	2	2
Holocanthus bermudensis	Blue Angelfish	0	0	2	0	0	0	0	0	0	2
Echeneis neucratoides	Remora	1	0	0	0	0	0	0	0	0	1
Pomacanthus paru	French Angel	0	0	1	0	0	0	0	0	0	1
Pterois volitans	Lionfish	0	0	1	0	0	0	0	0	0	1
Holacanthus ciliaris	Queen Angelfish	0	0	0	0	0	1	0	0	0	1
Epinephelus adscensionis	Rock Hind	0	0	1	0	0	0	0	0	0	1
Halichoeres bivittatus	Slippery Dick	0	0	1	0	0	0	0	0	0	1
	Total fish	485	471	751	704	456	669	90	262	512	**4400**

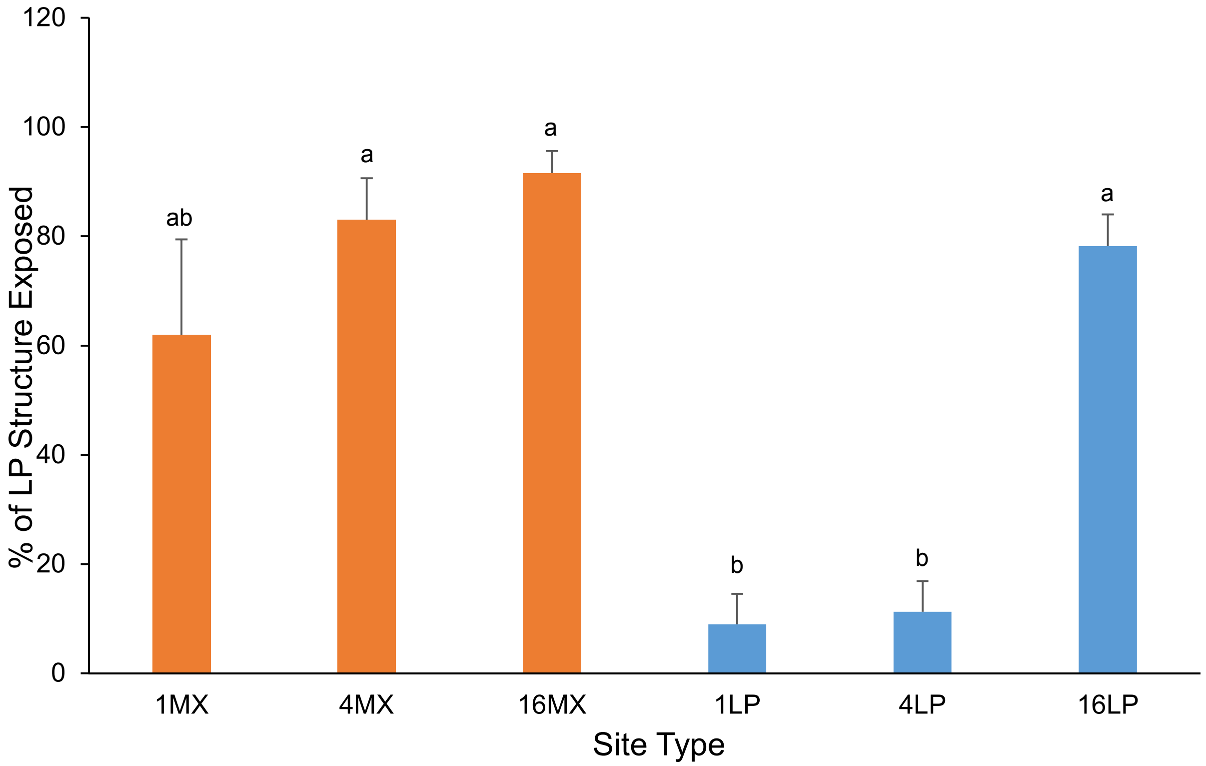


Figure 6: Percent estimated low-profile module structure exposed from the sediment (mean ± S.E) at LP, and MX sites. Bars which do not share the same letter have significant differences ($P < 0.05$) based on a Kruskal-Wallis test with post-hoc comparisons.

Species richness was significantly different between site types, (Kruskal-Wallis: $H_6 = 29.51$, $P < 0.001$). Site type 16MX had significantly higher species richness than site types 1MX ($H_6 = 19.80$, $P = 0.015$), 1PY ($H_6 = 23.20$, $P = 0.004$), and 16LP ($H_6 = -29.53$, $P = 0.001$). Site type 4MX had significantly higher species richness than site types 16LP ($H_6 = -23.73$, $P = 0.003$) and 1PY ($H_6 = -17.40$, $P = 0.036$). Site type 16PY had significantly higher species richness than site type 16LP ($H_6 = -18.92$, $P = 0.012$) (Figure 7).

