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research paper

Densities of reef-associated fish and corals on offshore platforms in the Gulf of Mexico

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ABSTRACT.—The northern Gulf of Mexico possesses 1320 offshore oil/gas platforms, currently being removed at a rapid rate. Thirteen species of scleractinian corals inhabit these structures, and a positive association is known to exist between reef-associated fishes and coral. Here, we studied 22 platforms on the Mississippi River delta, an area devoid of natural reefs. We quantified the abundance of reef-associated fishes on platforms occurring in 19–334 m depths. We recorded 18 reef-associated fish species, most commonly *Stegastes leucostictus* (Muller and Troschel, 1848), *Stegastes partitus* (Poey, 1868), *Abudefduf saxatilis* (Linnaeus, 1758), *Abudefduf taurus* (Müller and Troschel, 1848), and *Chromis multilineata* (Guichenot, 1853). In water depths ≥25 m, average fish densities ranged from 1.0 to 15.3 m^{-2}. No reef-associated fishes were observed on structures in <25 m water depth. Individual sample densities ranged from 0 to 32 m^{-2}. Average fish densities peaked on the platforms at depths of 18–36 m. At >66 m depth, the fish densities dropped to zero. Average coral densities per platform in waters >30 m deep ranged from 0.4 to 173.0 colonies m^{-2}. Individual sample densities ranged from 0 to 945.0 colonies m^{-2}. There was a significant positive correlation between average reef-associated fish density and bottom water depth. There was also a positive correlation between average fish density and average coral density. The data indicated that coral and fish densities were lower in inshore waters. These waters are generally characterized by low salinity, low winter seawater temperatures, high turbidity, and high nutrient levels. Our data showed that the fish community is linked to the coral community, as is known to occur on natural reefs. We believe that these numerous organisms add environmental value to the platforms.

The northern Gulf of Mexico currently possesses 1320 fixed offshore oil and gas production platforms, and they are currently being removed at a high rate (BSEE 2018). There are several types of offshore structures; however, the fixed platforms are the largest of the stable structures (jackets and decks) and they are installed in waters <400 m. They constitute approximately 60% of all the various production structures in the Gulf of Mexico. Based on an average production life of 17 yrs, most of the remaining structures could be decommissioned by 2025 (BSEE 2018). Table 1 presents the number of fixed platforms installed, removed, and the existing structures in the Gulf of Mexico over time.

In addition to scleractinian coral, in the past we have found soft corals, black corals, and fire corals. Other sessile organisms, such as algae, oysters, sponges, hydroids, tunicates, barnacles, and bryozoans, are known to inhabit platforms in the region (Gallaway and Lewbel 1982, Sammarco et al. 2004, 2012, Kolian et al. 2013, 2017). Also associated with these organisms are other vagile demersal organisms, such as polychates, microcrustaceans, mollusks, and other invertebrates (Gallaway and Lewbel 1982), which reef-associated fish use as a food source (Randall 1967).

While studying the coral communities on platforms, we noticed a high density of reef-associated fishes in proximity with the coral reef community. Reef-associated fish tend to be demersal, philopatric, territorial, and/or cryptic (Bohnsack 1989). We then compared the densities of reef-associated fishes and corals on a number of study platforms. Sportfish on platforms, such as lutjanids (snappers), serranids (grouper), and carangids (jacks), are commonly discussed in the literature (Stanley and Wilson 2000, Gallaway et al. 2009, Shipp and Bortone 2009, Cowan et al. 2011, Ajemian et al. 2015). We did not examine these sportfish, or other pelagic or semipelagic fish, here.

Occasionally, some researchers have reported reef-associated fish, such as pomacanthids (angelfish), labrids (Spanish hogfish), *Thalassoma bifasciatum* (Bloch, 1791) (blue-headed wrasse), chaetodonts (butterflyfish), and acanthurids (surgeonfish), to occur on platforms (Scarborough-Bull and Kendall 1994, Wilson et al. 2003). Many of these fishes are highly valued within the ornamental fish trade in the United States (Wabnitz et al. 2003). In fact, it has been suggested that retired offshore platforms should be used, after their production life is over, to culture reef fish, among other uses (Reggio 1996, Kolian and Sammarco 2005, Kolian 2011, Kolian et al. 2018, 2019).

