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Environmental Management

ISSN 0364-152X

Environmental Management
DOI 10.1007/s00267-017-0862-z

Springer

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Received: 21 May 2016 / Accepted: 28 March 2017

Abstract Scleractinian, octocoral, and antipatharian corals have colonized many of the offshore oil and gas platforms in the northern Gulf of Mexico. We surveyed 25 offshore oil and gas platforms for these cnidarians. Few to no corals were detected on inshore, shallow-water structures at <25 m depth; however, the abundance of corals increased, ranging from 14 to 194/m^2, on platforms in waters deeper ≥25 m. The most common coral encountered were *Tubastraea coccinea* (Scleractinia) and *Telesto* spp. (Octocorallia). The data suggest that the offshore platforms located in waters of >25–30 m in the study area are often colonized by these corals. We recommend that structures located in deeper waters should be surveyed for coral and, if the populations are substantial, consider alternate uses for the retired platforms, and leaving them in place, when feasible.

Keywords Offshore oil and gas platforms · Coral · Magnuson-Stevens Act · NEPA

Electronic supplementary material The online version of this article (doi:10.1007/s00267-017-0862-z) contains supplementary material, which is available to authorized users.

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Introduction

Thousands of fixed offshore oil and gas platforms have been installed in the U.S. Federal waters of the Gulf of Mexico since 1947. Thousands have been removed to date, in accordance with federal laws. Based on an average profitable lifespan of 17 years, ~90% of the remaining fixed platforms will reach the end of their production life by 2025 (Bureau of Safety and Environmental Enforcement [BSEE] 2016). At this time, offshore platforms are one of the most productive ecosystems known to exist (Wilson et al. 2003; Claisse et al. 2014). An unexpected, long-term effect of the platforms is that they have become habitat for sport and commercial fish (Stanley and Wilson 2000; Shipp and Bortone 2009) and several protected, threatened, and endangered species, such as sea turtles (Gitschlag et al. 1997) and coral (Sammarco et al. 2012).

Offshore platforms numbers are declining because they are removed after their useful production life. This is the result of existing federal laws. Federal legislation, approved in the 1970s, requires that platforms be removed within 1 year after oil or gas production ceases (30 CFR 250.112). These regulations were written when little was known about the biological communities that grow on the structures (C. Bedell, personal communication 2005, attorney on the legal team that drafted Title 30, CFR 250 regulations outlining the oil and gas operator's management responsibilities and the federal government's role in oil and gas management). Occasionally the platforms are toppled over and utilized for artificial reefs. Most of the time, it is not economical to leave the structure offshore. So far ~9% of the decommissioned structures in our study area have been redeployed as artificial reefs (Louisiana Department of Wildlife and Fisheries [LDWF] 2016).

Published online: 19 May 2017

Corals fall under the most stringent protection of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). There is a prohibition against removing coral from the federal waters of the Gulf of Mexico (50 CFR 622.2 and 622.32). Several underwater investigations provide documentation that corals have colonized offshore structures in varying abundances (Sammarco et al. 2004, 2012).

Previous studies of corals on platforms revealed that *Astrangia* spp. and other azooxanthellate corals occurred offshore of coastal Louisiana and Texas (Gallaway et al. 1981). Other researchers observed *Astrangia asteriformis* (Gunter and Geyer 1955) and *Astrangia solitaria*, *Phyllangia americana*, *Tubastraea coccinea*, *Oculina diffusa* (Dokken et al. 2000). Bright et al. (1991) noted four species of scleractinian corals on platforms near the National Oceanographic Atmospheric Administration (NOAA) Flower Garden Banks National Marine Sanctuary (FGBNMS)—*Diploria strigosa*, *Porites astreoides*, *Madracis decactis*, and *Madracis asperula*. The deep-water, azooxanthellate coral *Lophelia pertusa* was also found on platforms located on structures >100 m depth (Larcom et al. 2014).

Sammarco et al. (2012) reported the presence of nine species of hermatypic and four species of ahermatypic corals on platforms in the Gulf-wide study. The three most common hermatypic corals were *M. decactis*, *D. strigosa*, and *Montastraea cavernosa*, listed here in decreasing abundance, respectively. The other hermatypes found on platforms were *P. astreoides*, *Madracis formosa*, *Colpophyllia natans*, *Stephanocoenia intercepta*, and *Stephanocoenia michelinii*. The four ahermatypic corals observed were *T. coccinea*, *O. diffusa*, *Millepora alcicornis*, and *P. americana*. *T. coccinea* was the most abundant coral found on these platforms. This was consistent with the observations of Sammarco et al. (2010) who noted that there were hundreds of thousands of colonies of *T. coccinea* on a single platform, making it the most abundant coral in the Gulf of Mexico. *T. coccinea* was first observed on an offshore platform in 1989 (Scarborough and Kendall 1994). Colonies of the congener of *T. micranthus*, another more recent invasive species, were observed on a number of structures near the mouth of the Mississippi River (Sammarco et al. 2010, 2014; Kolian et al. 2013). Sammarco et al. (2010, 2014, 2015) and Precht et al. (2014) have recommended that precautions should be taken to limit the potentially harmful effects of these species on native habitats.