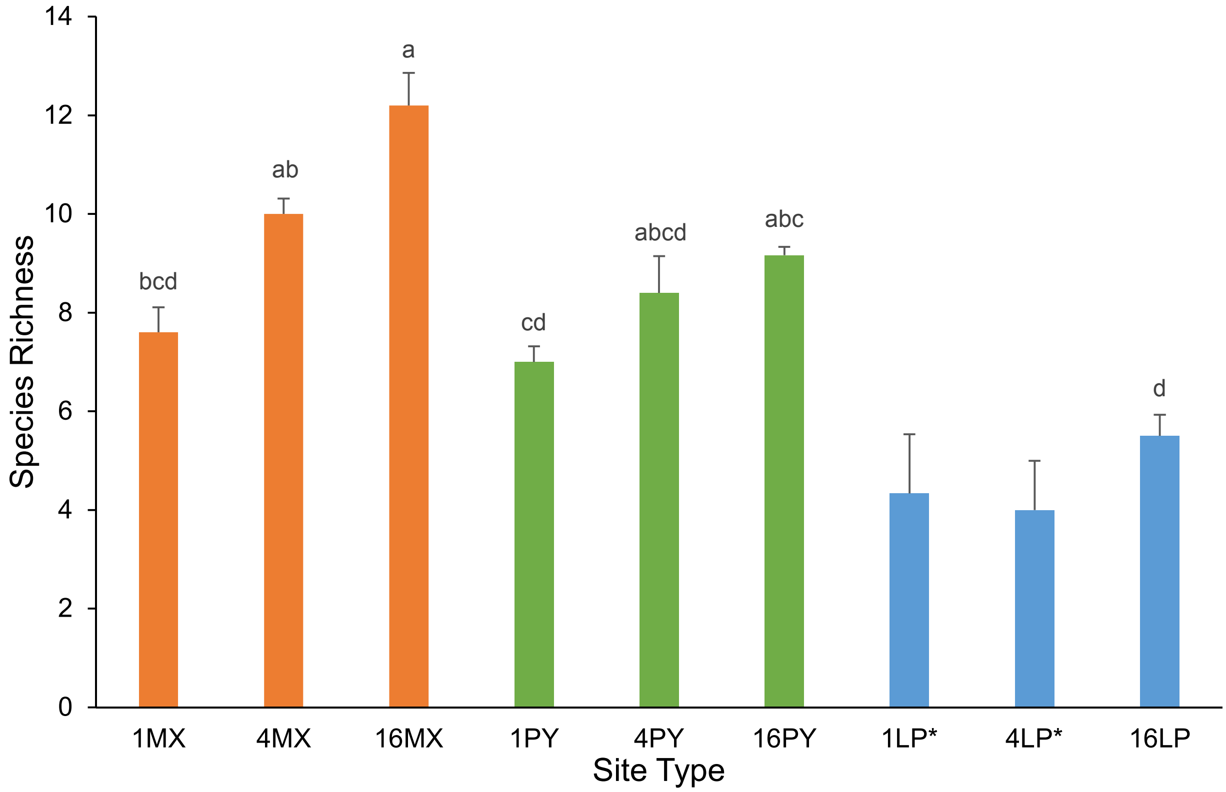


Figure 7. Species richness (mean ± S.E) for PY, LP, and MX site types at the RGV reef in the Gulf of Mexico. Bars which do not share the same letter have significantly different ($P < 0.05$) average species richness based on a Kruskal-Wallis test with post-hoc comparisons. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Fish communities differed significantly between site types (PERMANOVA: Pseudo-$F_6 = 2.75$, $P < 0.001$). Visibility as a covariate was not significant (PERMANOVA: Pseudo-$F_1 = 1.19$, $P = 0.289$). Site type 16LP had a significantly different fish community from all other site types (all $P < 0.046$), and site type 1MX was significantly different from 16MX ($P = 0.042$). All other site types were not significantly different from each other (Figure 8). SIMPER results indicated that fish community dissimilarity between site type 16LP and all other sites was generally driven by 16LP having fewer adult Red Snapper, more juvenile Red Snapper, and an absence of Atlantic Spadefish and carangid species (Table 3). Additionally, the greatest average dissimilarity was between site types 16LP and 16PY (72.01%), and 16LP and 16MX (70.04%) The fish community dissimilarity between site types 1MX and 16MX was primarily driven by more adult Red Snapper at 16MX, more juvenile Red Snapper at 1MX and more Grey Triggerfish at 16MX (Table 3).

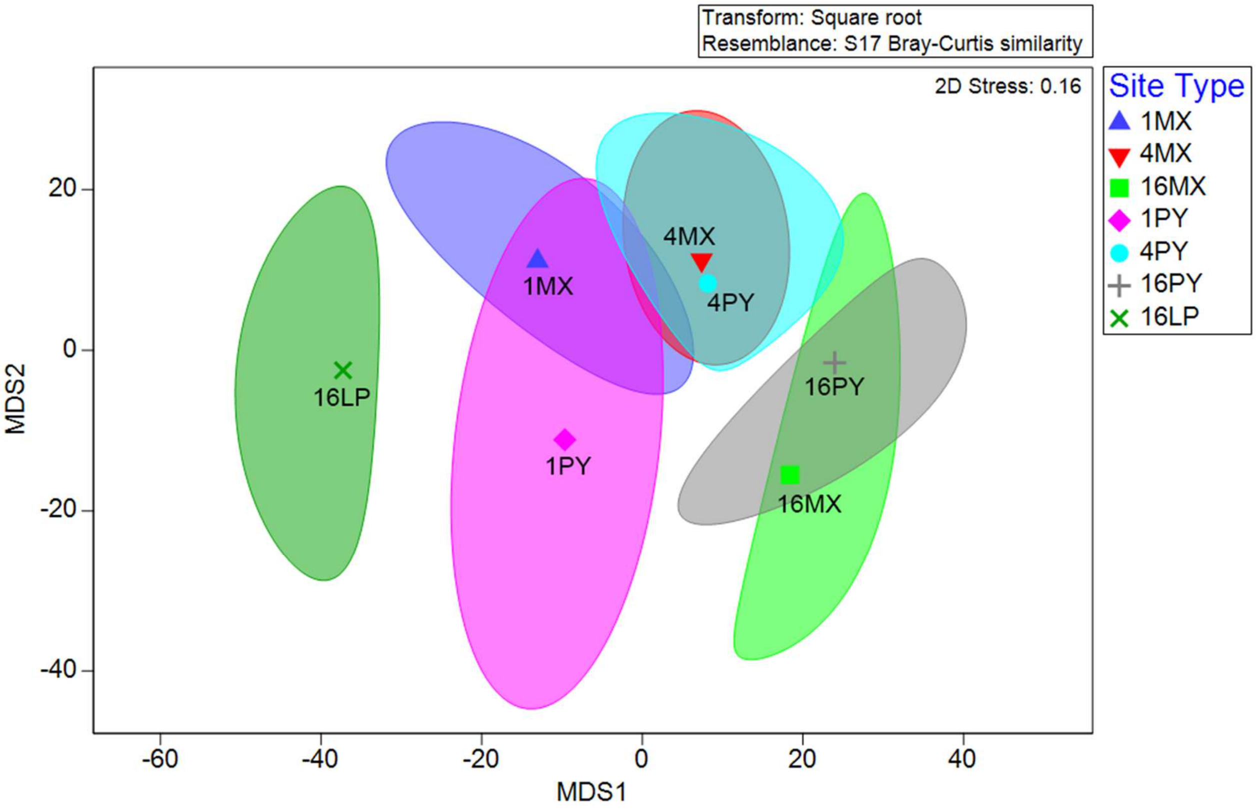


Figure 8: Metric multidimensional scaling plot with 95% confidence interval boundaries from bootstrap averaging comparing the fish community for PY, LP, and MX site types at the RGV reef in the Gulf of Mexico. According to PERMANOVA results 16LP had a significantly different fish community than all other site types ($P < 0.046$), and 1MX had a significantly different fish community from 16MX ($P = 0.042$). Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size. The 2D stress level indicates the degree of distortion from compressing the data to two dimensions.