There are few data in the literature regarding populations of the various reef-associated fish that inhabit offshore platforms in the Gulf of Mexico. There has been discussion at a number of levels regarding whether platforms should be removed or retained from offshore after their production life is over. The data collected here may assist in the decision process of removing retired platforms.

Natural coral reefs have been diminishing for decades due to climate change/global warming, nutrient enrichment, overfishing, etc. (Sammarco and Strychar 2016). The platforms can act as recruitment grounds for larval fish (Lindquist et al. 2005). We feel it would be wise to understand the value of offshore platforms to these fish resources in the northern Gulf of Mexico, as they represent one of the largest collections of artificial reefs in the world (Stanley and Wilson 2000).

It is known that there is a positive association between demersal reef-associated fish and benthic corals on natural reefs (Luckhurst and Luckhurst 1978, Carpenter et al. 1981, Bellwood and Hughes 2001, Bradshaw et al. 2003, Jones et al. 2004, Sammarco et al. 2016a). In the northern Gulf of Mexico, platforms represent hard substratum in areas devoid of natural reefs and other emergent hard substrata. In related studies, Dennis and Bright (1988) and Roberts and Aharon (1994) identified only 20 potential natural reef habitats in the deeper waters in this region. The Mississippi River and other tributaries contribute nutrients and sediments to inshore waters that characteristically can inhibit the growth of corals on the inner coastal continental shelf (Rabalais et al. 1996, Dagg and Breed 2003).

Table 1. Number of fixed offshore platforms installed, removed, and currently existing in the northern Gulf of Mexico. Other production structures in the region, but not included in the table, are spars, tension-leg platforms, caissons, and well protectors. Source: BSEE 2018. List of all platform structures as of July 1, 2018.

Years	Installed	Removed	Existing fixed platforms
1942–1969	719	0	719
1970–1979	768	23	1,464
1980–1989	875	153	2,186
1990–1999	766	508	2,444
2000–2009	486	724	2,206
2010–2018	60	946	1,320
Total	3,674	2,354	

In previous studies, we observed up to 13 species of scleractinian corals and three species of soft corals inhabiting these structures. The most common native scleractinian corals were *Madracis decactis* (Lyman, 1859), *Montastraea cavernosa* (Linnaeus, 1767), and *Pseudodiploria strigosa* (Dana, 1846), along with the common soft coral *Telesto* spp. (Sammarco et al. 2004, Kolian et al. 2017). In addition, the invasive azooxanthellate scleractinian species *Tubastraea coccinea* Lesson, 1829 were found there in high densities (Sammarco et al. 2012). *Tubastraea micranthus* (Ehrenberg, 1834) was also found there (Sammarco et al. 2010). Here, we attempt to expand the current database on ecological communities associated with platforms in areas devoid of natural reefs. This may help to identify any relationship which may exist between reef-associated fish and corals, which may help us to understand the environmental value of our offshore platforms.

Our objectives were to (1) identify and quantify the number of demersal reef-associated fish, (2) examine fish densities with respect to sample depths on the platforms, (3) assess the relationship between the densities of reef-associated fish and corals with respect to sampling depths, and (4) relate our general observations on fish behavior (feeding, mobility, etc.) to the above data.

Methods

The study area spanned from 20 km east to 200 km west of the mouth of the Mississippi River. We surveyed 22 platforms offshore of St. Bernard, Plaquemines, Jefferson, and Terrebonne parishes, from May 2006 to August 2011 (Fig. 1). The bottom depths where the platforms were located ranged from 19 to 334 m. Table 2 presents the platform names and codes, water depth, distance to shore, GIS coordinates, and survey dates for each platform. The platform information was collected from the records of Bureau of Safety and Environmental Enforcement, US Department of the Interior.

Remotely operated vehicles (ROVs) housing video cameras and scuba divers with handheld cameras in underwater housings recorded the target reef organisms. The platforms surveyed were located 21–86 km offshore. Depth of surveys were limited by platform location (depth of site), safety standards for scuba divers, and umbilical limits for the ROV. Divers recorded data on the platforms down to 36 m depth, and the ROV surveyed down to 102 m.

