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ARTICLE

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Reef fish movement and community assemblages associated with a newly deployed artificial reef

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Abstract

Artificial reefs provide critical habitat for fish in areas lacking benthic structure, yet our understanding of how artificial reefs function and develop is limited. Here, changes in fish community assemblages were monitored using baited remote underwater video (BRUV) surveys before and after a new artificial reef was deployed in the northern Gulf of Mexico. Movement of red snapper (*Lutjanus campechanus*) and gray snapper (*Lutjanus griseus*) between nearby oil and gas platforms ($n = 3$) and the new artificial reef was examined using acoustic telemetry, and residency was calculated for fish associated with both structure types. Fish community development at the artificial reef site was slow despite close proximity to existing habitat, and fish communities at the artificial reef site did not differ from control sites (unconsolidated substrate) one year after reef deployment. Residency of red snapper and gray snapper at the artificial reef was surprisingly low, with most tagged fish emigrating rapidly, and no tagged fishes from the surrounding platforms were detected moving to the artificial reef during the initial eight months following artificial reef deployment. While residency was much higher at the platforms, a major hurricane (Hurricane Ida) passed directly over the sites and led to large numbers of tagged fishes emigrating from the study area. Results highlight an artificial reef with limited fish community development and low residency after one year despite close proximity to existing habitats. Considering the presence of seasonal benthic hypoxia in this region, findings suggest that artificial reefs with limited vertical relief may offer sub-optimal habitat for reef fish in comparison with the substantial vertical relief offered by standing platforms, reducing the potential benefits to reef fish. Given the rapid decommissioning of oil and gas infrastructure in the Gulf of Mexico, this study has significant implications for rigs-to-reefs programs as well as artificial reef siting and design.

KEYWORDS
acoustic telemetry, artificial reef, baited remote underwater video (BRUV) survey, community development, gray snapper, Gulf of Mexico, hurricane, red snapper, reef fish movement, residency

INTRODUCTION

Artificial reefs are typically deployed to provide habitat and increase biological production in areas that lack benthic structure, making them valuable tools to enhance fisheries yields or promote recovery of overfished species (Baine & Side, 2003; Becker et al., 2018). While artificial reefs harbor considerable fish biomass (Boswell et al., 2010; Smith et al., 2016), the source of that biomass is often unclear, and the degree to which artificial reefs primarily attract fish or increase fish production has been debated for decades (Bohnsack, 1989; Brickhill et al., 2005; Pickering & Whitmarsh, 1997). Attraction and production scenarios have been widely explored (Cresson et al., 2014; Folpp et al., 2020; Strelcheck et al., 2005); however, evidence suggests that it may be more likely that the ecological role of most artificial reefs falls on the spectrum between these two endpoints and may vary based on a variety of factors, including artificial reef location and behavioral preferences of target species, among others (Lindberg, 1997; Lowry et al., 2014; Mavraki et al., 2021). Despite this basic understanding, our knowledge of how artificial reefs function as habitat and how reef communities develop remains surprisingly limited (Brickhill et al., 2005; Smith et al., 2015; Streich, Ajemian, Wetz, Shively, et al., 2017).

The challenge in clearly defining the ecological role of artificial reefs and understanding fish recruitment to these habitats is partly due to the wide range of artificial reef types and the abundance of factors that can affect the development of faunal communities. Artificial reefs are constructed from a variety of materials, ranging from waste/materials of opportunity (e.g., rubble, recycled concrete structures, retired platforms, sunken vessels) to prefabricated structures (e.g., concrete pyramids, cylindrical concrete modules) (Baine, 2001; Ramm et al., 2021). Additionally, man-made structures that were not intended to act as reef habitat, such as oil and gas platforms (hereafter referred to as platforms) or fish aggregating devices (FADs), effectively act as artificial reefs and support large fish populations (Claisse et al., 2014; Duedero et al., 1999). Critical factors influencing fish community development at artificial reef sites include the design of the reef (e.g., material, size, deployment location), environmental stressors (e.g., hypoxia, water chemistry), and the proximity to other reef habitat (Dance et al., 2011; Lenihan et al., 2001; Lenihan & Peterson, 1998; Yu et al., 2020). Reef height and habitat complexity (Charbonnel et al., 2002; Hackradt et al., 2011) also play a pivotal role in influencing fish behavior and community structure, particularly in sub-optimal conditions which can significantly affect recruitment and survival (Lenihan et al., 2001). Furthermore, the proximity of an artificial reef to other reef habitats may influence the principal recruitment method (attraction vs. production), with attraction more likely to occur at artificial reefs that are close to existing reef habitat and production more likely at isolated artificial reefs (Bohnsack, 1989). Despite this understanding, movement from adjacent habitats has rarely, if ever, been explored in practice. Ultimately, a better understanding of artificial reef development under different scenarios is critical for appropriate fisheries management and the effective construction and deployment of future artificial reefs (Paxton et al., 2020).

Artificial reefs have been widely deployed throughout the northern Gulf of Mexico (GoM) with stated purposes to enhance reef fish fisheries, diving opportunities, and to mitigate habitat loss (Dupont, 2008; Gallaway et al., 2009; Morgan et al., 2009). In response, a considerable amount of research effort has been focused on understanding the ecological function of these artificial reefs through studies evaluating reef placement (Strelcheck et al., 2005), documenting faunal assemblages and resident fish behavior (Boswell et al., 2010; Dance et al., 2011), characterizing food web structure (Dance et al., 2018), and examining the effect of reef design and size (Ajemian et al., 2015). Despite the wide range of research conducted on GoM artificial reefs, these studies have rarely established community baselines prior to artificial reef deployment and monitored artificial reef community assemblages over time following reef construction (Streich, Ajemian, Wetz, Shively, et al., 2017), leading to key gaps in our understanding of artificial reef community succession at new artificial reefs. Notably, despite the emphasis on attraction versus production, we know surprisingly little about how adult fish colonize artificial reef structures and the influence new structures have on fish assemblages in nearby reef habitat (Schulze et al., 2020).

In this study, the impact of artificial reef deployment on reef fish assemblages and movement was examined at a new artificial reef site in the northern GoM using complementary techniques (i.e., video surveys, acoustic telemetry).