Table 3: Top three species by dissimilarity contribution based on SIMPER results for PY, LP, and MX site types at the RGV reef in the Gulf of Mexico, which were determined to have significantly different ($P < 0.05$) fish communities based on PERMANOVA results. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Sites Compared	% Average dissimilarity	Species 1	% Dis. Contribution	Species 2	% Dis. Contribution	Species 3	% Dis. Contribution
16LP x 1MX	53.34	Adult Red Snapper	12.59	Juvenile Red Snapper	10.52	Grey Triggerfish	10.47
16LP average abundance		4.50		27.33		8.17	
1MX average abundance		31.00		32.80		4.60	
16LP x 4MX	60.02	Adult Red Snapper	20.10	Pinfish	14.97	Atlantic Spadefish	10.36
16LP average abundance		4.50		41.00		0.00	
4MX average abundance		49.20		0.00		7.80	
16LP x 16MX	70.04	Pinfish	13.43	Adult Red Snapper	12.16	Grey Triggerfish	9.69
16LP average abundance		41.00		4.50		8.17	
16MX average abundance		30.00		40.00		30.20	
16LP x 1PY	56.01	Pinfish	12.07	Adult Red Snapper	8.39	Blue Runner	6.90
16LP average abundance		41.00		4.50		0.00	
1PY average abundance		41.40		33.40		28.00	
16LP x 4PY	60.52	Adult Red Snapper	20.83	Pinfish	15.95	Atlantic Spadefish	10.13
16LP average abundance		4.50		41.00		0.00	
4PY average abundance		49.40		1.20		7.60	
16LP x 16PY	72.01	Adult Red Snapper	17.13	Juvenile Red Snapper	14.22	Pinfish	12.66
16LP average abundance		4.50		27.33		41	
16PY average abundance		55.33		2.67		2.166666667	
1MX x 16MX	59.23	Adult Red Snapper	12.59	Juvenile Red Snapper	10.52	Grey Triggerfish	10.47
1MX average abundance		31.00		32.80		4.60	
16MX average abundance		40.00		3.80		30.20	

Grey Triggerfish abundance was not significantly different between site types (ANCOVA: $F_{6, 37} = 1.78$, $P = 0.139$), visibility as a covariate was not significant (ANCOVA: $F_{1, 37} = 0.100$, $P = 0.755$) (Figure 9).

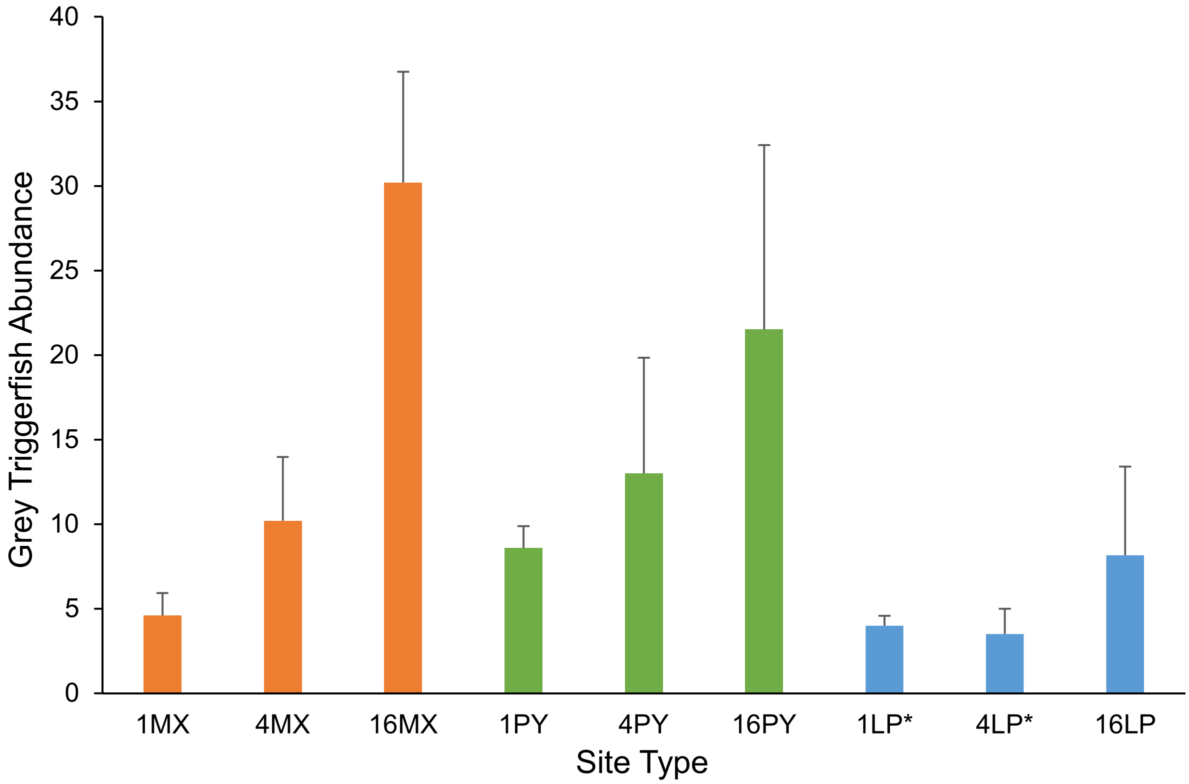


Figure 9: Grey Triggerfish abundance (mean ± S.E) for PY, LP and MX site types at the RGV reef in the Gulf of Mexico. One-way ANCOVA with visibility as a covariate revealed that there were no significant differences ($P < 0.05$) between site types. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Similarly, total Red Snapper abundance was not significantly different between site types (ANCOVA: $F_{6,37} = 1.31$, $P = 0.285$), visibility as a covariate was significant (ANCOVA: $F_{1,37} = 9.50$, $P = 0.004$). (Figure 10).

