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Artificial reef structure and material deployment decisions: A big data analytics exercise on presence and abundance of reef fish

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ABSTRACT

The benefit of artificial reefs appears to be accepted. Yet the benefit of differing structures to fish populations remains unknown. Accepting that uncertainty exits in the accumulation of data by visual monitoring, researchers have amassed a large database on species and abundance of fish at artificial reefs in the Northwestern Gulf of Mexico shelf. Big data analytics techniques were employed across this lengthy study with preliminary results suggesting that artificial reef structure impacts the presence of different fish species. This analysis addresses the decisions of the Texas artificial reef program and informs the larger debate on productivity of artificial reefs.

KEYWORDS: Business Analytics, Ecological Decision Making, Artificial Reefs, Fisheries Management

INTRODUCTION

Given continuing discussion regarding the location and optimal spacing of artificial reefs, the research objective was to analyze the Northwestern Gulf of Mexico (GOM) Shelf off the Texas Coast using data on fish abundance on differing artificial reef structures to suggest whether reef structure impacted the presence of individual species and, by extension, fish biomass. If indeed, some artificial reef structures were more likely to be associated with fish populations, other variables such as water depth associated with certain structures might be contributory. The results of this analysis can both aid decision making in a fisheries context and inform the discussion on artificial reef habitats.

Though artificial reef deployment continues in the GOM and indeed, worldwide in an effort to sustain reef fish, only recently has research been conducted to determine the program's success. Prior to this, it was generally determined that while artificial reefs had the potential to meet the program's objectives for presence of fish at structures used as artificial reefs, ongoing monitoring and management were paramount to determination of success (Baine, 2001). The study presented herein attempts to more quantitatively analyze the large monitoring dataset to enhance better fisheries management decisions with respect to artificial reef deployment.

LITERATURE REVIEW

Literature Review of Artificial Reefs to Fish Populations

The Goal and Objectives for the Artificial Reef Plan G sets forth the directive of the Seventy-first Texas Legislature to The Texas Parks and Wildlife Department (TPWD) to "promote, develop, maintain, monitor, and enhance the artificial reef potential in state waters and federal waters adjacent to Texas to enhance fishery resources and commercial and recreational fishing opportunities." Enhancement of fishery resources is considered to be the restoration or creation of habitat to improve recruitment and spawning potential of reef associated species. "An artificial reef covered under this Plan must be sited, constructed, maintained, monitored, and managed in a manner that uses the best scientific information available" (Stephan et al., 1990).

The Texas Parks and Wildlife Department in its TPW magazine (June 2014) reported that through its funding, divers from the Harte Research Institute (HRI) conducted a two-year study to address the ongoing debate of whether artificial reefs increase productivity in terms of the number of fish or serve merely as gathering points for existing fish and other species. The premise was that since the seafloor along the Texas coast has very little natural structure habitat, then if artificial reefs increase production, Gulf fisheries will be healthier. Results thus far show biodiversity on artificial reefs equal to or exceeding that on natural banks. Specific results for red snapper show that fish on natural and artificial reefs are larger than those on standing platforms and that snapper species accounted for 26 percent of the total fish abundance at sites surveyed in 2012. (http://tpwmagazine.com/archive/2014/jun/ed_2_reefs/)

Artificial reefs have been attributed to improved sport and commercial fisheries (Gallway et al., and 2009; Bohnsack & Sutherland, 1985) and since anglers typically desire larger fishes, information is needed because of current debates regarding the role of artificial reefs in the life cycle of red snapper (*Lutjanus campechanus*), especially considering its overfished status in the Gulf of Mexico (GOM) since the 1980s (Cowan et al., 2010; Diamond et al., 2007). Early in life, red snapper utilize low-relief, rubble-shell habitats moving to nearshore reefs (Gallaway et al., 2009), and later to deeper reefs, such as oil platforms, rock outcroppings and larger artificial reefs (Gallaway et al., 2009; Gazey et al., 2008). Thus, artificial reef complexity and size may be important factors influencing the age and size of red snapper over different reef structures.