To characterize reef fish community development at newly deployed artificial reefs, video surveys were used to examine temporal changes in community assemblages (i.e., relative abundance, species diversity) at the new artificial reef relative to existing nearby habitat and control sites. To explore methods of artificial reef colonization, acoustic telemetry was utilized to characterize movement dynamics (i.e., migration, residency) of two model reef fish species (red snapper, *Lutjanus campechanus*; gray snapper, *Lutjanus griseus*) between existing habitat and a newly deployed artificial reef. Both red snapper and gray snapper are ecologically and economically important reef fish species that are commonly found on artificial reefs in the GoM (Hood et al., 2007; Lindeman et al., 2016), making them ideal model species for this study. The source of fish biomass at new artificial reefs has long been debated, and this is one of the first studies to attempt to quantify movement of reef fish to a newly deployed artificial reef site. Moreover, this study aims to provide much needed information on the development of reef fish assemblages at an artificial reef site and allows for unique comparisons with existing habitat in the area around the new artificial reef. Through the synthesis of community-level data and individual fish's movement and behavior, the goal of this study was to characterize the development of reef fish communities at a new artificial reef site, document temporal shifts in fish assemblages, record immigration of fish from surrounding habitats, and compare fish residency patterns between established and new habitat, in order to increase our understanding of community development and colonization at new artificial reefs.

MATERIALS AND METHODS

Study site

The study was conducted in the north-central GoM approximately 20 km offshore of the southern Louisiana

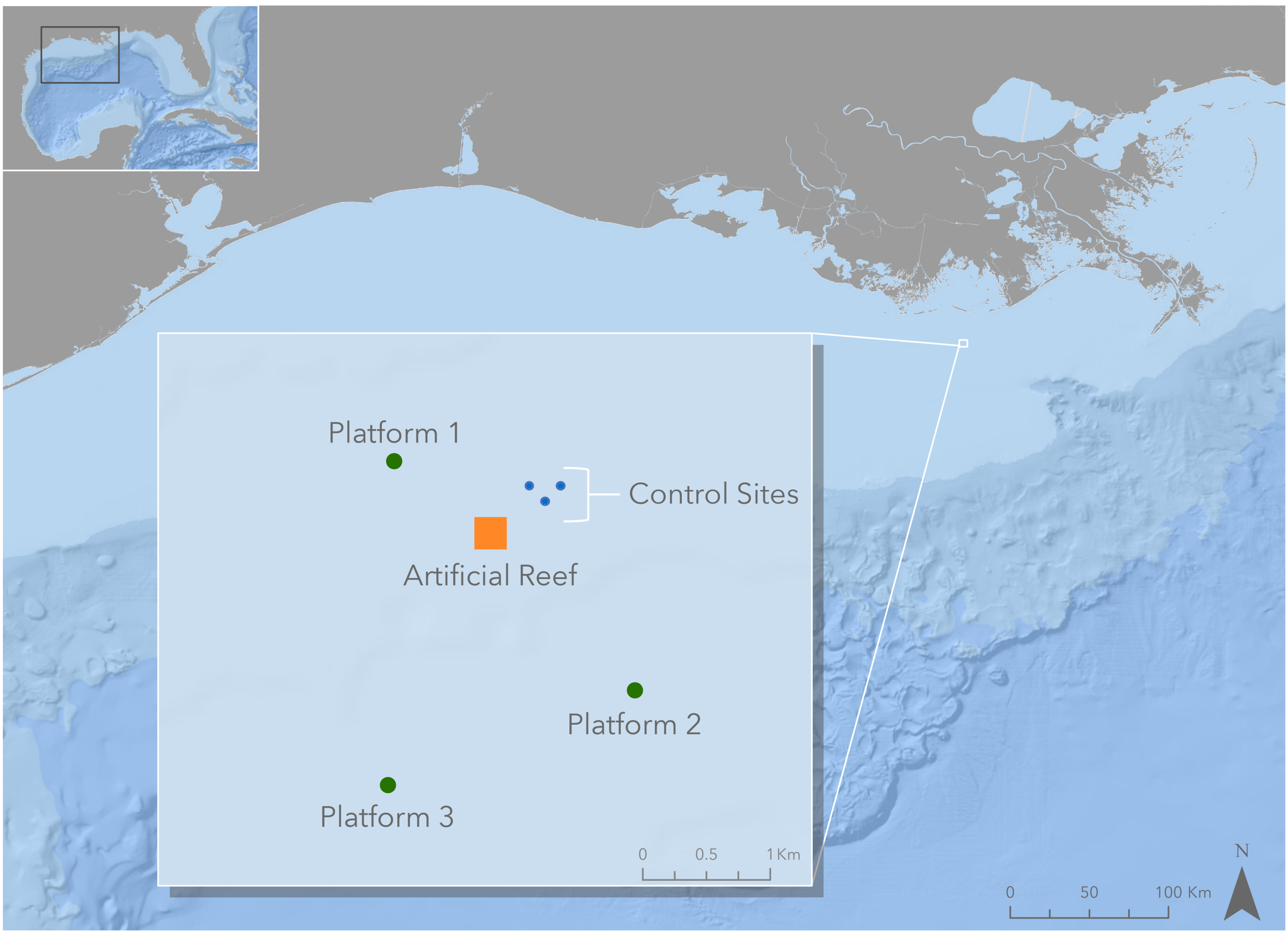

FIGURE 1 Map of the study site (located in the north-central Gulf of Mexico approximately 20 km offshore of the southern Louisiana coast at a depth of 20 m) showing the proximity of the artificial reef site to three nearby oil platforms.

coast at a depth of 20 m (Figure 1). This site originally contained an oil and gas platform, which was decommissioned and removed in 2015. In response to the loss of reef habitat, an artificial reef was deployed in October 2021, composed of approximately 40 recycled concrete culverts of varying lengths. All reef materials were contained in a 100 m × 100 m area with a maximum vertical relief of 2 m. Several existing platforms are located within 2 km of the artificial reef site, providing a unique opportunity to compare fish communities among structure types and examine fish movement dynamics between existing and new artificial structures (Figure 1).

Prior to artificial reef deployment, a major hurricane (Hurricane Ida) passed directly over the study site on August 29, 2021, at 11:00 AM CDT (Appendix S1: Figure S1). At the time of passing, Hurricane Ida had developed into a category 4 storm with a minimum central pressure of 93,300 Pa and maximum sustained winds of 67 m/s. A maximum significant wave height of 13 m was recorded near the center of the storm before its landfall (Zarate et al., 2022).