The octocoral soft coral *Telesto* (spp.) (Cnidaria, Octocorallia) is common on offshore platforms. Gallaway and Lewbel (1982) noted that some Louisiana offshore platforms contained populations of *Telesto* spp. Dokken et al. (2000) discussed the populations of the octocoral genus *Alcyonaria* on platforms surveyed off Texas. Brooks et al. (2012) observed octocorals on a number of deep-water platforms in the central and northwestern regions of the Gulf of Mexico.

The black coral *Antipatharia* were detected inhabiting structures in the northwestern Gulf of Mexico. *Plumapathes pennacea* was found on deep-water platforms in the north and northwest Gulf of Mexico (Boland and Sammarco 2005; Brooks et al. 2012). The hydrozoan *M. alcicornis* (Cnidaria, Hydrozoa)—the fire coral—has been observed inhabiting structures in the offshore waters of both Texas (Bright et al. 1991) and Louisiana (Sammarco et al. 2012). Photographs of different classes of coral inhabiting the offshore platforms in the Gulf of Mexico are presented in the Supplemental Information link on the Online Resources section.

We assessed the abundance of three groups of cnidarians—Scleractinia, Octocorallia, and Antipatharia—on 25 offshore oil and gas production platforms. In the past, researchers have documented a variety of corals that colonized the structures. Some studies were qualitative in nature, and others quantitative (Gallaway et al. 1981; Bright et al. 1991; Sammarco et al. 2004, 2012, 2013a, 2015; Larcom et al. 2014). Sammarco et al. (2012) presented data on the abundance of scleractinian corals; however, they did not consider other groups such as octocorals or antipatharians. Here, we discuss the abundance of all three of these groups. These data may be of use to U.S. Federal agencies in the future to assess the environmental impacts of decommissioning offshore oil and gas platforms (Minerals Management Service [MMS] 2005). In relation to coral colonization of scleractinian corals on the platforms, we understand that there is concern regarding the presence of *Tubastraea* spp. and its potential impacts. These concerns will be considered in the "Discussion" section below.

Our goals here were to—

- Identify and quantify the number of scleractinian, octocoral, and antipatharian corals.
- Record the relationship between density in these ecological groups and distance from shore and depth.
- Determine the relationship between density and their distribution in the water column down to 100 m.

Methods

Our study area covered an area including 20 km east of the Mississippi River to 200 km west of the river mouth, offshore from Terrebonne Parish. We surveyed 25 platforms. A location map of the structures (Fig. 1) is presented below. Table 1 provides the platform name/code, water depth, distance to shore, GIS coordinates, installation date, and survey date for each of the platforms. The date and depth of