The impact of different artificial reef structures raises the important decision of rigs-to-reefs (RTR) in the dialog of artificial reef deployment. Uncertainty has surrounded the use of decommissioned oil rigs as a tool to offset declines in fish populations, including the commercially valuable, but overfished red snapper. The National Fishing Enhancement Act (NFEA), that authorized this program requires the "best scientific information available" (BS IA), which according to one law review will be sufficient such that it will be unlikely for a court to provide pressure on agencies accumulating such information (McQueen-Borden, 2013). A very recent study continues the gathering of information and scientific data on offshore platforms as artificial reefs regarding the effect of depth and distance from shore environmental variables which are concluded to influence species assemblages significantly (van der Stap et al., 2016).

In line with consideration of concrete reef structures and rigs-to-reefs, sunken vessels have been used as artificial reef structures, but again, the effect of the latter in reef fish communities remains unknown. Though, the results of one study indicate that increases in vessels as artificial reef habitats may affect the relative abundances of particular species (Fowler & Booth, 2012b). Unlike the RTR program where structures are in place, concrete reefs hold high fish diversity (Moffitt et al., 1989) and allow different patterns or random deployment in an area (Lukens et al, 2004; Baine, 2001).

Again, considering the bioenergetics of red snapper, it has been determined that optimal artificial reef spacing should be between 0.50 and 0.95 km such that no more than 2 fit within a 1 km^2 area (Shipley & Cowan, 2010; Shipley & Shipley, 2009), based on artificial reef clumping or blocking for optimal fish foraging and consumption. Yet, a more recent study investigated fish population dynamics on natural reefs, bare areas and varying culvert patch density of 1-190 culverts in an artificial reef system. Using the same economically valuable, red snapper studied off the Texas Coast at Port Mansfield, it was noted that though abundance did not differ according to density categories, mean total lengths were greatest at lower density suggesting that 71-120 culverts be deployed in a 30-m radius (Froehlich & Kline, 2015).

Size and age of red snapper with age of artificial reefs in the Alabama Gulf of Mexico waters south of Mobile Bay showed that the mean age of red snapper at a particular reef was not related to depth or distance to other reefs. With a positive correlation between mean age of red snapper and age of the reef, it was estimated that artificial reefs enhance production of red snapper (Syc & Szedlmayer, 2012). Furthermore, young (age 2) red snapper appear to dominate artificial reef populations suggesting the positive aspect to fisheries through the establishment of significant numbers of artificial reefs (Gallaway et al., 2009).

Thus with differing results and conclusions, artificial reef placement at varying depths may or may not affect production of fish species when considering naturally wide depth ranges. Indeed, even when artificial reefs are of similar size and shape, populations can develop with different demographics. While the majority of the studies are concerned with the overfished red snapper albeit at differing life stages, the fact that small reef fish can be sustained on artificial reefs is conclusive (Fowler & Booth, 2012a).

Given the data accumulated by TPWD and HRI by surveys conducted between 2012 and 2013 with data on hydrographic variables and type of reef structure in the same artificial reef environment of the Northwestern Gulf of Mexico Shelf a recent study compiled the data from 59 fish species into 19 family groupings at 12 artificial reef sites and 2 platforms plus a vessel (Ajemian et al., 2015). Mean species richness showed more representation on toppled and cutoff rigs. This study then focused its analysis to the five federally managed fisheries species in the GOM, snapper, triggerfish and amberjack, where like the literature cited above, red snapper was used to determine that while there was no significant differences in red snapper catch per unit effort (CPUE) among the different structures at the different sites, structure type did influence mean total length and biomass. It was suggested that the conversion of standing platforms into artificial reefs could significantly alter fish community structure with standing platforms that should be retained by the upright orientation and relatively vertical relief of the structure. For the frequently studied red snapper, no strong evidence was discovered that structure type affects abundance, biomass or mean total length on the rigs-to-reefs structures. Bottom depth, though recognized as having a role in fish assemblages in natural habitats continues to be less known as to impact on artificial reef assemblages (Ajemian et al., 2015). Of importance, is the call for further investigation of this region which is supported by the considerably large dataset accumulated by TPWD and which could provide evidence of reef structure impact on multiple fish species more so than artificial reef data examined in previous studies.

Literature Review of Knowledge and Data

Previously, knowledge-based systems and uncertainty problems in ecological research have been limited due to the difficulty in acquiring knowledge that can be suitably structured and formalized as well as the essential problem that uncertainty exists in expert knowledge and ecological data. Such uncertainty stems from inaccuracy of data, inaccuracy of interpolation methods and unreliability of measurement tools as well as the fact that some measurements are not possible. For example, the number of fish in a lake can be approximated, but is not quantifiable without allowances for error (Salski, 1992). In an ecological investigation, perfect knowledge is rarely, if ever, available since natural systems do not conform to crisp definitions (Mackinson et al., 1999; Mackinson, 2000). As detailed in the studies conducted, primarily on red snapper in GOM waters, the benefit of artificial reefs appears to be agreed upon, yet the benefit of differing structures to fish populations is still unknown as is distances and depths of the structures.