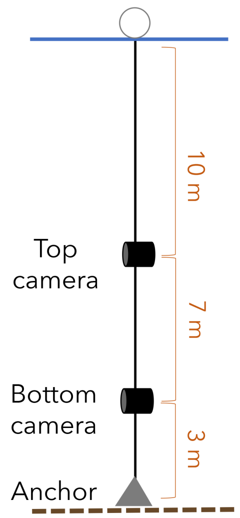

FIGURE 2 Schematic showing baited remote underwater video (BRUV) drop camera rig composed of two action cameras suspended in the water column.

Community assemblages and artificial reef development

Baited remote underwater video (BRUV; Bacheler & Shertzer, 2015; Cappo et al., 2006) surveys were used to document temporal changes in fish community assemblages at the artificial reef in relation to existing platforms and control sites (unconsolidated substrate). The BRUV setup consisted of a camera array with two action cameras (GoPro Hero9) suspended in the water column, one ~3 m and the other ~10 m off the seafloor (Figure 2). The cameras were placed in individual submersible housings fixed to a PVC frame with a rigid fin attached to each frame to stabilize the cameras in the current. Small mesh bait pouches containing approximately 3–5 cut Gulf menhaden (*Brevoortia patronus*) were attached below each camera. Replicate surveys ($n \geq 3$ per treatment) were conducted at the artificial reef, control sites (randomly selected sites from the area around artificial reef lacking structure, open sand/mud), and the three platforms. During each survey, the BRUV was lowered to the seafloor and the video was recorded for 5 min based on recommendations from Garcia et al. (2021). Surveys were performed once before and once immediately after artificial reef deployment and then seasonally until the reef had been monitored for a full year post-deployment, resulting in a total of six BRUV surveys (pre-deployment survey, fall 2021 to fall 2022) for each structure type (Appendix S1: Figure S1).

Movement dynamics, residency, and emigration

The movements of red snapper and gray snapper were monitored between the existing nearby platforms and the new artificial reef using acoustic telemetry. Two months prior to the deployment of the artificial reef, red snapper ($n = 20$) and gray snapper ($n = 20$) were caught using hook and line sampling over the course of a week at the three platforms in the study (Figure 1; Appendix S1: Figure S1). Each fish was fitted with an acoustic transmitter (Innovasea, V9-2H, 312-day tag life), which emits a uniquely coded acoustic signal at a random interval every 70–130 s (nominal delay = 100 s). All tagging procedures performed during this study were approved by the Institutional Care and Use Committee at Louisiana State University (Protocol number: 21-096). Transmitters were surgically implanted in the coelom of each fish via a small ventral incision (1–2 cm) and closed with 1–2 interrupted sutures. Tagged fish were released at the surface (due to minimal barotrauma) and near the platform structure (to provide refuge from predators). Prior to tagging and releasing the fish, a single omnidirectional acoustic receiver ($n = 3$, Innovasea, VR2Tx, 69 kHz) was attached to each platform included in the study. Receivers contained a hydrophone and were able to record and archive the unique transmitter signals present within the detection range (≤500 m; Babin et al., 2019; Lyu et al., 2023). Two of the three platform-attached acoustic receivers were lost when Hurricane Ida passed over the study site five days after the final tagged fish was released. Replacement receivers were deployed approximately two months after the hurricane passed once local marinas had recovered enough to allow field operations to resume (early November).

An acoustic receiver (Innovasea, VR2AR, 69 kHz) was placed at the center of the artificial reef structure shortly after the reef deployment (mid-October 2021). This receiver was used to document any movement of tagged reef fish from adjacent platforms to the artificial reef and to assess reef fish residency at the new artificial reef structure. Approximately six months post-reef deployment (March–June 2022; Appendix S1: Figure S1), additional 20 fish (red snapper $n = 12$, gray snapper $n = 8$) were caught using hook and line sampling techniques and fitted with acoustic transmitters. Initial sampling effort was focused at the artificial reef (red snapper $n = 4$); however, difficulty in obtaining an appropriate sample size required the majority of individuals to be sampled from the surrounding study platforms (red snapper $n = 8$, gray snapper $n = 8$). Each fish was surgically implanted with acoustic transmitters (Innovasea, V9P-2H, nominal delay = 100 s, 246-day estimated tag life) equipped with pressure sensors (0.3-m resolution, max depth = 68 m, ± 1.0 m accuracy) and released at the artificial reef. All tagged fish at the new artificial reef site were released to the seafloor using either a descender device (SeaQualizer) or a protective release cage (modeled after Williams et al., 2015) to minimize barotrauma and reduce the likelihood of predation upon release. A GoPro Hero 9 attached to the interior of the release cage was used to monitor fish health during release. The cage was allowed to sit on the seafloor for a minimum of three minutes with the cage door open to allow the tagged fish enough time to stabilize and exit.

Data analysis

All individuals observed during BRUV surveys were identified to the lowest taxonomic level possible. An estimate of relative abundance was generated using the MaxN technique, which is a standard measure of relative abundance used in numerous fisheries-independent visual surveys (Campbell et al., 2015; Cappo et al., 2006). The MaxN technique is calculated as the greatest number of individuals of a certain species seen in a single frame during the video (Ellis & DeMartini, 1995). Additionally, species richness was calculated as the number of species observed during each video. Kruskal–Wallis tests were used to examine the effect of survey (temporal) and structure type on species richness, overall reef fish relative abundance, and relative abundance of snapper (both red and gray). Species-specific Kruskal–Wallis tests were used to test for changes in the relative abundance of red and gray snapper across the six surveys. For significant Kruskal–Wallis tests, a Mann–Whitney U (MWU) test was used as a post hoc multiple comparisons test to determine pairwise significant differences among factor levels (Midway et al., 2020). MWU tests were also used to test for the difference in relative abundance between the two snapper species and the influence of camera depth ($n = 2$) on each species relative abundance. Significance for all Kruskal–Wallis and MWU tests was determined using an α of 0.05.