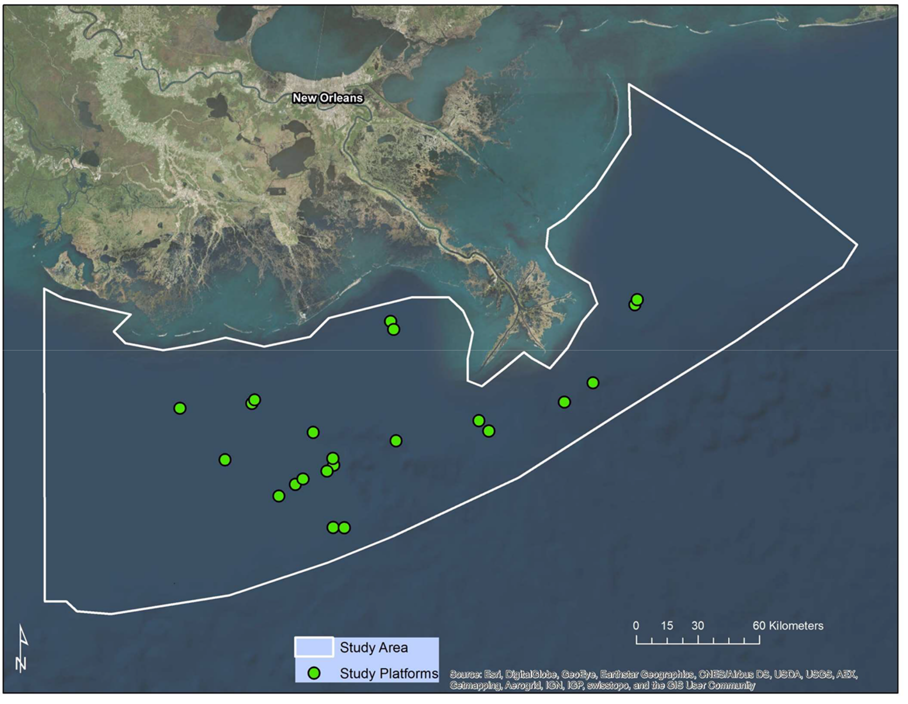

Figure 1. Map of the study area showing locations of the 22 offshore oil and gas platforms included in this survey.

Some techniques, such as use of ROV and scuba, can introduce bias in the sampling of reef fish due to differential sensitivity of various fish species to the presence of associated mechanical devices and/or the diver. In our case, any bias that was introduced due to the use of these methods was constant throughout the study. We did not attempt to determine the nature or magnitude of this potential bias.

The M/V Fling (Freeport, TX), M/V Marie Saint Claire (Houma, LA), M/V Reef Keeper (New Orleans, LA), and the R/V Acadiana (LUMCON) served as our research vessels. Scuba surveys were conducted with teams of 3–12 divers per survey, who examined the platform jackets. We collected data on numbers of reef-associated fish, depth of occurrence, and species identification.

Video data were collected from both vertical and horizontal support structures on the platforms. We gathered data from the videos in the laboratory following a uniform sampling model (not a random or continuous one). Sampling was performed every 6 m on either the vertical or horizontal support structures. Repetitive sampling was not employed (due to financial and logistic constraints), because it was not an objective of our study to provide information on temporal changes in the fish communities on the platforms. However, it is recognized that stochastic events, such as storms and seasonal environmental changes (temperature, salinity, etc.), can influence these fish communities.

With respect to data collection from video, images of the fish on the pilings were analyzed via software using a digitally generated grid (Kohler and Gill 2006). The grid was placed over the images and sized to 1 m^2 total area. The fish data were logged

Table 2. Identification codes and location information for the 22 oil and gas platforms studied here between 2005 and 2011. All were located offshore of north-central Louisiana. Water depth, distance from shore, GIS information, installation date, and survey dates are shown. Lease sector codes: GI = Grand Isle, MC = Mississippi Canyon, MP = Main Pass, SP = South Pass, ST = South Timbalier, and WD = West Delta.