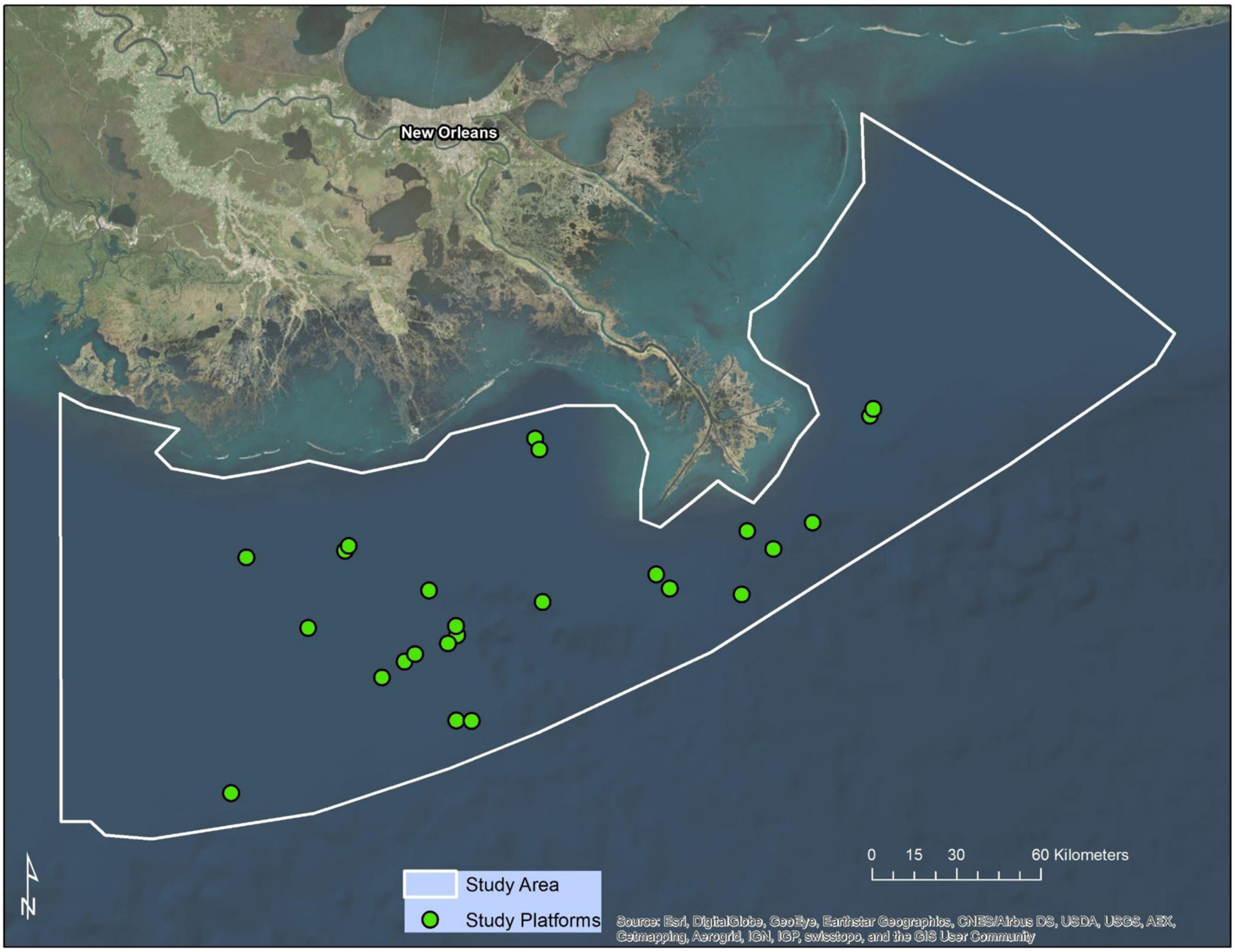

Fig. 1 A map showing the study area where 25 offshore oil and gas production platforms were surveyed for population densities of three cnidarian groups—scleractinian corals, octocorals, and antipatharians. Identification codes and GIS location information are provided in Table 1. *GOM* Gulf of Mexico

platform installation was determined from BSEE records. The range of water depths in which the platforms were located was 19–339 m (Table 1).

As mentioned above, three groups of cnidarians were studied here—scleractinian corals, octocorals, and antipatharians. General information on other invertebrate taxa known to colonize offshore platforms may be found in Shinn (1974), Driessen (1989), Adams (1996), and Boland (2002).

Data on the cnidarians were recorded using underwater cameras operated by remotely operated vehicles (ROVs) and SCUBA divers. Divers recorded the organisms on 11 of the platform jackets from the surface down to ≤37 m. On the other 14 platforms, the ROV descended down to ≤100 m, limited by water depth or the length of the umbilical. Therefore, all conclusions of this report pertain only to depths of ≤37 or <100 m. Details regarding the collection of data via ROV may be found in Sammarco et al. (2012, 2015). They will be summarized here briefly for the convenience of the reader.

Architectural drawings of the platform jackets were used to obtain the surface area of the structures. The total surface area of the platform was used to standardize density (number of corals per unit area). Diameters and lengths of the cylindrical horizontal cross-beams and the vertical and diagonal pilings were determined. The total surface area surveyed was converted into sq. m. for each platform, and used to calculate each 6 m depth interval.

We collected new data of octocorals and antipatharians from all the platforms. Scleractinian data from 14 of the platforms were published in previous manuscripts (Sammarco et al. 2012, 2015) and included in these data analyses. Here, we record scleractinian abundance from 11 new platforms and the octocoral and antipatharian data from all of the 25 structures.

Table 1 Study platforms

Platform code	Water depth (m)	Distance to shore (km)	Latitude	Longitude	Install date	Survey date
ST-81	19	28.8	28°47′12″	−91°34′21″	27 June 2007	13 May 2011
ST-75	20	28.8	28°46′03″	−91°15′25″	1 January 1988	13 May 2011
ST-67	20	28.8	28°47′56″	−91°35′08″	1 January 1967	12 May 2006
WD-39	25	24	29°06′02″	−90°10′51″	10 June 1998	2 September 2006
WD-40	27	24	29°04′09″	−90°11′40″	1 January 1969	2 September 2006
ST-164	30	72	28°34′10″	−91°27′18″	22 July 1986	21 August 2008
ST-130	49	44.8	28°40′30″	−91°50′29″	1 January 1962	21 August 2008
ST-185B	53	68.8	28°25′48″	−91°41′31″	1 January 1988	12 May 2011
ST-206	53	64	28°28′30″	−91°45′51″	1 January 1977	28 July 2010
ST-185A	55	62.4	28°29′44″	−91°47′49″	1 January 1973	28 July 2010
GI-93	64	60.8	28°32′56″	−91°55′53″	1 January 1975	19 October 2010
GI-94	64	62.4	28°31′33″	−91°54′07″	1 January 1974	28 July 2010
GI-90	68	57.6	28°34′31″	−91°55′39″	1 January 1985	28 July 2010
MP-311B	76	24	29°09′51″	−89°15′14″	1 January 1979	12 September 2010
MP-311A	76	24	29°11′00″	−89°15′47″	1 January 1980	12 September 2010
GI-116	99	86.4	28°18′33″	−91°55′46″	26 August 2000	21 October 2010
GI-115	111	86.4	28°18′27″	−91°58′41″	22 August 1997	20 October 2010
SP-87	119	20.8	28°43′12″	−90°34′9″	19 March 1995	11 May 2001
SP-89	128	25.6	28°40′50″	−90°36′45″	9 February 1982	11 May 2011
MC-311	130	46.4	28°38′33″	−90°12′21″	1 January 1978	21 August 2011
SS-332	133	102.4	28°6′15″	−91°12′27″	31 August 1985	13 August 2012
SP-52	161	12.8	28°50′28″	−90°51′38″	1 January 1991	12 May 2011
MC-280	304	33.6	28°39′46″	−90°50′32″	1 January 1983	20 August 2011
MC-194	311	20.8	28°47′27″	−90°56′37″	1 January 1978	9 May 2010
MC-109	334	24	28°51′53″	−89°4′9″	1 January 1991	11 May 2011