Acoustic telemetry data from fish tagged at platforms were examined to detect the immigration of red snapper and gray snapper to the adjacent artificial reef. These data were also used to examine red snapper and gray snapper residency to structures in the study area. Residency indices (I_r) were defined as the proportion of days an individual was detected (D_d) in the study area (i.e., platforms and artificial reef) divided by the total number of monitoring days in the study (D_t) (Equation 1; Kraft et al., 2023).

$$I_r = \frac{D_d}{D_t} \quad (1)$$

The resulting index value ranges from 0 (no residency) to 1 (full residency) for each tagged fish. Residency indices were only calculated for tagged fish that remained active in the study area after 48 h had passed post-release to minimize the influence of post-release mortality or stress-induced emigration that is most likely to occur during the first few days following release (Lowe et al., 2009; Topping & Szedlmayer, 2011). To examine how residency was influenced by a major hurricane, two separate residency indices were calculated for each individual: one for the entire study period and another excluding the effects of Hurricane Ida. For the first index, D_t was equal to the total number of monitoring days (i.e., transmitter tag life). For the second index, D_t excluded fish that were only detected prior to Hurricane Ida to evaluate residency in the absence of a storm event.

Additionally, emigration rates, defined here as the percentage of platform-tagged fish that left the study area (i.e., were no longer detected by study receivers) during defined time intervals, were calculated for both study species using acoustic telemetry data. Emigration rates were calculated for an initial 48-h post-release period and subsequently at two-month intervals. Prior to Hurricane Ida, limited acoustic telemetry data (a duration of six days post-tagging) were obtained from one of the receivers later lost during the storm. These data, combined with data from the receiver present throughout the entire study, provided known emigration rates from two platforms during the initial 48-h post-release period. Known emigration rates were used to create a correction factor that was applied to tagged fish unaccounted for during this window of time in order to estimate emigration rates at the third platform (for which no data were available). Actual and estimated emigration rates were then combined to approximate overall emigration from platforms during the first 48 h post-release.

Acoustic telemetry data from fish released at the artificial reef were used to examine residency of the study species at the artificial reef. A residency index was calculated for all tagged fish released at the artificial reef site that remained active at the reef for at least 48 h once released. For artificial reef residency indices, D_t was equal to the total number of monitoring days (i.e., transmitter tag life). Tagged individuals whose detected depths remained constant (i.e., any depth variation was within the tag margin of error, ±1.0 m) at the seafloor (approx. 20 m) for more than two days were considered a mortality event or tag expulsion, and data from those individuals were excluded from analysis. Predation upon release was inferred using release cage GoPro recordings or damage to SeaQualizer equipment, and acoustic telemetry data from individuals that experienced predation during release were also excluded from residency analysis.

RESULTS

Community assemblages and artificial reef development

A total of 20 unique species were observed during the BRUV surveys (Appendix S1: Table S1). Species richness differed significantly between the structure types (Kruskal–Wallis, $p < 0.001$) and was higher at the platforms (2.6 ± 0.2 species; mean ± SE) than at the artificial reef (0.1 ± 0.1 species) and control sites (0.1 ± 0.1 species) (MWU, $p < 0.001$), which did not differ (Figure 3A). Although variability in species richness was observed over time, differences were not significant (Kruskal–Wallis, $p > 0.05$) and no detectable temporal patterns were observed (Figure 3A). Similarly, overall reef fish relative abundance differed between structure types (Kruskal–Wallis, $p < 0.001$) but not over time. Fish relative abundance was higher at the platforms (14.6 ± 2.6 individuals) than at the artificial reef (0.3 ± 0.1 individuals) and control sites (0.5 ± 0.3 individuals) (MWU, $p < 0.001$), with no differences observed between the artificial reef and the control sites (MWU, $p > 0.05$; Figure 3B). Species richness and reef fish relative abundance at the artificial reef remained consistently low across all BRUV surveys more than one year post-deployment (Figure 3).

Red and gray snapper were observed exclusively at platforms with the exception of the final BRUV survey in fall 2022, when two red snapper were recorded at the artificial reef site. Thus, the results from red and gray snapper BRUV analyses predominantly apply to platform-associated fish. Relative abundance varied significantly between the two species (MWU, $p < 0.001$) with gray snapper (1.8 ± 0.4 individuals) observed in

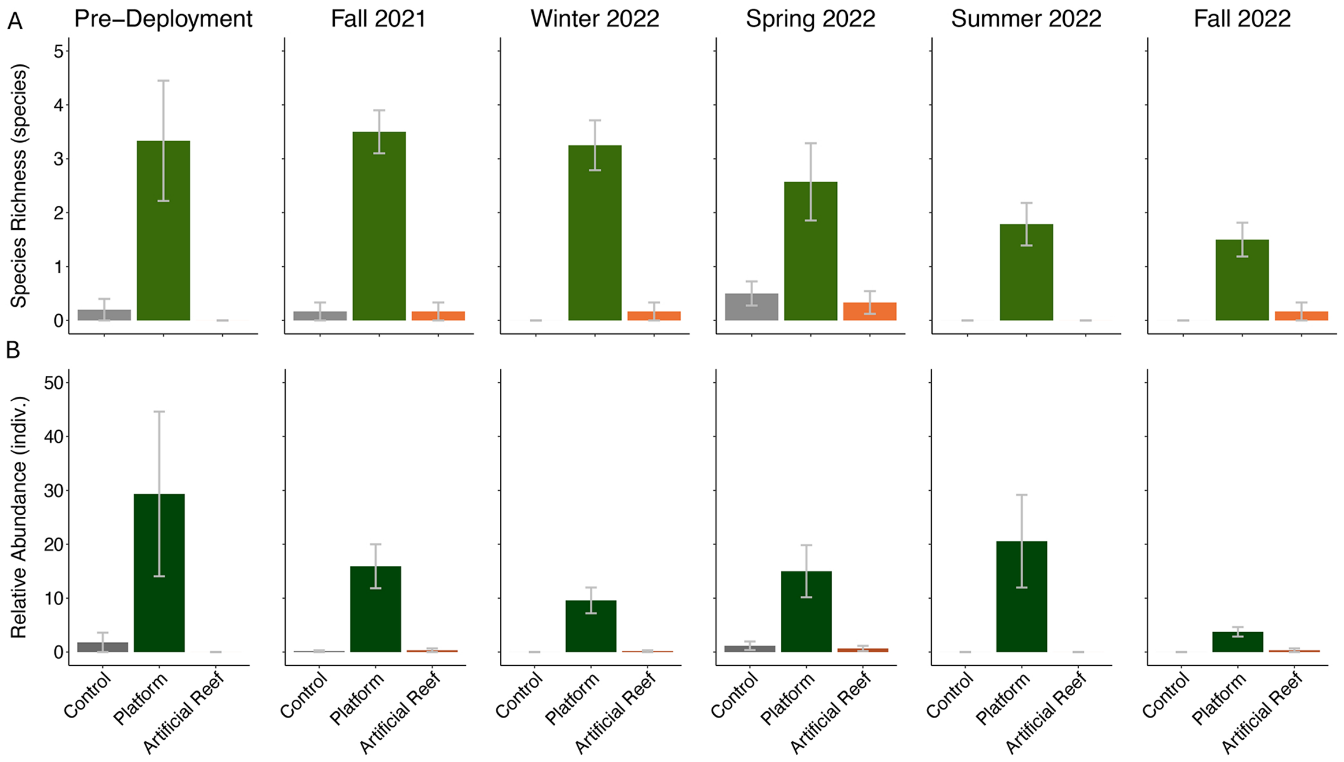

FIGURE 3 Bar plots showing (A) species richness (species) and (B) relative abundance (individuals) for each structure type across all baited remote underwater video (BRUV) surveys (mean ± SE). Structure types are indicated by color.