Platform code	Water depth (m)	Distance to shore (km)	Latitude	Longitude	Installation date	Survey date
ST-81	19	29	28°47′12″	−91°34′21″	27-Jun-2007	13-May-2011
ST-75	20	29	28°46′03″	−91°15′25″	01-Jan-1988	13-May-2011
ST-67	20	29	28°47′56″	−91°35′08″	01-Jan-1967	12-May-2006
WD-39	25	24	29°06′02″	−90°10′51″	10-Jun-1998	02-Sep-2006
WD-40	27	24	29°04′09″	−90°11′40″	01-Jan-1969	02-Sep-2006
ST-164	30	72	28°34′10″	−91°27′18″	22-Jul-1986	21-Aug-2008
ST-130	49	45	28°40′30″	−91°50′29″	01-Jan-1962	21-Aug-2008
ST-185B	53	69	28°25′48″	−91°41′31″	01-Jan-1988	12-May-2011
ST-206	53	64	28°28′30″	−91°45′51″	01-Jan-1977	28-Jul-2010
ST-185A	55	62	28°29′44″	−91°47′49″	01-Jan-1973	28-Jul-2010
GI-93	64	60	28°32′56″	−91°55′53″	01-Jan-1975	19-Oct-2010
GI-94	64	62	28°31′33″	−91°54′07″	01-Jan-1974	28-Jul-2010
GI-90	68	58	28°34′31″	−91°55′39″	01-Jan-1985	28-Jul-2010
MP-311B	76	24	29°09′51″	−89°15′14″	01-Jan-1979	12-Sep-2010
MP-311A	76	24	29°11′00″	−89°15′47″	01-Jan-1980	12-Sep-2010
GI-116	99	86	28°18′33″	−91°55′46″	26-Aug-1900	21-Oct-2010
GI-115	111	86	28°18′27″	−91°58′41″	22-Aug-1997	20-Oct-2010
SP-87	119	21	28°43′12″	−90°34′09″	19-Mar-1995	11-May-2011
SP-89	128	26	28°40′50″	−90°36′45″	09-Feb-1982	11-May-2011
MC-311	130	46	28°38′33″	−90°12′21″	01-Jan-1978	21-Aug-2011
MC-280	304	34	28°39′46″	−90°50′32″	01-Jan-1983	20-Aug-2011
MC-109	334	24	28°51′53″	−89°04′09″	01-Jan-1991	11-May-2011

into a database, and we calculated average density for each 6 m depth interval. Fish densities were standardized to number per m^2. We calculated density for all depths within the area surveyed for each platform.

We compared our fish data to coral data derived from earlier studies (Sammarco et al. 2014b, Kolian et al. 2017). The methods for collecting the coral data are described in detail in Sammarco et al. (2014b). Coral data were derived from video images and standardized for each 6 m depth interval within a video transect. Mean densities were calculated for each platform along with standard deviations.

Data Analysis.—We examined correlations between the density of reef-associated fish and scerlactinian corals. We also assessed the relationship between fish density and bottom depth of water where the platforms were located. In addition, we examined the depth distribution of reef-associated fish based on their occurrence on the pilings of the platform. Fish and coral density data were analyzed by standard parametric tests. Basic statistics (mean, SD, n) were calculated for fish and coral densities. Additional analyses included Pearson's Product-Moment Correlation on (1) fish density and water depth where the platform was located, and (2) fish density and coral density. Model II linear regression analyses (and associated analyses of variance) were also performed.

Analyses were performed using BiomStat 3.2 and 3.3 (Rohlf and Slice 1999). In some cases, where necessary, data were transformed by $\sqrt{(y + 0.5)}$ or $\log_{10} (y + 1.0)$

Table 3. Species of reef-associated fish observed at the 22 study platforms. Family, genus, species, and common names are provided.

Species name	Common name
Acanthuridae	
Acanthurus coeruleus Bloch and Schneider, 1801	blue tang
Acanthurus gahhm (Forsskål, 1775)	black surgeonfish
Chaetodontidae	
Chaetodon ocellatus Bloch, 1787	spotfin butterflyfish
Labridae	
Bodianus rufus (Linnaeus, 1758)	Spanish hogfish
Clepticus parrae (Bloch and Schneider, 1801)	creole wrasse
Thalassoma bifasciatum (Bloch, 1791)	bluehead wrasse
Pomacanthidae	
Holacanthus bermudensis Goode, 1876	blue anglefish
Holacanthus ciliaris (Linnaeus, 1758)	queen angelfish
Pomacanthus paru (Bloch, 1787)	French angelfish
Pomacentridae	
Abudefduf saxatilis (Linnaeus, 1758)	sergeant major
Abudefduf Taurus (Müller and Troschel, 1848)	night sergeant
Chromis multilineata (Guichenot, 1853)	brown chromus
Chromis viridis (Cuvier, 1830)	blue chromis
Stegastes leucostictus (Müller and Troschel, 1848)	beaugregory
Stegastes partitus (Poey, 1868)	bicolor damselfish
Stegastes variabilis (Castelnau, 1855)	cocoa damselfish
Scaridae	
Scarus iseri (Bloch, 1789)	striped parrotfish
Scarus vetula Bloch and Schneider, 1801	queen parrotfish

for normalization purposes (*see* Sokal and Rohlf 1995). Details of statistical results are presented in the figure legends. Graphics were performed using SigmaPlot 10.0.