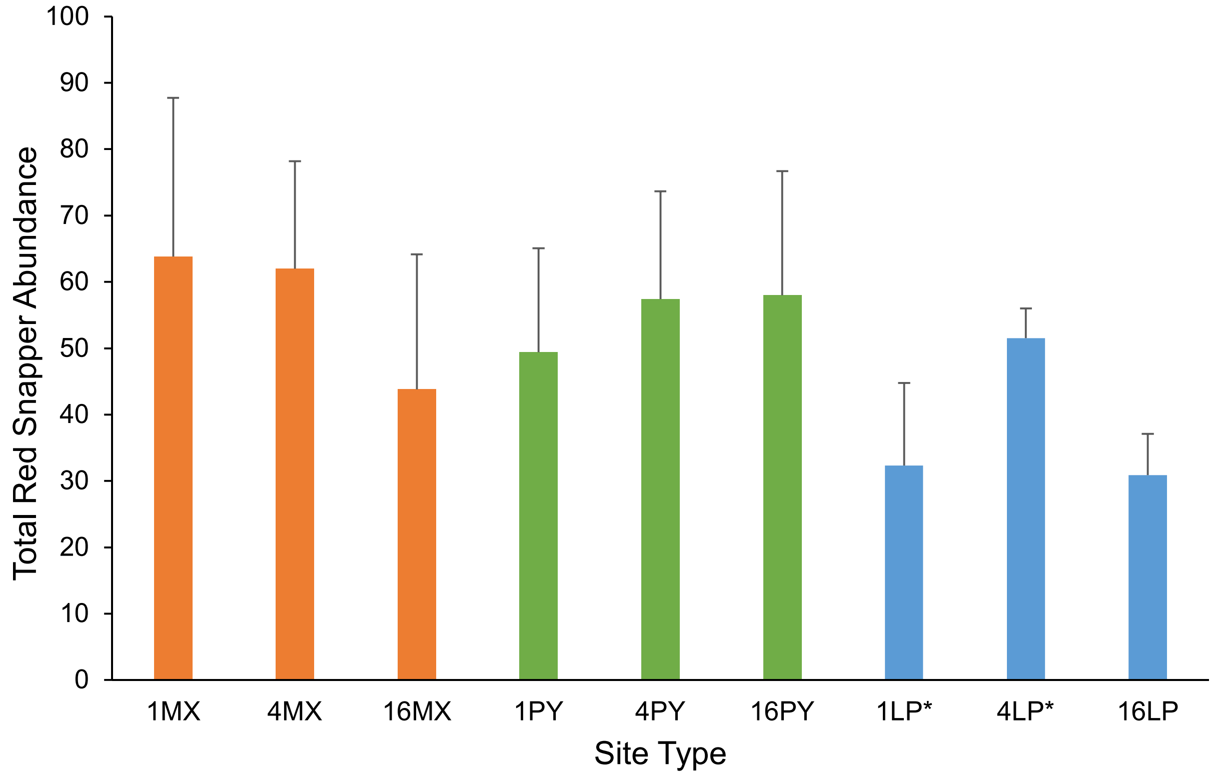
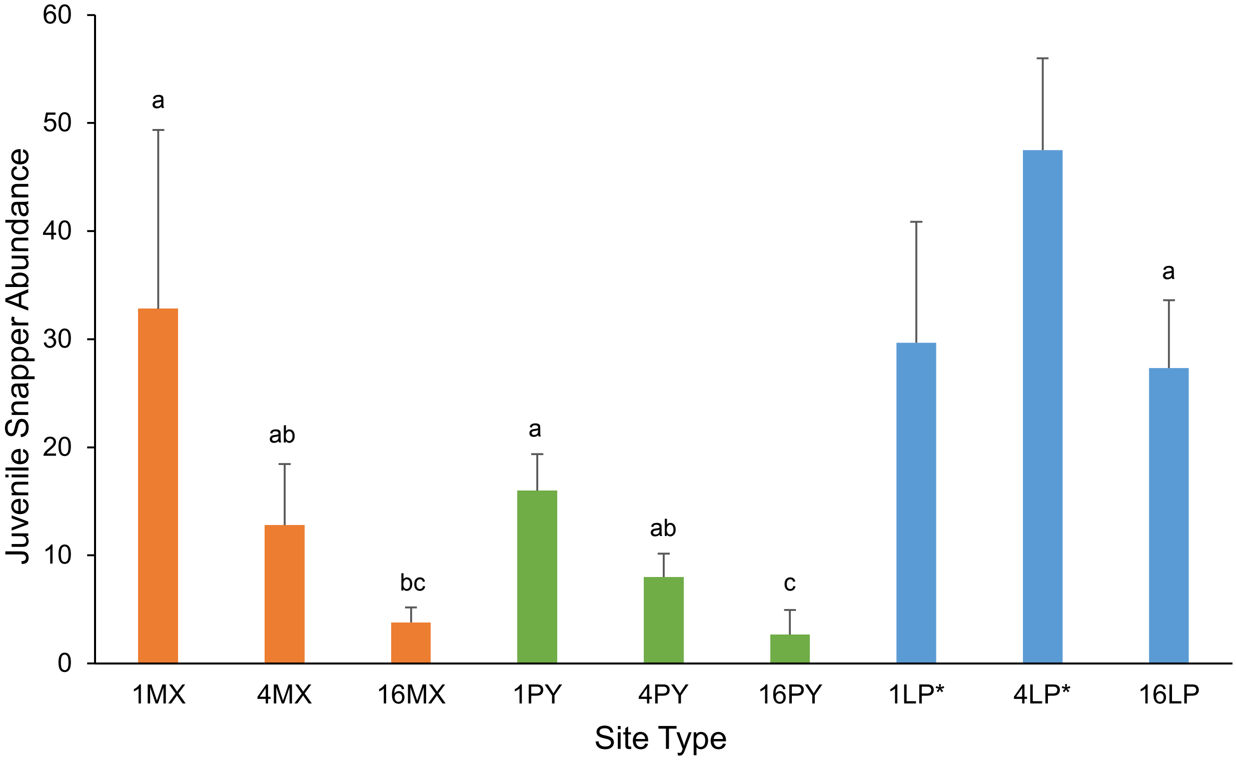


Figure 10: Total Red Snapper abundance (mean ± S.E) for PY, LP, and MX site types at the RGV reef in the Gulf of Mexico. An ANCOVA using visibility as a covariate did not find a significant difference ($P < 0.05$) between site types. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Juvenile Red Snapper abundance was significantly different between site types (ANCOVA: $F_{6, 37} = 7.96$, $P < 0.001$), visibility as a covariate was not significant (ANCOVA: $F_{1, 37} = 3.15$, $P = 0.087$). Post-hoc comparisons indicated that site types with more pyramids, such as 4MX, 16MX, 4PY, and 16PY sites, had significantly fewer juvenile Red Snapper (Table 4) (Figure 11).