greater relative abundance than red snapper (0.5 ± 0.08 individuals) (Figure 4A). The greatest mean relative abundance for snappers at the platforms was documented during the winter 2022 (red snapper) and spring 2022 (gray snapper) surveys (Figure 4); however, no significant differences were observed across survey periods for either species (Kruskal–Wallis, $p > 0.05$). Mean relative abundance of gray snapper recorded by the shallower camera (2.7 ± 0.8 individuals) was significantly higher than that by the deeper camera (0.6 ± 0.2 individuals). However, the relationship between red snapper mean relative abundance and depth was not significant (shallow: 0.6 ± 0.1 individuals; deep: 0.5 ± 0.1 individuals) (Figure 4B,C). Still, red snapper were generally more abundant on the shallow camera during spring and summer and on the deeper camera in the fall and winter.

Movement dynamics, residency, and emigration

A total of 969,921 detections from platform-associated fish were recorded during the study. Detection data were available for 80% of the original 40 tagged platform-associated fish (red snapper $n = 18$; gray snapper $n = 14$) due to the temporary loss of acoustic receiver coverage during Hurricane Ida. However, analysis of the remaining acoustic telemetry data revealed that no tagged fish migrated to the artificial reef from the adjacent platforms during the initial eight months after the artificial reef was deployed. Overall residency for fish tagged at the platforms was calculated for a total of 27 fish (red snapper $n = 14$; gray snapper $n = 13$) once fish that emigrated during the 48-h post-tagging period were excluded (red snapper $n = 4$, gray snapper $n = 1$), and post-hurricane residency was calculated for the 16 tagged fish remaining after Hurricane Ida (red snapper $n = 8$, gray snapper $n = 8$). Post-hurricane residency (red snapper 0.85 ± 0.11; gray snapper 0.89 ± 0.08) was greater than overall residency (red snapper 0.49 ± 0.13; gray snapper 0.56 ± 0.13) for both species (Figure 5).

A total of 13 tagged fish (red snapper $n = 7$, gray snapper $n = 6$) that were released at the platforms in August 2021 remained in the study area at the end of June 2022, with most individuals emigrating in the first two months of the study. Approximately 20% of the fish (25% of red snapper, $n = 5$; 15% of gray snapper, $n = 3$) emigrated during the first 48 h after tagged fish were released (Figure 6A). However, the greatest period of emigration occurred during the next two months, and by November 2021, approximately 60% of the remaining fish had emigrated (47% of red snapper $n = 7$, 71% of gray snapper $n = 12$). This percentage includes three gray snapper emigrating from their original release site (Platform 1) to another study platform (Platform 3). These individuals remained at Platform 3 for the rest of the study, and outside of this instance, no other fish were detected moving between platforms. This time period of greatest emigration corresponded to Hurricane Ida passing directly over the study site in late August. Following this period, emigration was relatively rare and stayed less than 13% for red snapper ($n = 1$) and less than 14% for gray snapper ($n = 2$) during each remaining two-month window (Figure 6A).

Of the 20 tagged fish released at the artificial reef, only two (both red snapper) remained at the reef for more than 48 h. Six fish (red snapper $n = 4$, gray snapper $n = 2$) were considered mortalities/tag expulsions due to constant depth detections near the seafloor, and one fish (red snapper $n = 1$) was predated upon during release using the SeaQualizer. The other 11 individuals (red snapper $n = 5$, gray snapper $n = 6$) all left the artificial reef within 27 h of their release. On average, tagged red snapper left within 6.7 h (±5.3, SE) and gray snapper within 3.2 h (±2.1). As these fish were emigrating, six (red snapper $n = 3$, gray snapper $n = 3$) were detected at study platforms, although only one individual was detected at a platform for more than eight hours (gray snapper $n = 1$; Platform 1, 42 days). Residency for the remaining red snapper at the artificial reef was 0.23 ± 0.2. Both individuals left the reef eight days after their release and moved to the closest platform (Platform 1), although one red snapper (RSN024) returned to the artificial reef 150 days later and stayed there for the remainder of its tag life (99 days). Residency at the artificial reef (red snapper 0.23 ± 0.2, gray snapper 0 ± 0) was lower than overall residency at the platforms (red snapper 0.49 ± 0.13, gray snapper 0.56 ± 0.13). However, the sample size at the artificial reef ($n = 2$) was insufficient for statistical comparisons between the two residency indices.

DISCUSSION

Characterizing how reef fish communities develop at artificial reefs under different scenarios is critical to improving our understanding of the ecological function of these habitats (Bohnsack, 1989; Brickhill et al., 2005). At one year post-deployment, species richness and relative abundance at this artificial reef did not differ from control sites of open sand/mud bottom. Artificial reef communities typically do not reach full equilibrium until 1–5 years have passed (Dance et al., 2011; Perkol-Finkel & Benayahu, 2005); however, most