Results

Fish Species.—We observed a total of 18 different species of reef-associated fishes in this study (Table 3). Some of the fishes are known to be egg-layers and brooders, while others were broadcast spawners (DeLoach 1999). In our survey, the five most abundant species were *Stegastes leucostictus* (*see* Table 3 for common names and authorities), *Stegastes partitus*, *Abudefduf saxatilis*, *Abudefduf taurus*, and *Chromus multilineata*. These five species of pomacentrids comprised 78% of the reef-associated fish. All the reef-associated fish species encountered are listed in Table 3.

Fish Densities.—The single highest sample density count was observed on GI-93 with 32 fish m^{-2}. This sample was located on a horizontal transom at 12 m depth. The range of average fish density on deeper structures (≥25 m) was 1.0–15.3 fish m^{-2}. Table 4 presents the density of reef-associated fish at various depths and locations. The average fish density, considering all platforms, was 5.0 m^{-2}. The platform with the highest average fish density was MC-280 (15.3 fish m^{-2}). This platform was located 34 km southwest of the Mississippi Main Pass, in 304 m of water. On structures located in ≥25 m depths, the minimum average density was found on SP-87 (1.0 fish m^{-2}),

Table 4. Density of reef-associated fish with respect to platform sampling depth. Mean fish density per sample depth are shown, along with its standard deviation and sample size. Mean fish density per platform also shown. Blank cells represent no data due to depth, diver, or remotely operated vehicle /umbilical restrictions. Platforms presented, top to bottom, in order of increasing bottom depth. *See* Table 2 for platform names and water depth.

	Sample depth (m)																	Mean density
Platform code	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	per platform
ST-81	0	0	0	0														0.0
ST-75	0	0	0	0														0.0
ST-67	0	0	0	0														0.0
WD-39	0	6	4	2														3.0
WD-40	0	2	3	5														2.5
ST-164	2	4	14	10	1													6.2
ST-130	2	6	20	14	10	2	0											7.7
ST-185B	4	2	3	5	2	1	0	0	0									1.9
ST-206	0	0	4	12	16	3	2	0	0									4.1
ST-185A	2	1	10	13	26	16	3	0	0	0								7.1
GI-93	0	12	32	18	16	11	8	4	0	0	0	0						8.4
GI-94	2	30	12	11	8	7	2	0	0	0	0	0						6.0
GI-90	3	16	4	8	12	9	5	6	1	0	0	0						6.0
MP-311B	4	2	14	17	6	5	2											7.1
MP-311A	3	0	16	18	7	4	1											7.0
GI-116	2	10	14	7	16	11	8	3	12	3	0	0	0	0	0	0	0	5.1
GI-115	0	8	11	15	10	21	16	5	2	1	0	7	0	0	0	0	0	5.6
SP-87	0	1	3	2	6	1	4	0	0	0	0	0	0	0	0	0	0	1.0
SP-89	0	12	16	9	10	14	6	4	2	3	0	0	0	0	0	0	0	4.5
MC-311	4	5	16	26	22	16	6	8	2	2	1	4	0	0	0	0	0	6.6
MC-280	2	16	28	23	15	21	2											15.3
MC-109	6	2	4	16	21	14	19	6	4	4	2	1	0	0	0	0	0	5.8
Mean density per depth	1.6	6.1	10.4	10.5	12.0	9.8	5.3	3.0	1.9	1.3	0.3	1.3	0.0	0.0	0.0	0.0	0.0	5.8
SD	1.8	7.5	8.9	7.5	7.0	6.8	5.4	2.9	3.4	1.6	0.7	2.5	0.0	0.0	0.0	0.0	0.0	3.5
n	22	22	22	22	17	16	16	12	12	10	9	9	6	6	6	6	6	22.0