Table 4: Significant (*P* < 0.05) post-hoc comparisons based off estimated marginal means from an ANCOVA comparing juvenile Red Snapper abundance at sites in the RGV reef in the Gulf of Mexico. Visibility was used as a covariate. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Comparison	Site type I	Site type J	Mean difference I - J	lower bound for 95% confidence interval for difference	upper bound 95% confidence interval for difference	P-val
16MX x 1MX	16MX	1MX	-31.976	-52.428	-11.524	0.002
16MX x 1PY	16MX	1PY	-10.485	-30.744	9.774	0.029
16MX x 16LP	16MX	16LP	-22.856	-42.176	-3.536	0.003
16PY x 1MX	16PY	1MX	-31.024	-50.356	-11.693	0.000
16PY x 1PY	16PY	1PY	-9.533	-29.327	10.261	0.003
16PY x 4MX	16PY	4MX	-8.884	-28.241	10.474	0.005
16PY x 4PY	16PY	4PY	-3.617	-23.022	15.788	0.024
16LP x 16PY	16LP	16PY	21.904	3.226	40.583	<0.001



RGV reef in the Gulf of Mexico. Bars which do not share the same letter have significantly different ($P < 0.05$) average species richness based on an ANCOVA, with visibility as a covariate, and estimated marginal means used for post-hoc testing. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Adult Red Snapper abundance was significantly different between site types (ANCOVA: $F_{6, 37} = 4.11$, $P = 0.004$), visibility as a covariate was also significant (ANCOVA: $F_{1, 37} = 4.84$, $P = 0.036$). Post-hoc analysis using estimated marginal means indicated that site type 16LP (mean ± S.E) (4.5 ± 2.56) had significantly fewer adult Red Snapper than site types 16PY (55.33 ± 19.54) ($P = 0.006$), 4MX (49.20 ± 13.92) ($P = 0.005$), and 4PY (49.40 ± 17.44) ($P = 0.005$) (Figure 12).

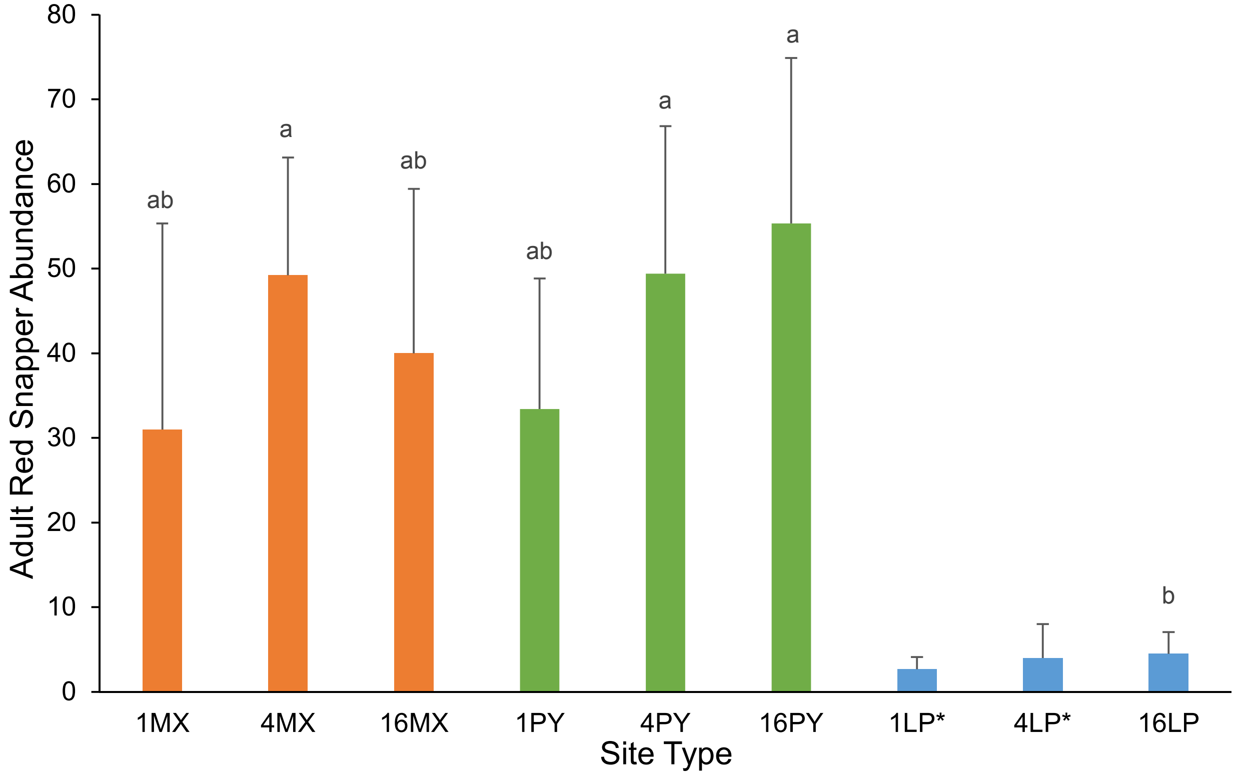


Figure 12: Adult Red Snapper abundance (mean ± S.E) at PY, LP, and MX site types at the RGV reef in the Gulf of Mexico. Bars which do not share the same letter have significantly different ($P < 0.05$) average species richness based on an ANCOVA, with visibility as a covariate, and estimated marginal means used for post-hoc testing. Site types 1LP (n = 3) and 4LP (n = 2) were excluded from the statistical analysis due to low sample size.

Further, a Spearman's rank-order correlation indicated that juvenile Red Snapper abundance was negatively correlated with adult Red Snapper abundance (r_s (42) = -0.532, $P < 0.001$). Another Spearman's rank-order correlation showed a stronger negative correlation between juvenile Red Snapper abundance and Grey Triggerfish abundance (r_s (42) = -0.593, $P < 0.001$). This contrasted with a final Spearman's rank-order correlation which revealed a positive correlation between adult Red Snapper abundance and Grey Triggerfish abundance (r_s (42) = 0.459, $P = 0.002$).

