BioOne COMPLETE

Influences of Artificial Reefs on Juvenile Red Snapper Along the Mississippi Gulf Coast

Authors: Brandt, Jason R., and Jackson, Donald C.

Source: Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 5(5) : 1-10

Published By: American Fisheries Society

URL: https://doi.org/10.1080/19425120.2012.736445

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 5:1–10, 2013
© American Fisheries Society 2013
ISSN: 1942-5120 online
DOI: 10.1080/19425120.2012.736445

ARTICLE

Influences of Artificial Reefs on Juvenile Red Snapper along the Mississippi Gulf Coast

Jason R. Brandt* and Donald C. Jackson
Department of Wildlife, Fisheries and Aquaculture, Mississippi State University, Mail Stop 9690, Mississippi State, Mississippi 39762, USA

Abstract

Red Snapper *Lutjanus campechanus* represent one of the more economically important fisheries in the northern Gulf of Mexico; as such, Red Snapper abundance has decreased dramatically in the past two decades. The use of artificial reefs could aid in the rehabilitation of Red Snapper stocks by providing refuge for juveniles and a place of foraging and recruitment. A study was initiated to determine the effectiveness of different artificial reef distribution patterns in attracting and sustaining juvenile Red Snapper in the northern Gulf of Mexico. Fish traps (0.97 m long; 0.64 m high; funnel mouth size = 175 × 115 mm) were used to collect Red Snapper (<406 mm TL) that were associated with pyramid-shaped artificial reef structures (3.7-m triangular base; 2.4-m height; 3.2 metric tons) to evaluate two reef distribution designs: (1) five closely spaced pyramid units ("clumped" pattern) and (2) five closely spaced pyramids plus two sets of two pyramids at 30.5, 61.0, or 91.5 m from the five pyramids ("outlier" pattern). In 26 sampling trips, 927 Red Snapper were captured. Catch per unit effort (number of fish/trap soak-hour) did not differ significantly among artificial reef patterns ($P = 0.396$). Red Snapper TLs differed significantly among patterns ($P = 0.005$), with the largest mean TL (235 mm; SE = 5.14) occurring at the outlier pattern with 61.0-m spacing. Results from this study indicate that reef spacing and horizontal extension are important factors to consider when designing an artificial reef program, especially those that target juvenile Red Snapper.

Artificial reefs have been constructed and placed in the northern Gulf of Mexico to provide structure for a wide range of reef-associated fish species and to further management goals, such as the enhancement of recreational and commercial fishing and the rehabilitation of depleted fish stocks. The exact role, if any, that artificial reefs play in these endeavors is a topic of some controversy and debate (Cowan et al. 2011), yet artificial reef structures continue to be placed in waters of the northern Gulf of Mexico. Artificial reef material has been deployed off the Mississippi coast since the 1960s, providing hard-bottom substrate in an area that naturally consists mostly of sand, mud, and hard-bottom structure with little vertical relief. Today, roughly 65 km^2 of designated artificial reef sites can be found in Mississippi's offshore waters, with reef material ranging from sunken ships, concrete rubble, and culverts to prefabricated concrete structures. Although substantial research has focused on artificial reefs off the coast of Alabama (Szedlmayer and Shipp 1994; Strelcheck et al. 2005) and oil rigs off the coast of Louisiana (Westmeyer et al. 2007; McDonough 2009), relatively little research has been conducted on artificial reefs off the coast of Mississippi and the possible roles of these reefs in resource management (Lukens 1980; Lukens et al. 1989).