THEORETICAL DEVELOPMENT/MODEL

Accepting that uncertainty does exist in the accumulation of data gathered by visual monitoring and that further investigation of reef structure to fish populations based on environmental aspects, including, depth, remains a point for discussion in fisheries management, the following methods were utilized to address this big data analytics problem.

Data Accumulation Methods

The TPWD biological monitoring program seeks to establish baseline data and fish community composition at each artificial reef site using standard fish census methods. Each site is evaluated post-deployment for fish species, abundance at predetermined depths, and total abundance. Every attempt is made to survey the reef sites quarterly if possible with fish species, abundance, and size evaluated to determine seasonal changes in fish use at each site. A variety of gears have been used for sampling reef systems and include submersibles (Barans, 1982; Shipp et al., 1986), remotely operated vehicles (ROV; Barans, 1982), fisheries acoustics (FAS; Barans, 1982; Gledhill et al., 1996; Gledhill, 2001), fish traps, long-lines, trawls, gill nets, and hook-and-line (Barans, 1982; Haynes, 1990). Each gear has some advantages and disadvantages in terms of selectivity, sampling bias, logistics and cost. However, most surveys of reef fishes employ some visual technique using divers, cameras, submersibles or ROVs (Jones & Thompson, 1978; Sale & Douglas, 1981; Kimmel, 1985; Bohnsack & Bannerot,1986; Bortone et al., 1986; Shipp et al., 1986; Thresher & Gunn, 1986; McCormick & Choat, 1987; Bortone et al., 1989; Bortone et al., 1991; Ellis & DeMartini, 1994; Parker et al. 1994).
SCUBA diving has been the primary method of conducting research within the Artificial Reef Program. Diving projects have been executed by a core team comprised of TPWD staff with the assistance of volunteer divers from universities and other agencies. Diving conditions have varied greatly within the reef site with visibility ranging from zero to over 150 ft.

For each survey conducted, divers swam randomly around the dive location within the reef site and recorded the species present and their relative abundance at each reef site or individual structure within a reef site. Fish were accurately identified to their lowest taxonomic division. Fish were not identified to species unless the fish could be identified accurately. Juvenile fish of a species were designated as such. Fry or fish too small to be identified were recorded under a generic juvenile fish heading. Fish abundance was recorded as: Single(S) =1; Few (F) = 2-10; Many (M) = 11-100 and Abundant (A) = 100+. Environmental characteristics of the water column were conducted to examine any connection between water quality and the biotic that exist in the regions. At each sampling site, a Data Sonde was lowered into the water column and collected data related to dissolved oxygen, pH, salinity, conductivity, water depth, and water temperature.

The structures by which each fish sighting was evaluated were categorized into different reef materials including: Fly-ash blocks, Vessels, Concrete utility poles, concrete culverts, wellheads, reef balls, oil and gas jackets, and fabricated structures. The Reef Site Aliases yielded the types of structures being deployed as artificial reefs in the Texas Coast GOM: Liberty Ship, Standing, Base, Toppled, Top, Reef Balls, Navy Barge, Base and Top, Top, Towed and Toppled, Pile-Based, Texas Clipper, Deck (oil Rig), Culverts (as of 2007) and Oil and Gas Jackets (as of 2013). These were then combined into general structure materials and deployment methods as: Concrete, Culverts, Fabricated, Oil-Gas Component, Oil-Gas Jacket, Reef Balls, Vessel, Accidental Sinking, Partial Removal, Surface Deployed, Toppled, Towed and Towed then Sunk. Data categories of sightings and type of structure are in Table 1 below.
While water depths (ft.) were noted for each sighting, these ranged from a minimum of 10 feet to a maximum of 180 feet with the majority of those beyond 120 being observed in July and August 2013. The mode of recording sightings was stated as Roving (roving diver) except for May through September 2012 when the method was stated as Stationary (as given in Bohnsack & Bannerot, 1986).