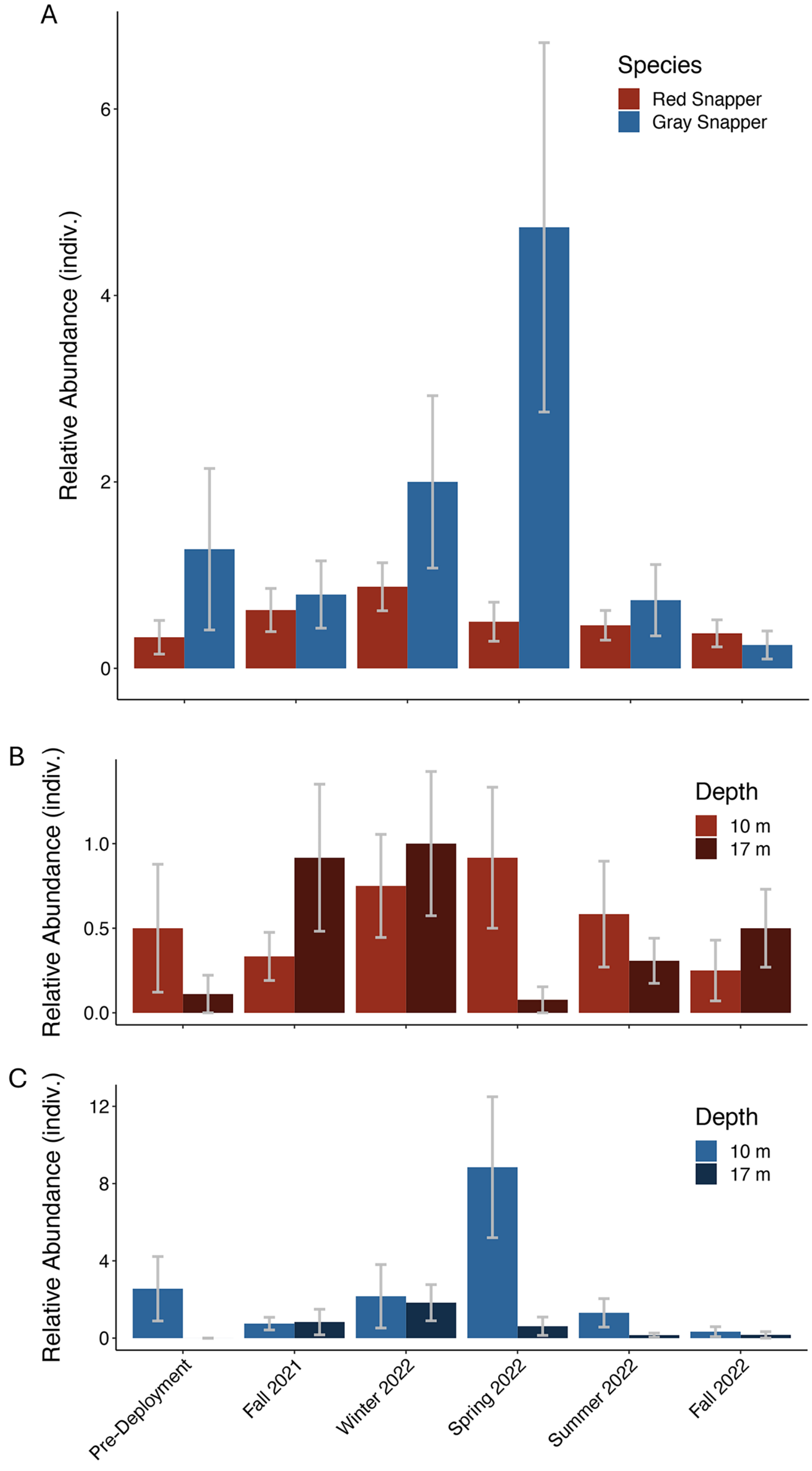

FIGURE 4 Bar plots showing (A) overall relative abundance for each species across all structure types (control, platform, artificial reef sites) for baited remote underwater video (BRUV) surveys, and relative abundance for (B) red snapper and (C) gray snapper by camera depth across all structure types for each BRUV survey (mean ± SE).

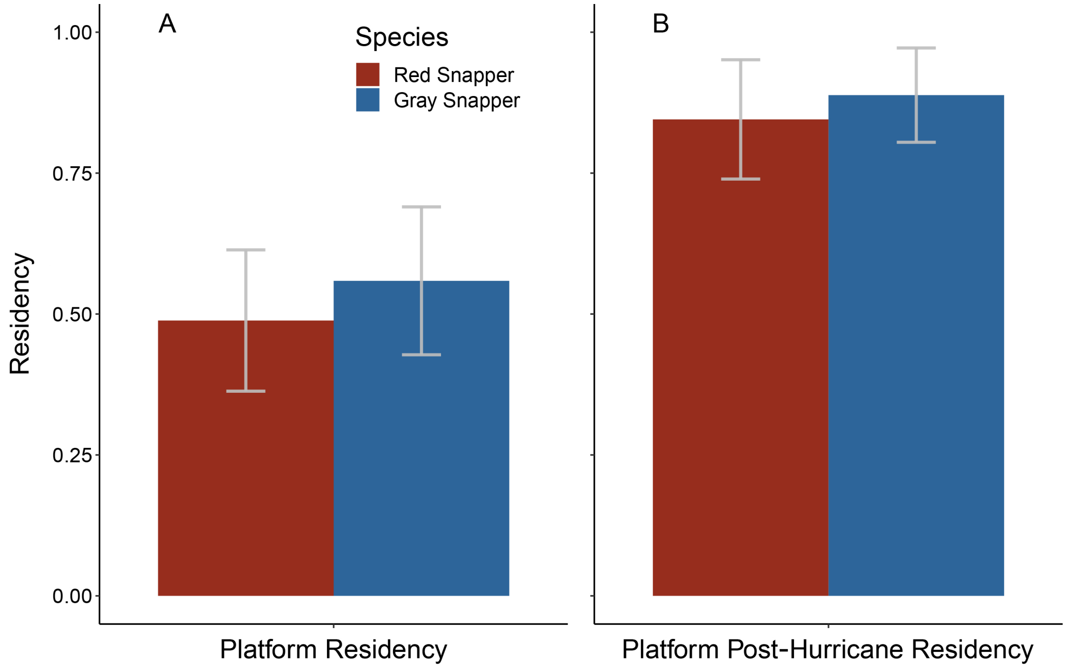

FIGURE 5 Bar plots showing residency indices for (A) platform-associated red snapper and gray snapper for the entirety of the study and (B) platform-associated red snapper and gray snapper after Hurricane Ida (mean ± SE).