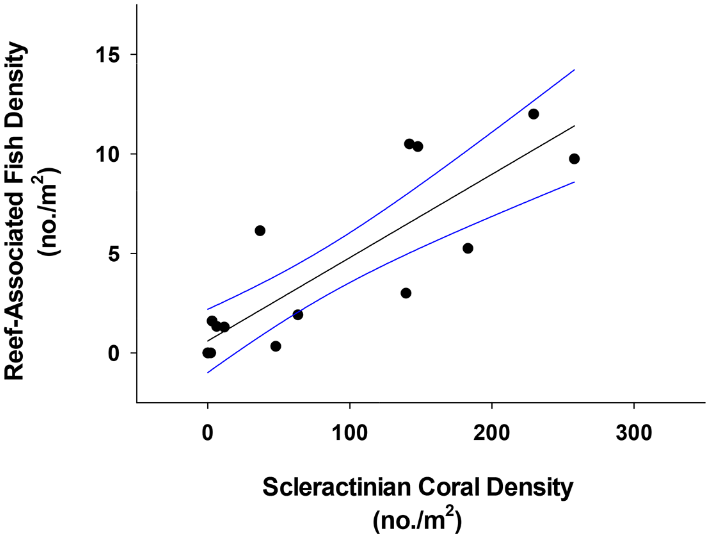

Figure 2. The relationship between coral and fish density at sampling depths on the platforms. Coral densities from previous studies have been used here (Sammarco et al. 2014b, Kolian et al. 2017). Coral/fish ratios have been compared for all platforms at all sample depths ($r = 0.857$, Pearson's Product-Moment Correlation, $P < 0.01$; Model II Regression, $y = 0.559 + 0.042x$, $P < 0.001$). Outer lines represent 95% confidence intervals for the fitted line.

located 10 km south of the Mississippi River mouth in 129 m water depth. There were no reef-associated fish observed on Platforms ST-81, ST-75, and ST-67. These platforms are located in shallow water <25 m depth.

Coral Densities.—The average density of scleractinian corals on an individual platform in waters ≥30 m deep ranged from 0.4 to 173 colonies m^{-2}. The mean density of scleractinian corals for all structures deployed at these depths was 81 colonies m^{-2}. The range of coral densities per individual quadrat varied between 0 and 258 m^{-2}. Scleractinian population densities were highest on GI-116, a platform west of the Mississippi Canyon (MC) sector, at 100 m depth. The minimum average scleractinian density was observed on GI-90. The splash zone did not contain scleractinian or any other corals. Corals were first encountered at 4–10 m below the surface. Their densities increased with depth down to 30 m, after which their densities began to decline (*see* Table 5). Population densities were generally highest at 18–30 m depth.

The Association between Fish and Corals.—There was a highly significant, positive correlation between the density of fishes and corals. Figure 2 presents the correlation of fish and corals considering all locations in the study area.

Depth Distribution of Fish on the Platforms.—In deeper water, the density of all reef-associated fish combined decreased significantly at depths of >36 m. Densities decreased to zero levels at 72 m depth. They remained that way down to the sea floor or to the operational limits of the ROV (100 m; Fig. 3). The data indicate that the fishes were most abundant at platform depths between 6 and 36 m.

Table 5. Density of Scleractinian coral with respect to platform sampling depth originally published in Sammarco et al. (2014b). Mean coral density per sample depth shown, along with its standard deviation and sample size. Blank cells represent no data due to depth, diver, or remotely operated vehicle/umbilical restrictions. Platforms listed top to bottom, sampling depths shown left to right. *See* Table 2 for platform names and water depth.