Note: Identification code and location information for the 25 oil and gas platforms studied here between 2005 and 2011. Platforms are located on the north-central continental shelf of the Gulf of Mexico, off Louisiana. Water depth, distance from shore, GIS information, installation date, and survey dates are also shown. Lease sector codes: *GI* Grand Isle, *MC* Mississippi Canyon, *MP* Main Pass, *SP* South Pass, *SS* Ship Shoal, *SP* South Pass, *ST* South Timbalier, and *WD* West Delta

Images provided by the diver surveys were analyzed via computer using the translucent grid coral counter (Kohler and Gill 2006) to facilitate counting. The grid was placed in the center of the computer screen and used as a reference guide to facilitate counting within each square. We did not use the software to collect data on percent cover. The National Environmental Protection Act (NEPA) regulations require information on colony counts, which is what was collected here. Species like *Telesto* spp. (Cnidaria, Stolonifera, Clavulariidae) are erect branching octocorals which grow and reproduce asexually via stolons. Therefore, corals that were located adjacent to each other can be clones and may be considered the same genotype, or essentially the same colony. Most of the time (≥90%) we observed small individual colonies of *Telesto* spp. that were independent to each other; and in these cases, they were considered as individual colonies.

One to three quadrats were analyzed for every 6 m depth per transect on each vertical piling. For analytical purposes, we combined data over 6 m depth intervals. Colony densities were standardized to no./m^2, and results were logged into a database. We then calculated average densities for each 6 m depth interval and standardized the density for all depths.

The surface area of the platforms ranged from 4000 to 12,000 m^2 of subsurface habitat/platform. The data presented here were collected at disparate points in time and space; therefore, no attempt has been made to build a time-series analysis that may indicate temporal changes.

Results

Table 2 contains the average densities (no./m^2) on the 25 platforms surveyed within the study area. Scleractinian corals were the most abundant cnidarians on the platforms. The average density of scleractinian corals in waters ≥30 m deep ranged from 0.4 to 173 colonies/m^2. The splash zone

Table 2 Coral abundance on existing platforms in northern Louisiana study area

Location		Average density no./m^2			
Area code	Water depth (m)	Scleractinian	Octocoral	Antipatharian	Total
ST-81	19	0.4	0.0	0.0	0.4
ST-75	20	0.0	0.0	0.0	0.0
ST-67	20	0.0	0.0	0.0	0.0
WD-39	25	0.0	13.6	0.0	13.6
WD-40	27	0.0	105.8	0.0	105.8
ST-164	30	0.4	127.4	0.0	127.8
ST-130	49	109.5	23.0	0.0	132.5
ST-185B	53	121.3	30.1	0.0	151.3
ST-206	53	78.7	11.3	0.0	89.9
ST-185A	55	111.2	77.4	0.0	188.6
GI-93	64	51.0	8.1	0.1	59.2
GI-94	64	164.9	9.0	0.2	174.0
GI-90	68	39.6	3.3	0.1	42.9
MP-311B	76	122.4	50.2	0.0	172.6
MP-311A	76	140.6	45.2	0.0	185.8
GI-116	99	172.8	1.1	0.1	174.0
GI-115	111	76.4	3.0	0.1	79.5
SP-87	119	77.9	2.2	0.2	80.2
SP-89	128	105.4	0.4	0.1	105.8
MC-311	130	125.5	15.0	0.2	140.7
SS-332	133	65.0	15.6	0.0	80.6
SP-52	161	104.6	13.6	0.0	118.2
MC-280	304	153.8	0.7	0.0	154.6
MC-194	311	138.5	24.7	0.0	163.2
MC-109	334	126.5	3.8	0.1	130.4

Note: Average densities (no./m^2) of cnidarian colonies from three taxa—scleractinian corals, octocorals, and antipatharians. Data derived from surveys of 25 offshore platforms in the northeastern Gulf of Mexico. Average density also shown by survey depth