The database for consideration in the study reported herein, thus, included 1248 surveys from 1993 to 2014 although sighting numbers varied. Overall, the dataset included a total of over 240 thousand observations.

ANALYSIS & RESULTS

The presence and abundance of 193 different species or groups of species of fish were recorded in each survey. Variables relevant for this analysis were survey number, survey date, site, structure material type, survey depth, water clarity, species or species grouping, and abundance. Abundance was estimated according to several categories: zero, one, few (2-10), many 11-99, and abundant (100+).Two dependent variables were explored in the first stage of this big data analytics problem: Abundance recorded as an ordinal from 0 – 4 with 0 = zero to 4 = abundant, and Presence recorded as a binary variable with 0 = zero and 1 = one or more sighted. The data were particularly sparse. Nearly 210 thousand of these observations (87%) were zero.

Correlation Analysis

Several rounds of correlation analysis were conducted. For this analysis, structure material type was represented as a group of indicator variables. These variables were correlated with Species Abundance and Presence. In addition, partial correlations were conducted using depth and water clarity as control variables.

Table 1: Surveys by Years, Months, Sightings and Structure(s)

Year	Months	No. of sightings	Structure
1993	July	1	Liberty Ship and Ash blocks
1995	June-Sept.	10	Liberty Ship
1996	Aug.-Oct.	5	Mixed
1997	May-Sept.	5	Mostly vessels
1998	Aug.	14	Base, Toppled, Top and Standing
1999	July-Sept.	14	Liberty Ship, Barge, Reef balls, Base, Base + Top, Top, Standing
2000	June-Oct.	29	Liberty Ship, Barge, Base, Base + Top
2001	Feb.-Nov.	146	Base, Base + Top, Top, Standing, Liberty Ship, Coal-ash blocks, Deck, Barge
2002	April-Oct.	91	Standing, Base, Liberty Ship (Star Reef), Toppled, Towed and Toppled
2003	June-Oct.	66	Standing, Base, Base + Top, Towed and Toppled, Base, Top,
2004	Feb.-Sept.	84	Texas Clipper, Standing, Base, Deck, Barge, Liberty Ship,
2005	May-Sept.	47	Standing, Toppled, Base + Top, Top, Base,
2006	June	62	Standing, Base, Toppled, Liberty Ship (Star Reef),
2007	Aug.-Sept.	7	Texas Clipper and Culverts
2008	Jan.-Nov.	9	Vessels
2009	May- Nov.	11	Vessels
2011	June- Oct.	186	Mostly Standing or Base; vessel in Sept.
2012	Mar.-Sept.	145	Texas Clipper, Liberty Ship, -- mostly Base or Standing
2013	June-Dec.	164	Oil and Gas Jacket, Culverts, Texas Clipper—mostly Base, Toppled and Standing
2014	June-Oct.	209	Oil and Gas Jacket, Toppled, Texas Clipper, Liberty Ship, Base, Standing

The results of the correlation analysis were inconclusive. Although a few species had modest significant correlation with one or the other of the dependent variables, there was not enough consistency across species to conclude that Abundance or Presence of species in general were highly correlated with structure material type. Furthermore, partial correlations were not helpful in this analysis. No conclusion could be reached as to the correlation of water depth to Abundance and Presence.

Cross Tabulation Analysis

Given the failure of the correlation analysis, other data analytics tools were used to try to explain the relationship of species and reef structure. Since the abundance measures are categories, cross tabulations were created to learn more about these relationships. This analysis is ongoing as of the writing of this paper, but some encouraging preliminary results suggest that there is a relationship between species and reef structure type.

Crosstab analysis and Chi -square tests of significance are hampered by sparsity. So, the data were partitioned by narrowing the list of species to the top 30 in terms of sighting frequency and by combining related structure material types to a manageable five categories. Fabricated material was combined with reef balls, and groups of concrete utility poles, concrete culverts and various discarded oil and gas components were combined into the Other category.

Table 2: Chi-squared tests of significance

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	807.509[a]	116	.000
Likelihood Ratio	795.660	116	.000
N of Valid Cases	12836		

a. 11 cells (7.3%) have expected count less than 5. The minimum expected count is 3.17.

Similarly, a simple species presence variable for the dependent variable rather than abundance, avoided the usage of multi-level crosstabs.