Finally, Red Snapper length was significantly different between site types (Kruskal-Wallis: $H_7 = 95.1$, $P < 0.001$). Post-hoc testing indicated that site types 4MX (291.3 ± 19.29 mm), 16MX (272.7 ± 15.59 mm), 4PY (283.6 ± 19.95 mm), and 16PY (278.7 ± 20.58 mm) had significantly larger Red Snapper than 16LP (143.3 ± 7.05 mm), 1MX (192.4 ± 17.41 mm) and 1PY (202.7 ± 14.71 mm) (all $P < 0.029$) sites (Figure 13).

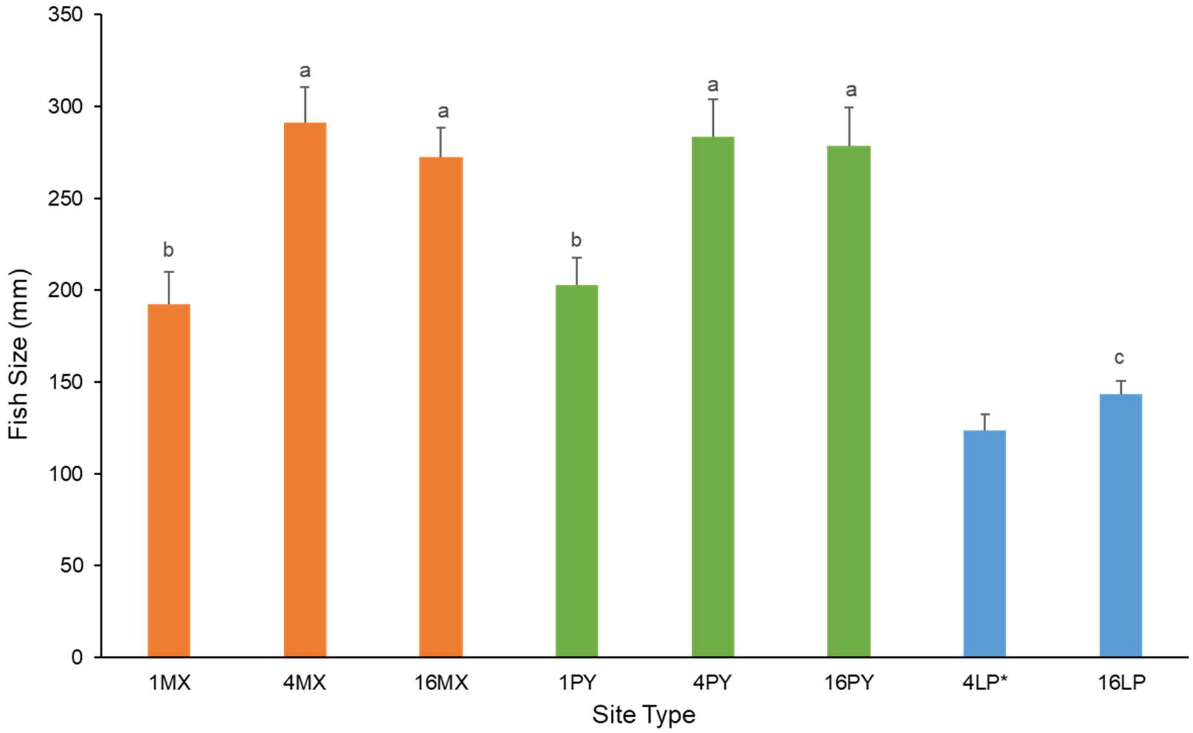


Figure 13: Red Snapper length (mean ± S.E) at PY, LP, and MX site types at the RGV reef in the Gulf of Mexico. Bars which do not share the same letter have significantly different ($P < 0.05$) average species richness based on a Kruskal-Wallis test and post-hoc testing. Site types 1LP and 4LP were excluded from the statistical analysis due to low sample size.

CHAPTER IV

DISCUSSION

Enhancement of Red Snapper and Grey Triggerfish fisheries are important components of artificial reef management plans in the GoM (Texas Parks and Wildlife 1990; Alabama Marine Resources Division, 2014). The results of the present study suggest that high quantities of reefing pyramids in a small area may provide suitable habitat for adult Red Snapper and Grey Triggerfish, but not for juvenile Red Snapper. However, large deployments of low-profile modules and isolated single pyramids with associated low-profile material hosted the highest abundance of juvenile Red Snapper and thus are suitable habitat. Given that juvenile Red Snapper abundance had a negative correlation with adult Red Snapper and Grey Triggerfish abundance, it may not be possible to create habitat for juveniles and adults in the same small area. Rather, planning separate juvenile and adult habitats throughout an artificial reefing area may be preferable for these species.

Fish Community

Hypothesis one, which stated LP sites will have significantly different fish communities than PY or MX sites, was supported. The fish community at site type 16LP was significantly different from all other site types, driven by high abundance of juvenile Red Snapper and Pinfish, few adult Red Snapper, no carangid species, and overall low species richness. This is comparable to another study located in the RGV reef that examined juvenile fish abundances at purpose-built, low-profile artificial reefs. These reefs contained high abundances of juvenile Red