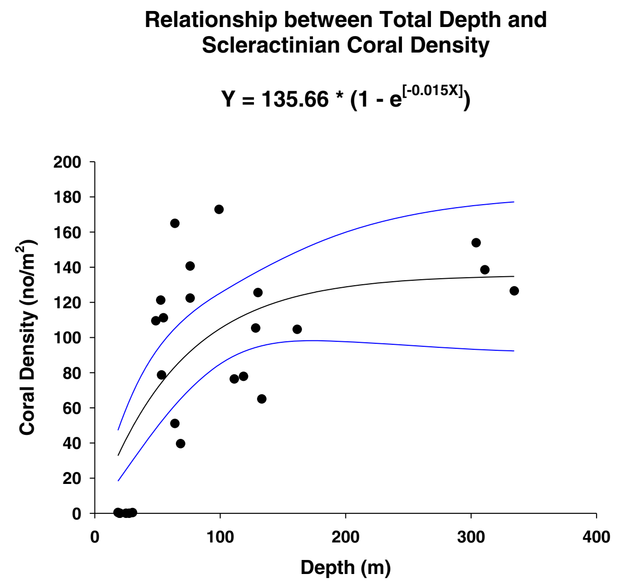

Fig. 2 Density of scleractinian corals on 25 offshore oil and gas production platforms surveyed for cnidarians on the continental shelf in the northeastern Gulf of Mexico. Density (no./m^2) is shown as a function of total bottom depth. Significant increase in scleractinian density with bottom depth (dynamic curve-fitting analysis, $p < 0.001$, $Y = 135.66 \times (1 - e[-0.015X])$). *Outer lines* represent 95% confidence intervals for the fitted line

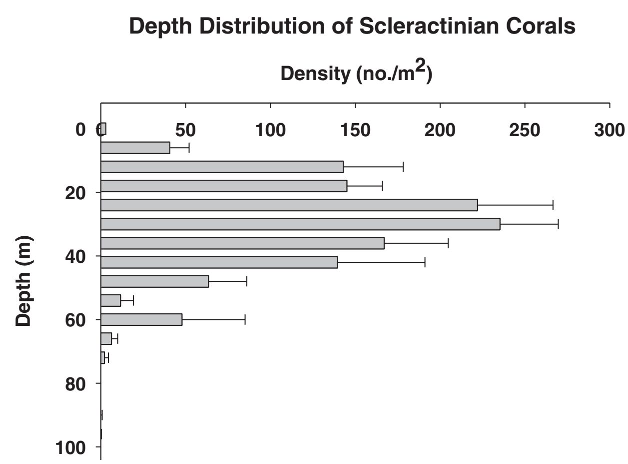

Fig. 3 Summary of the depth distribution of scleractinian corals found on 25 offshore oil and gas production platforms surveyed for cnidarians on the continental shelf in the northeastern Gulf of Mexico. Density shown as no./m^2

did not contain scleractinian or any other corals. Corals were first encountered at 4–10 m below the surface. Their abundance increased with depth (Fig. 2). Population densities were usually highest at 18–30 m depth and then declined below 30–40 m (Fig. 3). 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 mean density of scleractinian corals was 83 colonies/m^2 for all structures located in the 30–339 m depth range.

The ahermatypic coral *T. coccinea* was the most common and abundant scleractinian coral found on the platforms within the study area. Other ahermatypic species included *O. diffusa* and *T. micranthus*, which were observed on some of the structures in numbers as low as ≤0.001 colonies/m^2. *T. micranthus* was, on average, usually found in waters >70 m depth on the platforms. They also inhabited mid-depth regions on the platforms—between 18 and 30 m depth. *O. diffusa* was found at 8–15 m depth on one structure (ST-164) which was located in 30 m of water. *Madracis decactus* and *D. strigosa*, zooxanthellate corals, were the most abundant hermatypes observed on several platforms, although their densities were highly variable between platforms.

Five platforms contained few to no scleractinians (Table 2). These were ST-67, ST-81, ST-76, WD-40, and WD-39. We observed that barnacles, hydroids, and sometimes octocoral were the dominant species inhabiting these shallow-water (Fig. 2) structures. They were located west of the Mississippi River offshore of Timbalier and Barataria Bays, in turbid coastal water <28 m deep.

Octocorals were common as well (Table 2). The shallow-water *Telesto* spp. were observed on all platforms with the exception of ST-67, ST-81, and ST-76. These structures were located in turbid water. Thick mats of *Telesto* spp. inhabited the shallow-water platforms WD-39 (at 25 m depth) and WD-40 (at 28 m depth), offshore of Barataria Bay. *Carijoa riisei* (Dushassaing and Michelotti 1860) was observed on one platform. These species were considered to be native to the western Atlantic; more recent molecular genetic evidence suggests that it may have originated, however, from the Indo-Pacific (Invasive Species Specialist Group 2008). The question of its origins remains unresolved at present.

The density of octocorals tended to decrease as bottom depth increase (Fig. 4). This trend, however, was not significant ($p > 0.05$, correlation and regression analyses). The lack of significance was due to a particularly high variance in octocoral density inshore, where the highest range of values occurred. Our observations of the photographs suggested that this outcome would have been the same whether colony counts or percent-cover were used in the analyses.

ROV surveys revealed the deep-water octocorals *Thesea nivea* and *Swifta exserta* in waters >50 m depth. Colonies of shallow-water octocorals were observed in as little as 4 m depth. Abundances were highest at 12–18 m depth and declined below 24 m depth (Fig. 5). The deep-water octocorals were observed at 42 m and greater depths.