Cell counts, expected counts and adjusted standardized residuals were recorded for each species and structure type. For this analysis, adjusted standardized residuals were assumed to be asymptotically normal with mean equal to zero and variance equal to one. If the absolute value of this measure was greater than or equal to two, the null hypothesis that the observed and expected count were equal was rejected (at $\alpha = 0.05$, an adjusted standardized residual greater than or equal to two is significant; see Agresti (1984) for details).

The results of the Chi-square significance test are shown below. The p-value was zero at three decimal places, which suggests that at least some fish are more likely than expected to frequent one type of reef structure more than another.

The Chi-square statics provided support to this study's objective of whether particular reef structures contributed to fish presence according to the partitioned species and structure categories for which sufficient data were available. (Results of the cross-tabulations are shown in Table 3.) The observed counts of most species were significantly different than their corresponding expected counts on at least one of the structure types. Fabricated and reef balls has a higher significant amount of shark species present; oil and gas jackets of 3-4 piles also had shark species likely but also Atlantic Spadefish; oil and gas jackets of 6-12 piles had more likelihood of Bermuda Chub being present and vessels, though not as strongly supported, showed Crevalle Jack as most abundant. The Other category had no such significant presence on any of the 30 species reported most often in the surveys. In addition, over half of the species have significantly different observed counts on two or more categories. For example, Almaco Jack was more likely to frequent large oil and gas jackets than fabricated reefs or sunken vessels. Atlantic Spadefish, on the other hand, was more likely around fabricated or smaller oil and gas jackets rather than larger oil and gas jackets. Shark species greatly preferred the fabricated and reef balls as well as the oil and gas jackets containing 3-4 piles and were significantly unlikely to be at the 6-12 pile oil and gas jackets. Similarly, though Trumpetfish preferred the oil and gas jackets of 3-4 piles, they were highly unlikely to be present at oil and gas jackets of 6-12 piles. Goldentail Moray also showed the preference for the smaller oil and gas jackets as did the Redband Parrotfish and Spanish Mackerel, while Gray Angelfish and the Hawksbill Sea Turtle had the reverse preferences.

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Table 3: Cross tabulation of top 30 species to general reef structure. O is observed count, E is expected count, and R is the adjusted standardized residual.