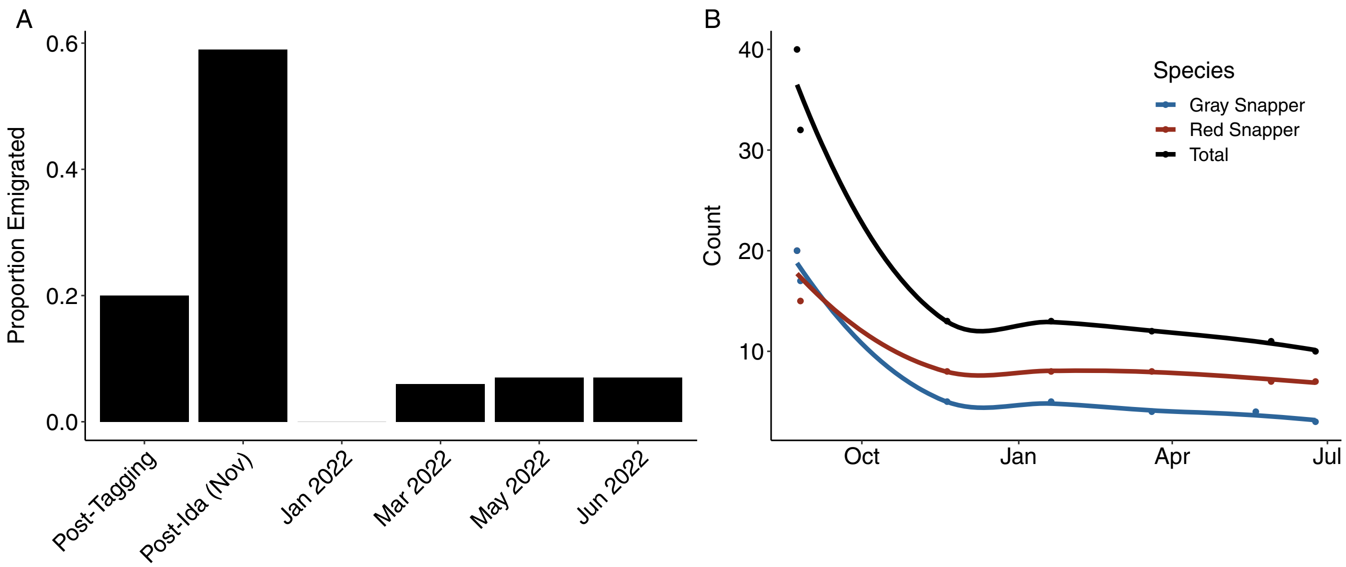

FIGURE 6 (A) Bar plot showing the proportion of fish that emigrated from the study site during set time intervals out of the fish remaining from the previous time interval. The first interval indicates the estimated proportion of fish (of the original 40) that emigrated during the first 48 h after release. All following intervals are for 2-month periods. (B) Number of tagged fish (total and separated by species) that remained at their original tagging sites over time.

artificial reefs of similar size are rapidly (within days to months) colonized by reef fish following initial deployment, quickly distinguishing communities at artificial reef habitat from surrounding natural open bottom (Dance et al., 2021; Paxton et al., 2018; Streich, Ajemian, Wetz, Shively, et al., 2017). Thus, while it is possible that the relatively short duration of the study precluded observation of an established reef fish community at the artificial reef, a gradual increase in abundance and richness over time at an artificial reef as a community develops is generally expected (Folpp et al., 2011; Lowry et al., 2014; Streich, Ajemian, Wetz, Shively, et al., 2017). Slower colonization might be expected if juvenile recruitment (rather than movement and settlement of adults) is the primary source of fish to a reef, particularly given that deployment was in the fall after the primary settlement periods for snappers (Rooker et al., 2004). Still, younger fish (age 0, age 1) are typically present within a year of deployment (Streich, Ajemian, Wetz, Shively, et al., 2017), and the lack of reef fish present at this artificial reef site suggests that other factors may be limiting reef fish recruitment to the structure, such as limited complexity of the artificial reef structure (Hackradt et al., 2011; Sherman et al., 2002) or sub-optimal environmental conditions (i.e., water temperature/chemistry; Song et al., 2022; Yu et al., 2020).

The structural design of artificial reefs greatly influences the demographics of resident reef fish populations (Charbonnel et al., 2002; Hackradt et al., 2011). Structural differences between the two types of artificial habitats in this study may have led to higher species richness and relative abundance observed at platforms versus the artificial reef. Platforms have high vertical relief and structural complexity that support large numbers of fish and diverse species by providing extensive shelter and food throughout the water column (Ajemian et al., 2015; Claisse et al., 2014). By contrast, small or low relief habitats offer fewer hiding places and less surface area for fouling communities to develop, which limits the number, size, or life stage of fish present, potentially inhibiting the diversity of species in their resident communities (Hackradt et al., 2011; Hylkema et al., 2020; Jaxion-Harm & Szedlmayer, 2015). Still, small artificial reefs (<4 m) support substantial fish communities in other regions of the GoM (Dance et al., 2021; Froelich et al., 2021; Streich, Ajemian, Wetz, Shively, et al., 2017), and it seems unlikely that the overall lack of fishes observed at the artificial reef in the current study was due to the size of the structure alone. It is well documented that nearshore benthic habitats in the northern GoM near the Mississippi River Delta are seasonally exposed to hypoxic (i.e., dissolved oxygen [DO] <2 mg/L) bottom water which could partially or completely envelop smaller structures with limited vertical relief (Rabalais et al., 2001; Reeves et al., 2018; Stanley & Wilson, 2004). Given that reef fish typically avoid hypoxic waters (Craig, 2012; Zhang et al., 2009), low relief artificial reefs (such as the one described here) may not provide sufficient habitat for reef fish above the hypoxic layer, limiting the suitability of the habitat relative to structures with higher relief (i.e., platforms) (Lenihan et al., 2001; Lenihan & Peterson, 1998; Reeves et al., 2018; Stanley & Wilson, 2004).

Sympatric species often exhibit species-specific patterns of habitat use or preference that result in partitioning of available habitat (Dance & Rooker, 2015; Matley et al., 2016; Moulton et al., 2017). Red and gray snapper are congeners that co-occur at both natural and artificial reefs throughout the GoM (Allman & Goetz, 2009; Dance et al., 2011; Munnelly et al., 2019; Streich, Ajemian, Wetz, & Stunz, 2017). Although red snapper are typically the more abundant species in the region (Marshak & Heck, 2017; Reynolds et al., 2018), gray snapper were more numerous at oil platforms in the current study, with abundance increasing in the mid-water column. Red snapper are generally demersal, primarily foraging off the reef on benthic organisms (Dance et al., 2018; Gallaway et al., 2009), while gray snapper feed more substantially on pelagic prey sources in the water column (Bank et al., 2007). The greater relative abundance of gray snapper at platforms in this study is also in accord with a prior study in the GoM, suggesting that vertical habitat and associated fouling communities provided by mid-shelf platforms may provide critical food or shelter for gray snapper in the water column (Rademacher & Render, 2003). By contrast, the limited vertical relief and lack of fouling at the artificial reef may have contributed to the lack of gray snapper at that site. Nevertheless, it should be noted that the highly variable nepheloid layer in the GoM can impact visibility in the lower water column (Shideler, 1981), which could also explain why demersal species, such as red snapper, were observed in lower abundance than gray snapper at the platforms.