	Sample depth (m)																	
Platform code	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	Mean density per platform
ST-81	0	0	2	0														0
ST-75	0	0	0	0														0
ST-67	0	0	0	0														0
WD-39	0	0	0	0	0													0
WD-40	0	0	0	0	0													0
ST-164	0	1	1	0	0													0
ST-130	0	118	242	194	157	135	29	0										109
ST-185B	0	0	262	72	225	523	7	2	0									121
ST-206	0	0	60	219	171	159	90	10	0									79
ST-185A	0	41	35	213	199	321	206	81	16	0								111
GI-93	21	26	71	164	157	135	0	7	27	5	0	0						51
GI-94	0	112	290	221	945	133	147	22	109	0	0	0						165
GI-90	22	24	58	124	108	103	16	19	1	0	0	0						40
MP-311B	3	15	123	121	234	183	174											122
MP-311A	1	11	140	247	237	184	165											141
GI-116	0	0	789	283	0	401	602	477	71	28	285	0	1	0	0	0	0	173
GI-115	0	0	105	81	197	303	178	308	0	0	116	10	0	0	0	0	0	76
SP-87	0	13	156	186	197	148	175	136	199	66	29	17	0	0	0	2	0	78
SP-89	0	111	141	163	231	486	327	274	39	16	0	4	0	0	0	0	0	105
MC-311	22	199	373	330	363	333	262	60	163	0	1	26	0	0	0	0	1	125
MC-280	0	97	252	281	199	133	115											154
MC-109	0	43	154	225	275	448	439	418	137	0	0	0	11	0	0	0	0	126
Mean density per depth	3.0	37.0	148.0	142.0	205.0	258.0	183.0	140.0	63.0	12.0	48.0	6.0	2.0	0	0	0	0	81
SD	7.5	54.9	180.3	108.1	206.0	143.4	163.2	170.4	71.3	21.2	96.8	9.4	4.5	0.00	0.00	0.86	0.35	60.10
n	22	22	22	22	17	16	16	12	12	10	9	9	6	6	6	6	6	22

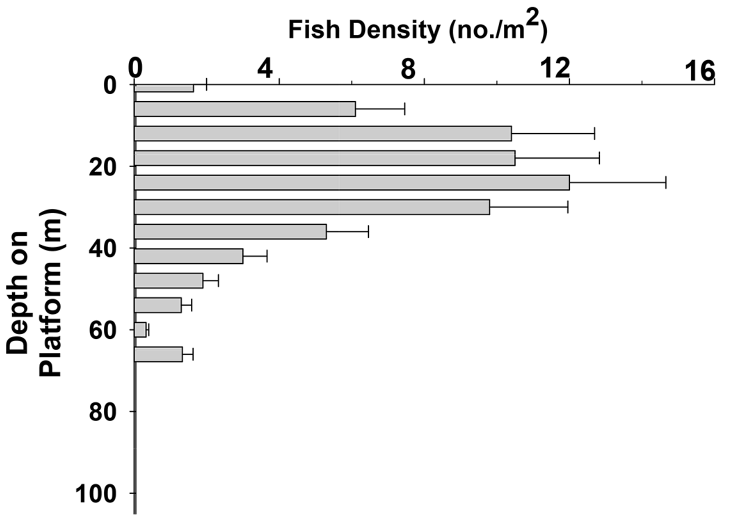

Figure 3. Summary of the depth distribution of reef-associated fish sampled on the 22 study platforms. Density shown as number per m^2.

Relationship between Fish Density and Water Depth Associated with Platform Locations.—We found no reef-associated fishes or corals on structures located in waters <25 m depth; these platforms were ST-67, ST-81, and ST-76. Further, there was a significant positive relationship between platform structure depth and fish density, where average fish density increased with bottom depth (Fig. 4).

Discussion

The construction of offshore platforms in the northern Gulf of Mexico has provided hard substrate for the settlement and growth of a variety of reef species. In the present study, our analysis on the density of coral populations on these artificial substrates revealed that their populations peaked between 10 and 30 m depth. We found that the density of corals was highly correlated with the density of reef-associated fishes, as they provide preferred habitat for these fish species (Chartan and Ruzafa 1998, Gratwicke and Speight 2005). Azooxanthellate/hermatypic corals, like those encountered here, are not restricted or limited to shallow water, as they are not limited primarily by light penetration (Sammarco et al. 2014a,b, Kolian et al. 2017); food-limitation may become more important in deeper water.

Our data showed that reef-associated fish inhabit platforms deployed in >25 m depth, and in general, fish densities on platforms increased as bottom depth increased. It is not known what caused a general fish absence in shallower water, though the inshore (shallower) areas are characterized by low salinities, lower winter seawater temperatures (these organisms are tropical), and high turbidity and nutrients (e.g., nitrates and phosphates; these coral and fish species generally live in low turbidity and low nutrient environments). Platform SP-87, a deep-water platform, yielded an anomalous result: nominal fish density for its bottom depth; though this was probably due to its proximity to the mouth of the Mississippi River (10 km).