Snapper and other juvenile reef fish, and few larger adult fish or predators (Dance et al. 2021). No carangid species or Atlantic Spadefish were observed on any LP sites in the present study, though they were found at every other site type. This is a marked difference from most artificial reef studies in the GoM, where carangid species and Atlantic Spadefish were observed at artificial reef sites ranging from concrete culverts and pyramids, to sunken ships and oil platforms (Lingo and Szedlmayer 2006; Ajemian et al. 2015a; Froehlich and Kline 2015). Material in each of these studies was substantially larger than the low-profile modules in the present study, and it is likely that these species are attracted to reefs with greater relief. Fish community differences due to site density were detected at site types 1MX and 16MX, but not between 1PY, 4PY and 16PY. Comparatively, the fish communities at varying densities of concrete culverts at an artificial reef off the coast of Port Mansfield, TX did not differ between density levels (Froehlich and Kline 2015). Similarly, off the coast of Brazil, fish communities did not differ between artificial reef patches consisting of one, two or three reef ball modules (Gatts et al. 2014). The present study provided limited support for hypothesis two, which predicted that fish communities at 1, 4 and 16 sized sites within the same module type (PY, LP or MX) will be significantly different from each other. Grey Triggerfish abundance was greater at 16MX than 1MX sites, which is consistent with studies at other artificial reefs in the GoM which found Grey Triggerfish to prefer reefs with larger footprints and with greater growth of encrusting organisms (Bortone et al. 1997; Plumlee et al. 2020). Grey Triggerfish preference for larger footprint reefs makes sense considering they feed on encrusting organisms and reef-associated invertebrates (Nelson and Bortone 1996; Dance et al. 2018). Interestingly, the densest sites with low-profile modules: 4LP, 16LP, 4MX, and 16MX, were the only sites where post-settlement recruit Red Snapper (identified by the white halo surrounding the black spot on very small juveniles) were observed. Mean species richness was highest at 16MX (12.2), 4MX (10), 16PY (9.17), and 4PY (8.4). Lingo and Szedlmayer (2006) found similar results at artificial reefs ranging from loose oyster shell, to cinderblock and shell, and combined pyramid, blocks, and shell habitats in the Northern Gulf of Mexico, with the greatest species diversity observed at the more complex reefs. Additionally, in a study in southern Florida comparing configurations of one to eight reef modules found that species diversity and abundance was greater at larger reefs when compared to small reefs (Bohnsack et al. 1994).

Hypothesis three, which stated that the highest species richness will be observed on intermediate-density sites (4PY, 4LP, 4MX), was not supported. In the present study, species diversity, as well as abundance of commonly targeted species like adult Red Snapper and Grey Triggerfish, did not increase proportionally to the increase in artificial structure density. For example, 16MX sites did not have sixteen times as many species or Red Snapper as 1MX sites. This is a trend that is consistent with other studies comparing multiple densities of artificial reef material (Schroeder 1987; Bohnsack et al. 1994). However, large reefs can improve fishing opportunities because they are easier to locate with recreational sonars and tend to contain larger Red Snapper, which are generally preferred by the recreational fishing community. It is also important to note that the nature of the maxN method of counting fish could result in the underrepresentation of abundance estimates at larger sites. Similar to a study by Wetz et al. (2020), Grey Triggerfish, Atlantic Spadefish, Red Snapper, and Jack species exhibited strong attraction to the ROV in the present study, making multiple maxN counts impossible without double counting individuals. Groups of these fishes would follow the ROV from module to module and would sometimes swim to the ROV from distances between 20-30 m away based on the distance to the nearest artificial reef structure. It is likely that the attraction of these species to the ROV results in their maxN counts being closer to the true abundance of the surveyed sites, though those species maxN counts are also likely to be inflated compared to fish that did not exhibit attraction.

Juvenile Red Snapper

While total Red Snapper abundance was not significantly different between site types, the adult and juvenile abundances were. Hypothesis four, which predicted that the highest average juvenile Red Snapper abundance would be at LP sites, was partially supported. Juvenile Red Snapper abundance was highest at site types 1MX, 16LP and 1PY, and generally decreased as density of pyramids increased. The effects of predation and competition with larger fishes are two possible explanations for the reduced abundance of juvenile Red Snapper at large pyramid and mixed sites. Predation has been shown to limit post-recruitment survival of reef fish. A study in the Red Sea took isolated artificial reefs and relocated them directly adjacent to a large coral reef. Resident fish density declined sharply after relocation and many direct predatory attacks were recorded (Belmaker et al. 2005). Further, a study at artificial reefs in the northern GoM by Piko and Szedlmayer (2007) found that sites with predator exclusion cages harbored substantially more juvenile Red Snapper than uncaged sites. 16LP sites in the present study had fewer potential juvenile Red Snapper predators observed such as Greater Amberjack *Seriola dumerili*, and Yellow Jack *Carangoides batholomaei*. However, site type 1MX, which had similar juvenile Red Snapper abundance to site type 16LP, appeared to have levels of potential predators comparable to the rest of the site types.

In the present study, it appears that juvenile Red Snapper abundance is influenced less by predators and more by competition between both larger Red Snapper and Grey Triggerfish. Large Red Snapper have been observed aggressively defending habitat from, and even cannibalizing, smaller Red Snapper (Bailey et al. 2001; Mudrak and Szedlmayer 2012). A study off the coast of Dauphin Island, AL placed cinderblock reefs, similar to the ones in the present study, either 15 m from a mid-profile reef or 500 m from a mid-profile reef. They found significantly higher juvenile Red Snapper abundance at the cinderblock reefs farthest from the mid-profile reef, and attributed this to reduced threat from larger fishes at more isolated small reefs (Mudrak and Szedlmayer 2012). In the present study, the greatest Red Snapper lengths occurred at 4PY, 4MX, 16PY and 16MX sites, a finding consistent with Jaxion-Harm and Szedlmayer (2015), who found that the largest Red Snapper occurred on artificial reef patches consisting of tanks, oil platforms or sunken ships compared to smaller and lower-profile reef patches. Further, Jaxion-Harm and Szedlmayer (2015) found that individual pyramids and small reefs had size distributions dominated by smaller Red Snapper, a finding supported by the present study which observed the greatest juvenile Red Snapper abundance at 1MX, 1PY, and 16LP sites and the least at 16MX and 16PY sites. This provides partial support for hypothesis five, which predicted 16MX and 16PY sites would have the greatest average Red Snapper length. Grey Triggerfish, which were most abundant at 16MX and 16PY in the present study, exhibit aggressive territoriality and have been observed chasing and attacking Red Snapper (Simmons and Szedlmayer 2012). In a 2018 study at the same reef, removal of Grey Triggerfish from artificial reef sites resulted in a higher frequency of smaller size classed Red Snapper (Simmons and Szedlmayer 2018). Further, like Mudrak and Szedlmayer (2012) and Simmons and Szedlmayer (2018), significant negative correlations were observed between juvenile Red Snapper abundance and both Grey Triggerfish and Adult Red Snapper abundances in the present study. Additionally, a significant positive correlation was identified between the abundances of adult Red Snapper and Grey Triggerfish, this is likely due to similar habitat requirements, though it suggests that Grey Triggerfish aggression has a less substantial impact on larger Red Snapper, a finding supported by Simmons and Szedlmayer (2018). Combined, these results suggest that juvenile Red Snapper can benefit from low-profile only sites and 1PY and 1MX sites because those sites do not provide sufficient habitat to support high abundances of Grey Triggerfish or large Red Snapper. Conversely, juvenile Red Snapper are being limited on larger PY and MX sites by high abundances of Grey Triggerfish and larger Red Snapper.