The source of fish biomass at artificial reefs is often attributed to the aggregation of fish from surrounding habitat or increased fish production at the reef, although direct evidence is complex and heavily debated (Bohnsack, 1989; Grossman et al., 1997; Powers et al., 2003). In theory, new artificial reefs in close proximity to existing habitat could increase the probability of colonization by fish from the nearby habitat (Bohnsack, 1989; Strelcheck et al., 2005). While considerable existing habitat was present within 2 km of the newly deployed artificial reef in the current study, the complete lack of movement of tagged red and gray snapper from the nearby platforms to the artificial reef suggests that attraction of snapper from adjacent structure was likely not a major source of biomass at the artificial reef. The slow rate of development recorded at the artificial reef during BRUV surveys could indicate that this habitat lacked a sufficient prey base to support meso-predators such as red snapper and gray snapper, although previous studies have documented rapid colonization by lutjanids prior to the development of mature fouling communities (Dance et al., 2011, 2021; Streich, Ajemian, Wetz, Shively, et al., 2017). By contrast, available shelter can limit reef fish densities, and individuals may make decisions based on density-dependent habitat selection, initially choosing habitat for shelter rather than food (Lindberg et al., 2006). Thus, the larger size and vertical habitat of the platform sites may provide superior refuge (from predators/and or hypoxia) relative to the lower relief habitat at the artificial reef, offering snapper little incentive to leave (Lenihan et al., 2001).

The degree of residency exhibited by fishes to artificial reef sites has important implications for the potential of a reef to increase production (Brickhill et al., 2005; Smith et al., 2016). Previous acoustic telemetry studies have shown that red snapper exhibit a high affinity for platforms and artificial reefs (Everett et al., 2020; Topping & Szedlmayer, 2011), while relatively little is known about the fidelity of gray snapper to artificial structures. Both species exhibited similar residency at the study platforms, but red snapper residency was low (<50% of red snapper remained in the study site after two months) relative to previous estimates in the GoM where annual site fidelity was estimated to be 31% per year (Everett et al., 2020). While a variety of factors (habitat quality, environmental conditions, predation) may have caused fish to emigrate, hurricanes are known to redistribute reef fish populations (Addis et al., 2013; Dance et al., 2011; Patterson et al., 2001), and here a category 4 hurricane (Ida) passed directly over the study site just one week after tagging. Multiple studies have demonstrated that red snapper exposed to hurricanes are more likely to relocate (Addis et al., 2013; Patterson et al., 2001), and while temporary loss of receiver coverage precluded detailed information on hurricane-induced emigration at two of the three platform sites, 3 of 5 fish on the third site emigrated during the hurricane. This observation combined with the broader finding that approximately 60% of tagged fish in the study emigrated during the two-month window that Hurricane Ida occurred suggests that the hurricane strongly influenced residency patterns. Post-hurricane residency was higher than overall residency at the platforms for both species, with several individuals that were not displaced by the storm remaining on tagging sites for the duration (~9 months) of the study.

Low residency at the artificial reef (all fish left the site within eight days) for both species was unexpected, considering fish were not exposed to a hurricane. Likewise, lower reef fish abundance at the artificial reef would likely decrease intraspecific and interspecific competition, which can be high at platforms (Everett et al., 2020). Several factors may trigger reef fish emigration, including limited prey availability or sub-optimal environmental conditions such as low DO or high water temperature (Diamond et al., 2007; Reeves et al., 2018). Interestingly, the one fish that later returned to the site did so in the fall when benthic hypoxia typically subsides (Rabalais et al., 2001), lending some support to the notion that emigration was driven by low DO at the artificial reef. However, this could not be confirmed due to the lack of in situ DO measurements. Finally, translocation of fish may have also contributed to increased emigration at the reef site (Patterson et al., 2001), although it should be noted that none of the fish returned to the original platforms they were captured at despite close proximity and all fish that were tagged directly at the reef site also initially emigrated within eight days.

The development of reef fish communities at artificial reefs is influenced by many complex factors including structural design (Hackradt et al., 2011; Jaxion-Harm & Szedlmayer, 2015), deployment location (Strelcheck et al., 2005), reef age (Dance et al., 2011), and environmental conditions (Lenihan et al., 2001; Song et al., 2022). Unfortunately, our understanding of early colonization at newly deployed artificial reefs and mechanisms of recruitment (i.e., movement) from existing habitat remains surprisingly limited. Examples of deployments with poor fish recruitment are rarely reported despite the fact that this information is critically needed to improve future artificial reef siting and design. This study documented an artificial reef with low reef fish residency and limited development during the first year of deployment despite close proximity to existing habitat. These findings also add to a growing body of research suggesting that tropical cyclones play a key role in the redistribution of reef fish and population connectivity. While a myriad of reasons may have contributed to the lack of reef fish community development at this artificial reef, results indicate that smaller, low relief artificial reefs may be sub-optimal habitat in comparison with the substantial vertical relief offered by standing platforms, particularly in areas that are exposed to benthic hypoxia. Given that many platforms are now being decommissioned in the GoM, this study has important implications for rigs-to-reefs programs. Results presented here support the recommendations of Reeves et al. (2018) and suggest that the successful replacement of platforms with artificial reefs in areas of seasonal hypoxia will be dependent on reefs providing sufficient vertical relief above the hypoxic layer for fish to escape hypoxic conditions. Additional research focused on the influence of structural relief, deployment location, and environmental conditions on artificial reef development is clearly needed in order to optimize artificial reef design in the northern GoM.

AUTHOR CONTRIBUTIONS

Jade M. Carver and Michael A. Dance conceived and designed the experiments, analyzed the data, and wrote the original draft of the paper. Jade M. Carver, Brett J. Falterman, Christian Walker, and Creed C. Branham performed the experiments. All authors reviewed and edited the paper.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Carver & Dance, 2025) are available from Dryad: https://doi.org/10.5061/dryad.1ns1rn94z.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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