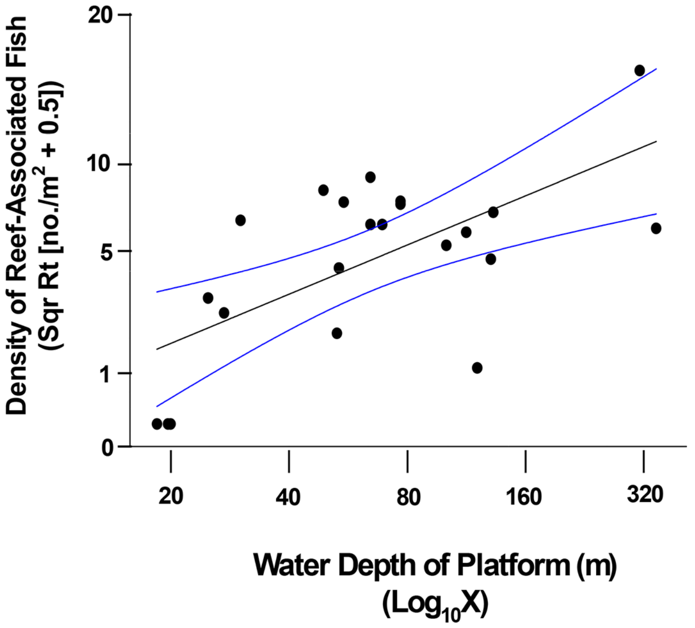

Figure 4. Density (no m^{-2}) of reef-associated fish shown as a function of bottom depth at the various platform locations on the continental shelf. Significant increase in fish density with bottom depth (r = 0.856, P < 0.01, Pearson's Product-Moment Correlation; P < 0.001, Model II Regression, $y = 0.53 + 1.53x$). Outer lines represent 95% confidence intervals for the fitted line.

The most abundant coral species in the study area was *Tubastraea* spp. (Sammarco et al. 2012, 2014b), a highly abundant azooxanthellate coral on the platforms. *Tubastraea* spp. are invasive to the Gulf of Mexico (Cairns 2000, Fenner and Banks 2004, Sammarco et al. 2010, 2013, 2014b, Creed et al. 2017). Based on previous coral studies, combined with the results of the present study and anecdotal observations, it would appear that the association between reef fish and *Tubastraea* spp. is particularly strong, and that this coral species appears to support a diverse community of reef-associated fish. *Tubastraea* spp. are known to inhabit pilings, piers, and other artificial reefs. They are, however, uncommon on healthy natural coral reefs in the Gulf of Mexico (Precht et al. 2014, Sammarco et al. 2016b, Kolian et al. 2017). *Telesto* spp. (Octocorallia) were also very common on the pilings and were observed to provide habitat for reef-associated fish.

The relationship between coral density and fish density is clear and both groups of reef organisms are considered valuable to natural coral reefs. We believe that the relationship between the reef-associated fish and corals, which are protected by federal regulations such as the Magnuson-Stevens Act, makes these platforms valuable as artificial reefs in the northern Gulf of Mexico.

With respect to behavior including reproduction and mobility, we commonly observed damselfish nesting in the bell housings of the conductors (devices used to support the vertical pipes transporting crude oil or gas from the bottom). We observed that small damselfish and juvenile fishes would rarely venture farther than 1 m from the platform pilings (this is most likely a behavioral adaptation to avoid predation). This contrasts with our observations of larger reef-associated fish (>25 cm) that we observed swimming as far as 5–15 m from the structure.

With respect to feeding, species of the families Pomacanthidae, Acanthuridae, and Scaridae were observed grazing on the vertical and horizontal pilings. A variety of pomacentrids were feeding on small invertebrates dwelling on the platforms [*see* Gallaway and Lewbel (1982) for a discussion of micro- and macroinvertebrates inhabiting offshore platforms] and on plankton passing in the current.

As mentioned earlier, the fixed offshore platforms currently number approximately 1320 and are being removed at the rate of about 130 yr^{-1} (BSEE 2018). Retaining these platforms would help to maintain reef-associated fish and coral populations in the Gulf of Mexico. We have demonstrated here that there is a clear relationship between reef-associated fish and corals on platforms in the northern Gulf of Mexico. These corals are protected by federal regulation (Magnuson-Stevens Act), and we believe that the data presented here will supplement and enhance our understanding of the inherent value of these structures as artificial reefs.

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