The average density of octocoral colonies on the platforms in waters ≥25 m depth varied from 0.7–127 colonies/m^2. Average octocoral density was highest on ST-164, a platform just west of the MC in 30 m of water. The minimum average density was found on SP-89, located 10 km south of the Mississippi River in 129 m depth. The mean density of octocorals for all structures was 22 colonies/m^2.

The antipatharians *Cirrhipathes leutkeni* (wire coral), *Plumapathes pennacea* (feather black coral), and *Antipathes caribbeana* (bushy black coral) were found in deep-water environments. These black corals were observed on structures located in deeper waters of 50 and 115 m (Table 2, Fig. 6). *Antipatharia* was the most abundant antipatharian genus at ≥60 m depth, with its densities reaching up to 3 colonies/m^2. The mean density of black corals on deep-water structures was 0.05 coral colonies/m^2.

The hydrozoan *M. alcicornis* was only observed a few times. We encountered 10–15 colonies on a few structures. These were located on the shallow-water horizontal support transoms of three platforms, including GI-116, ST-185A, and ST-185B.

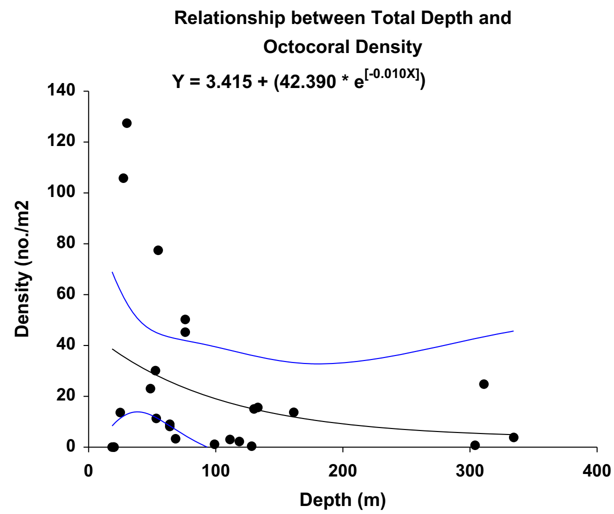

Fig. 4 Density of octocorals on 25 offshore oil and gas production platforms surveyed for cnidarians on the continental shelf in the northeastern Gulf of Mexico. Density (no./m^2) is shown as a function total bottom depth. There is a decreasing trend in octocoral density with bottom depth, but it is not significant ($p > 0.10$, Kendall's rank correlation test). *Outer lines* represent 95% confidence intervals for the fitted line

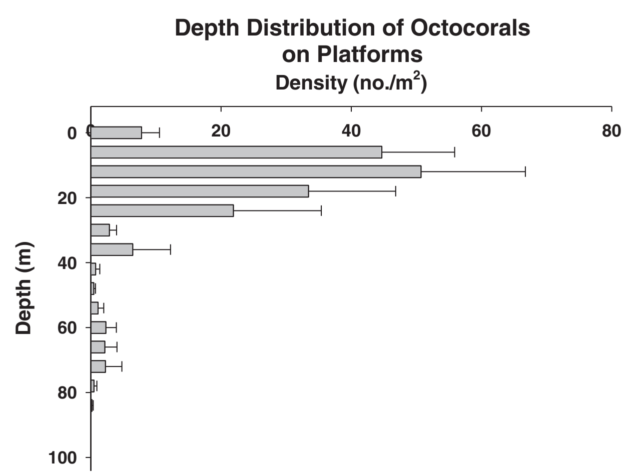

Fig. 5 Summary of the depth distribution of octocorals found on 25 offshore oil and gas production platforms surveyed for cnidarians on the continental shelf in the northeastern Gulf of Mexico. Density shown as no./m^2

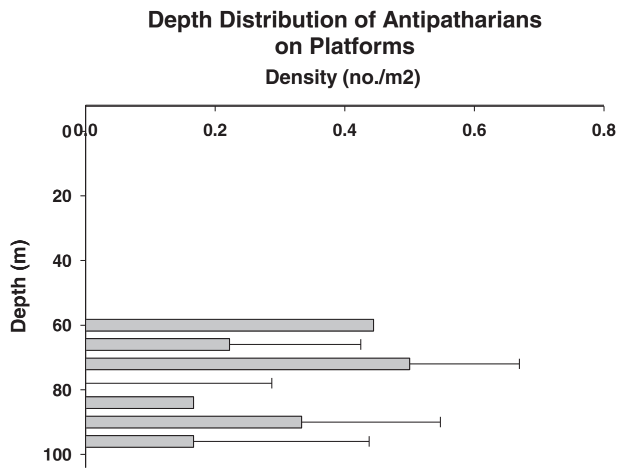

Fig. 6 Summary of the depth distribution of antipatharians found on 25 offshore oil and gas production platforms surveyed for cnidarians on the continental shelf in the northeastern Gulf of Mexico. Density shown as no./m^2

Discussion

The populations of hermatypic scleractinian corals were located in waters ≥28 m depth and probably originated from the NOAA FGBNMS (Sammarco et al. 2013a). We believe that the reason octocorals were observed on structures located in water depths of ≥25 m, and antipatharians on structures ≥60 m depth was primarily a preference of the larvae. On the north-eastern Louisiana continental shelf, we suspect that coral abundance is highly variable in the 25–50 m depth range. There are few to none of the target organisms on structures in <25 m depth. This is most likely due to freshwater input and perhaps seasonally cold water temperatures (Rabalais et al. 1996; Dagg and Breed 2003; Lohrenz et al. 2008; Dagg et al. 2008).