Juvenile Red Snapper abundance was not significantly different between 1PY and 1MX, 4PY and 4MX, or 16PY and 16MX. These results did not support hypothesis six, which stated that mixed sites, 1MX, 4MX, and 16MX will have significantly more juvenile Red Snapper than their pyramid counterparts: 1PY, 4PY, and 16PY. Low-profile habitat is considered to be beneficial to juvenile reef fish because it provides refuge without attracting larger fishes (Arney et al. 2017; Dance et al. 2021). It is likely that this quality is mitigated when low-profile modules are placed within close-proximity to mid-profile structures, because mid-profile structures provide habitat for larger fish and more predators (Bohnsack et al. 1994; Mudrak and Szedlmayer 2012). These results are important when considering artificial reef design because it suggests that it may be difficult to provide habitats complex enough to support high species diversity and abundance of species like adult Red Snapper and Grey Triggerfish while still providing juvenile Red Snapper habitat. Tagging studies for both Grey Triggerfish and Red Snapper suggest that they have high site fidelity and generally spend most of their time within 100 m of their home range (Topping and Szedlmayer 2011; Herbig and Szedlmayer 2016). Considering their high site fidelity, it may be preferable to use a separate patch approach, where within a reefing area, juvenile Red Snapper habitats are placed at least 100 m from more complex adult habitats.

Longevity of low-profile modules

Low-profile modules at one and four LP sites were frequently found buried in this study, and in many cases could not be found at all. However, large low-profile module deployments or the addition of pyramids appeared to mitigate burial. 16LP sites, 4MX, and 16MX sites contained low-profile modules which had significantly more exposed material than the 1LP and 4LP sites. Artificial reefs can effect current flow in an area around the structure (Ambrose and Anderson 1990) (Manoukian et al. 2011) and it is possible that a change in turbulence associated with many structures or larger structures like pyramids was affecting the deposition and erosion processes on nearby low-profile modules. Bell and Hall (1994) noted that Hurricane Hugo buried several small and low-profile artificial reefs, while leaving some larger reefs exposed. Additionally, observation of larger "Octoreef" low profile modules (~3m × ~3m) on other sections of the RGV reef indicate that a larger structural footprint might reduce burial rates. Given the expense of deploying artificial reefs it may be that small groups of low-profile reefs of the design used in this study are not effective over long time periods and are not practical choices for new reefs unless modified to reduce burial rates.

Further Research

Larval reef fish in some cases actively select habitat to settle on, possibly by auditory or visual cues (Montgomery et al. 2001). 4MX, 16MX, 4LP and 16LP sites were the only locations that post-settlement recruit Red Snapper were observed in this study. It is possible that larger sites provide some cue that attracts larval Red Snapper to them. However, overall juvenile Red Snapper abundance was low at 4MX and 16MX sites, presumably due to larger adult Red Snapper and Grey Triggerfish. Low-profile only sites were susceptible to burial and may not have a useful lifespan beyond a few years. 1MX sites had a high abundance of juvenile Red Snapper even though the availability of low-profile habitat was limited, and the presence of pyramids seemed to mitigate the burial of the associated low-profile modules. Combining one pyramid and 16 low-profile modules to create an asymmetrical reef patch may be able to enhance juvenile Red Snapper recruitment while increasing the lifespan of the low-profile modules. Changes in sediment characteristics, and entrapment of organic matter have been documented at large artificial reefs, presumably due to changes in current flow around the reefs (Fabi 2002; Reeds et al. 2018). Examining the smaller structures from the experimental reef zone with an acoustic doppler current profiler (ADCP) could determine if changes in current flow are consistent between larger and smaller artificial reefs. Additionally, the water current profile could be used to identify the processes determining the burial or exposure of low-profile modules. The experimental reef area in this study is only a portion of the larger RGV reef. Other habitat types included concrete railroad tie piles, sunken ships, large steel cable spools, cinderblocks, and clay roofing tiles. Comparing the fish communities between these “materials of opportunity” and the purpose-built pyramids and low-profile modules might identify artificial reef material that is similarly functional, but available from “waste” material.

CHAPTER V

CONCLUSION

This study suggests that it may be difficult to effectively create habitat in a single reef patch that is suitable for adult Red Snapper and Grey Triggerfish, as well as juvenile Red Snapper. This is most likely due to competition between juvenile Red Snapper and larger fishes. However, 1MX sites came the closest to providing a middle-ground habitat which contained a high abundance of juvenile Red Snapper and a moderate amount of species richness and adult Red Snapper. Species richness, Red Snapper and Grey Triggerfish abundances did not increase proportionately with the amount of artificial reef structures in a patch. While this may suggest diminishing returns on increased module density, there are other benefits to large artificial reef sites. Site types 4MX, 16MX, 4PY and 16PY had the highest species richness and the largest average Red Snapper. Further, large sites enhance recreational fishing opportunity. Low-profile modules supported high abundances of juvenile Red Snapper but were quickly buried in the sediment if not placed in large numbers or with mid-profile structures. To design a wholistic artificial reef area which provides fishing opportunity and habitat for a diverse array of species as well as for target species like juvenile Red Snapper a separate patch approach should be used. Large patches of mid-profile reef can be placed to support more diverse fish communities with large individuals. And to enhance juvenile Red Snapper populations, isolated patches of low-profile modules can be placed in high numbers or with the addition of individual mid-profile structures

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BIOGRAPHICAL SKETCH

Keegan Angerer attended Grand Valley State university and earned his Bachelor of Science in Natural Resource Management in December of 2018. After graduating, Keegan performed rangeland health monitoring in Nevada and Northern California. From there he monitored invasive species and worked in soil erosion permitting and enforcement in northern Michigan. In the Spring of 2021 Keegan began his Master of Science in Ocean, Coastal and Earth Sciences at the University of Texas Rio Grande Valley which was successfully completed in August of 2022.

Permanent Address:
2237 Eagle Blvd,
Holland, Michigan 49424
Email:
keeganangerer@gmail.com