	Fabricated & Reef Balls			Oil & Gas Jacket (3-4 Piles)			Oil & Gas Jacket (6-12 Piles)			Vessel			Other			
Species/groups	**O**	**E**	**R**	**O**	**E**	**R**	**O**	**E**	**R**	**O**	**E**	**R**	**O**	**E**	**R**	**Total**
Almaco Jack	2	8.8	-2.4*	125	140.0	-1.5	308	278.9	2.8*	19	28.0	-1.8	17	15.3	0.5	471
Atlantic Creolefish	2	12.0	-3.0*	150	191.7	-3.7*	422	382.0	3.3*	47	38.4	1.5	24	20.9	0.7	645
Atlantic Spadefish	17	7.3	3.7*	173	116.8	6.3*	166	232.8	-7.0*	26	23.4	0.6	11	12.7	-0.5	393
Bermuda Chub	1	7.8	-2.5*	80	124.5	-4.8*	319	248.1	7.2*	16	24.9	-1.9	3	13.6	-3.0*	419
Bicolor Damselfish	0	3.2	-1.8	31	50.5	-3.3*	125	100.7	3.8*	9	10.1	-0.4	5	5.5	-0.2	170
Blue Angelfish	15	11.7	1.0	214	187.5	2.4*	339	373.7	-2.9*	44	37.6	1.1	19	20.4	-0.3	631
Bluehead	13	11.5	0.5	177	182.8	-0.5	371	364.2	0.6	37	36.6	0.1	17	19.9	-0.7	615
Blue Tang	4	9.7	-1.9	119	154.3	-3.5*	356	307.4	4.4*	25	30.9	-1.1	15	16.8	-0.5	519
Brown Chromis	0	3.2	-1.8	30	51.1	-3.5*	135	101.9	5.2*	6	10.2	-1.4	1	5.6	-2.0*	172
Cobia	2	3.2	-0.7	58	51.4	1.1	102	102.5	-0.1	6	10.3	-1.4	5	5.6	-0.3	173
Cocoa Damselfish	14	11.8	0.6	163	189.0	-2.3*	415	376.7	3.2*	29	37.9	-1.5	15	20.6	-1.3	636
Crevalle Jack	4	7.2	-1.2	105	114.7	-1.1	212	228.6	-1.7	47	23.0	5.2*	18	12.5	1.6	386
Goldentail Moray	13	12.3	0.2	238	197.1	3.6*	332	392.7	-4.9*	55	39.5	2.6*	25	21.5	0.8	663
Goldface Toby	17	8.7	2.9*	185	138.2	4.8*	236	275.4	-3.8*	13	27.7	-2.9*	14	15.1	-0.3	465
Gray Angelfish	1	4.0	-1.5	45	64.2	-2.9*	154	127.9	3.6*	11	12.9	-0.5	5	7.0	-0.8	216
Graysby	9	10.5	-0.5	174	167.0	0.7	339	332.8	0.5	25	33.5	-1.5	15	18.2	-0.8	562
Gray Triggerfish	12	11.3	0.2	189	180.1	0.8	337	358.9	-1.9	48	36.1	2.1*	20	19.6	0.1	606
Hawksbill Sea Turtle	0	4.4	-2.1*	35	70.7	-5.1*	166	141.0	3.3*	20	14.2	1.6	17	7.7	3.4*	238
Porkfish	4	3.5	0.3	65	55.9	1.5	106	111.3	-0.8	8	11.2	-1.0	5	6.1	-0.5	188
Queen Angelfish	0	3.3	-1.8	43	52.6	-1.6	107	104.8	0.3	20	10.5	3.0*	7	5.7	0.5	177
Redband Parrotfish	17	11.0	1.9	223	175.4	4.4*	298	349.4	-4.4*	25	35.1	-1.8	27	19.1	1.9	590
Reef Butterflyfish	14	14.4	-0.1	236	229.4	0.5	459	457.2	0.1	35	45.9	-1.7	28	25.0	0.6	772
Scamp	9	9.0	0.0	144	143.3	0.1	293	285.5	0.7	21	28.7	-1.5	15	15.6	-0.2	482
Schoolmaster	1	7.6	-2.5*	69	121.9	-5.8*	299	242.8	5.7*	25	24.4	0.1	16	13.3	0.8	410
Shark Species	17	3.2	7.8*	97	51.7	7.6*	38	103.0	-10.1*	14	10.4	1.2	8	5.6	1.0	174
Slippery Dick	12	3.3	4.9*	34	52.6	-3.1*	115	104.8	1.6	7	10.5	-1.1	9	5.7	1.4	177
Soapfish	10	15.5	-1.5	234	247.0	-1.0	516	492.2	1.7	54	49.5	0.7	17	26.9	-2.0*	831
Spanish Mackerel	13	4.2	4.4*	100	67.2	4.8*	98	133.8	-4.9*	9	13.5	-1.3	6	7.3	-0.5	226
Spanish Sardine	1	10.6	-3.1*	162	169.7	-0.7	350	338.2	1.0	40	34.0	1.1	18	18.5	-0.1	571
Trumpetfish	15	4.8	4.7*	117	76.7	5.5*	89	152.8	-8.2*	23	15.4	2.0*	14	8.4	2.0*	258
Total	239	239		3815	3815		7602	7602		764	764		416	416		12,836

*Significant at the 0.05 level or better

DISCUSSION AND DIRECTIONS FOR FUTURE RESEARCH

Some of these results (see Table 3) could certainly be based on the hydrographic variables including water depth. At this time, the big data analytics problem investigated in this study can neither prove nor disprove the effects of the variables at each of the structures. What these results do provide, however, are conclusive evidence to inform the discussion of reef structure materials and the Rigs-to-Reefs initiatives using the “best scientific information available” at this time over the 20-year range of the TPWD’s dataset.

While particularly challenging analytically, the data from this survey have many unique attributes that will provide material for several forthcoming articles. The summary data in Table 3, for example, are particularly rich. The results of this analysis suggest that type of reef structure does have an impact on fish presence. Furthermore, it is clear that some species prefer larger structures over smaller ones, which should be particularly valuable to fisheries managers. What is unclear from this research, thus far, is how reef structures affect the five managed species, including the commercially and recreational valuable, though overfished, red snapper so prevalent in fisheries management studies especially those related to artificial reef deployments, which are less frequently sighted than the top 30 sighted species shown here.

In future research by these authors, focus will be upon (1) identifying the impact of structure on managed species abundance, (2) assessing the impact of proximity of reef structures on abundance of top species, and (3) building longitudinal models that highlight changes in species presence and abundance over time

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