In earlier studies by Sammarco et al. (2004, 2012), it was found that scleractinian corals occur down to ~30 m depth. Sammarco et al. (2012) observed that native hermatypic corals in the northern Gulf of Mexico ranged in density from approximately 0.2–2.5/1000 m^2. The ahermatypic corals, particularly *T. coccinea*, exhibited a density range of ~5000–28,000/1000 m^2. The other ahermatypic corals were very low in number. The abundance of *T. coccinea* appears to dominate the coral populations in the study area.

The early benthic development on these platforms are conducive to the colonization and growth of *T. coccinea*, and possibly *T. micranthus*. It is important to put coral community development on these platforms into the context of time—both ecological and geological. Sammarco et al. (2004) observed that their populations decreased on older structures. Corals grow slowly, and their communities develop slowly. The oldest platform that Sammarco et al. (2004) surveyed was ~35 years old. The FGBNMS, which possess a highly mature coral community with high cover, are between 16,000 and 18,000 years old. Sammarco et al.'s (2004, 2012) studies observed a total of 11 coral species of the 23 known to exist on the FGBNMS.

Scleractinian coral such as *Tubastraea* spp. are protected by both the Magnuson-Stevens Act and the Gulf of Mexico Marine Fisheries Council (GMFC)—Coral Management Plan (GMFC 2010). More recent studies have shown that the azooxanthellate coral *T. coccinea* occurs down to ~96 m depth on the platforms, and *T. micranthus* to 138 m (Sammarco et al. 2013b). The limiting factor with respect to depth for the zooxanthellate/hermatypic scleractinian corals is most likely light attenuation and possibly temperature. The limiting factor of the depth distribution of the *Tubastraea* spp. is not yet known, but may be related to larval dispersal, settlement preferences, or other factors.

The densities of octocorals were greater than scleractinian corals on shallow platforms located in waters 25–30 m deep. Two of the shallow-water platforms in 25–28 m depth contained octocorals but no scleractinians. There, octocoral densities ranged from 14 to 106 colonies/m^2. The minimum and maximum counts of scleractinian corals occurred within 30 km of each other. Depth varied a great deal with respect to distance from shore, which was probably due to the meandering character of the shelf edge in this region. Populations of the black coral *Antipathes* were low compared with density of scleractinians and deep-water octocorals observed on platforms occurring in waters >60 m.

In their recent northern Gulf-wide study, Sammarco et al. (2014) found that scleractinian coral densities were highest in the offshore waters of eastern Louisiana at 35 colonies/m^2. The summary densities we show here were greater than this. Sammarco et al. (2012) observed 13 different scleractinian species on platforms occurring offshore of the western Louisiana and Texas continental shelf, compared those with 6 platforms observed offshore of eastern Louisiana. They suggest that the increase of scleractinian coral diversity west of the study area was due to proximity of the platforms to the NOAA Flowers Gardens Banks National Marine Sanctuary. Those platforms are directly east of these banks, and are subject to easterly along-shelf currents which would direct larvae to the platforms. A more stable salinity regime may also have enhanced successful coral recruitment and survival there.

No cross-shelf trends were found with the distribution and abundance of the corals. As noted above, we believe this was due to the edge of the continental shelf which meanders in and out of this region, carrying with it changes in depth. This had a confounding effect on distance from shore. Cnidarian abundance, however, was strongly associated with bottom depth as one moved offshore. Octocoral densities decreased as bottom depth increased.

It is possible that the corals occurring on the platforms surrounding the FGBNMS could be cross-seeding the FGBNMS. Dispersal to and recruitment on those banks from the platforms, however, would most likely be of a much lower intensity compared with self-seeding systems (Brazeau et al. 2005). In the case of a mass mortality on the FGBNMS, such cross-seeding could play a role in the regeneration of coral populations there, since these banks are so remote from sister coral reefs in the northern Gulf of Mexico (Sammarco et al. 2012).

T. coccinea was the most abundant scleractinian coral observed on the platforms. Interestingly, all scleractinian corals are a federally protected species (50 CFR Part 622, Appendix A). It is originally from the Pacific Ocean, however, and is considered to be an invasive species. Artificial substrata are known to be a preferred substrate for *T. coccinea*, but they do not appear to be a threat to natural coral reefs in the region. On natural coral reefs, *T. coccinea* occurs in low densities and occurs cryptically, living beneath overhangs or in caves (Sammarco et al. 2015). There was low variability in its densities between platforms. This supports the hypothesis that these older *T. coccinea* coral populations (vs. the younger *T. micranthus* populations; Sammarco et al. 2010) may be adapted to this new community and may have reached some level of equilibrium with respect to competition for space in these communities (Sammarco et al. 2015). Both *T. coccinea* and *T. micranthus* appear to be successful competitors for space on artificial substrate, both in laboratory experiments (Hennessey and Sammarco 2014) and on platforms in the field (Sammarco et al. 2015). Our data suggest that, within the study area, the platforms located in waters >25–30 m depth are often colonized by at least one of these species of protected corals.

Issues Concerning the Invasive Species *Tubastraea* spp. and Similar Species in the Gulf of Mexico

T. coccinea invaded the western Atlantic in the early 1940s and spread through most of the Caribbean by the 1980s (Cairns 2000; Humann and Deloach 2002). Clearly, the initial distribution of these species was not due to oil and gas platforms in the Gulf of Mexico. These species are now represented widely in the tropical and sub-tropical western Atlantic, from the Florida Keys to Brazil. It is evident that this invasive species is now a permanent member of these ecosystems.

These species have dominated the younger platforms in the northern Gulf of Mexico (Sammarco et al. 2004). The first observation of *T. coccinea* on a platform was recorded in 1989 (Scarborough and Kendall 1994). Recently, it has colonized the NOAA FGBNMS, although it has remained a rare species. This may be due to the maturity and diversity of the Flower Gardens. Mature coral communities are known to be resistant to invasives (Davis 2003), this phenomenon is often referred to as the Biotic Resistance hypothesis. For one reason or another, *T. coccinea* does not grow or survive there well. Precht et al. (2014) also reported this relationship by noting that *T. coccinea* is generally absent on coral reefs that exhibit areas of dense coral growth. They also point out that deeper topographic features (banks) in the northern Gulf of Mexico, where scleractinian coral cover is low, could possibly support successful recruitment; however, a detailed survey of 13 banks in this region revealed no colonization of these species, despite a low coral cover (Sammarco et al. 2016). In addition, it is known that *T. coccinea* occurs at a maximum depth of 92 m, in very low abundances (Sammarco et al. 2013b). Our recent studies of mesophotic benthic communities on banks across the central region of the northern Gulf of Mexico did not reveal the presence of any *T. coccinea*. These FGBNMS have been exposed to settling larvae of these species for decades and yet their presence is nominal there. When they do appear, however, they are removed.

Hennessey and Sammarco (2014) showed that both *T. coccinea* and *T. micranthus* were good competitors for space when contacting *Ricordea florida* (Cnidaria, Corallimorpharia), *Epicystis crucifer*, and *Condylactis gigantea* (Cnidaria, Actinaria). Precht et al. (2014) have also documented their competitive superiority against *D. strigosa*. This competitive advantage appears to work quite well against species that colonize during the early stages of community development, as evidenced by the monopolization by *T. coccinea*.

We also encountered another species in our surveys that have come into question as an invasive. This is *Carijoa riseii* (Cnidaria, Stolonifera, Clavulariidae). As mentioned above, although believed to be a native of the western Atlantic which invaded the Pacific in Hawaii, recent molecular genetic evidence suggests that its origin may be the western Pacific (Invasive Species Specialist Group 2008). Nothing has been reported to date regarding the competitive abilities of these species.

Platforms, once they reach the end of their productive life, are often removed, placed on a barge, and transported to shore for either refurbishing or scrapping (MMS 2005). In that case, the inshore waters are not exposed to any species that have colonized the pilings or their reproductive propagules. In addition, the act of exposure to the atmosphere will cause desiccation of the organisms, killing them.

Environmental Aspects of Platform Removal

A major concern has been the continued release of contaminants from the structure into the surrounding waters. In most cases, the deck of the platforms is shipped inshore:

any hydrocarbons or other toxic waste are returned to shore for disposal. The structures may be re-deployed offshore as part of the Rigs-to-Reefs program (LDWF 2016; see Macreadie et al. 2011 for a discussion of the benefits and disadvantages of Rigs-to-Reefs structures).

Implications of Findings for Platform Removal

Removal of offshore platforms is regulated by federal law. The platforms are subject to legislation that protects marine life; however, regulations require the federal government to investigate alternatives to removal (Magnuson-Stevens Act [16 U.S.C.A. § 1801, et seq.] and NEPA [42 U.S.C.A. Ch. 55, et seq.]). We recommend that, as part of the federal evaluation, the responsible parties first consider the corals attached to the structure, and protected, rare, threatened, or endangered species. If they inhabit a platform, we recommend that federal agencies examine alternatives that preserve and/or enhance the environment. Such alternatives may include the use of the platform for artificial reefs, sustainable fisheries, the production of renewable ocean energy, and CO_2 enhanced oil recovery or capture and storage (Kolian and Sammarco 2005; Kolian 2011; 30 CFR 285.1000 Subpart J). Evaluating alternate uses for offshore platforms that are no longer in production could lead to the preservation of platform habitats and avoid the mortality of many protected organisms, while meeting the objectives of U.S. Federal environmental, energy, and fisheries legislation.

Acknowledgements Many thanks to Jim Flagg, Dean Scwheinler, and Toby Armstrong who assisted us with photographs and surveys. We would also like to extend a note of gratitude to the oil and gas companies and their staff who provided access us to their offshore platforms. Thank you to the U.S. Department of Interior, BOEM for their support through Cooperative Agreement M10AC20006 and funding of the ROV video surveys.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

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