Because a large number of structural possibilities exist in designing an artificial reef program, research that examines different artificial reef patterns, orientations, and structural characteristics and how these factors may influence each other is necessary to elicit the best results for a given reef program (Gregg 1995). Various studies have examined how reef material, complexity, depth, isolation, density, height, and horizontal extension relate to fish abundance and artificial reef success (Bohnsack and Sutherland 1985; Gregg 1995; Herrera et al. 2002; Strelcheck et al. 2005). Spacing among elements of

Subject editor: Donald Noakes, Thompson Rivers University, British Columbia, Canada
*Corresponding author: jbrandt@cfr.msstate.edu
Received February 2, 2012; accepted September 26, 2012

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

individual reefs may be a particularly important consideration for artificial reef managers (Jordan et al. 2005). Investigations by Bohnsack and Sutherland (1985), Sherman et al. (2002), Jordan et al. (2005), and Shipley and Cowan (2011) explored the effects of reef spacing on fish abundance and production and the amount of spacing between artificial reef structures that would be required to maximize research objectives. Their results indicated that reef spacing did play an important role in reef complex function and in providing benefits for desired fish species.

The effectiveness of artificial reefs for management purposes is most likely species specific and life stage specific (Bohnsack 1989; Bortone et al. 1994; Jordan et al. 2005). In the waters offshore of Mississippi, Red Snapper *Lutjanus campechanus* represent an economically and culturally important marine species that utilizes the large number of artificial reef structures (Collins et al. 1980; Allman et al. 2002; Franks et al. 2004). Capable of reaching close to 1 m in size (Szedlmayer and Shipp 1994) and approximately 50 years in age (Wilson and Nieland 2001), Red Snapper are bottom-dwelling, predatory fish that range from Cape Hatteras, North Carolina, across the continental shelf in the Gulf of Mexico, to the Yucatan Peninsula (Patterson et al. 2001a). Red Snapper numbers in the northern Gulf of Mexico have shown significant declines in recent decades, prompting the National Marine Fisheries Service and the Gulf of Mexico Fishery Management Council to undertake a series of regulatory efforts (minimum size limits and total allowable catch) aimed at restricting the direct harvest of adult Red Snapper and the indirect harvest of juveniles (Gillig et al. 2001; Garber et al. 2004; Mitchell et al. 2004; Saillant and Gold 2006). Although Red Snapper numbers in the northern Gulf of Mexico have shown signs of improvement (Cowan et al. 2011), the closure of the Atlantic Red Snapper fishery and the possible severe consequences (i.e., overfishing in the Gulf of Mexico) highlight the importance of research that examines the effects of artificial reefs on Red Snapper stocks.

Continued improvement in Red Snapper stocks may be linked directly to the protection and management of juveniles. Geary et al. (2007) stated that recruitment variability and year-class strength of Red Snapper are likely determined during early life and that the identification of habitats or conditions favoring survival during the nursery period is critical to management of Red Snapper. Control of juvenile mortality related to fishing and bycatch from fishery activities (e.g., shrimp trawling) is viewed as one of the most important factors in the continued recovery of Red Snapper stocks (Gillig et al. 2001; Peabody 2004; Saillant and Gold 2006; McDonough 2009). Parsons and Foster (2007) reported that 90% of the fishing mortality among juvenile (age-0 and age-1) Red Snapper comes from shrimp trawl bycatch. Juveniles enter the shrimp trawl fishery at 50 mm TL and become fully vulnerable at 100 mm TL (Gallaway et al. 1999, 2007).

In the continental shelf waters of the northern Gulf of Mexico, the bottom substrate consists mostly of sand and mud with little to no vertical relief, and these bottom traits are conducive to shrimp trawling (Patterson and Cowan 2003; Wells and Cowan 2007). Although Red Snapper spend most of their first year over sand and mud bottoms in the northern Gulf of Mexico, juvenile Red Snapper show an increasing preference for natural and artificial habitat with vertical relief (Workman et al. 2002; Nieland and Wilson 2003; Mudrak and Szedlmayer 2012). Patterson et al. (2001a) found that Red Snapper reach maturity at 208–309 mm TL. Due to the Red Snapper's increasing preference for vertical structure, artificial reefs may act as important components of stock rehabilitation by offering a place of preferred refuge to juvenile Red Snapper that are vulnerable to shrimp trawling (McDonough 2009).

The effects of artificial reef spacing and horizontal extension on juvenile Red Snapper in Mississippi offshore waters are relatively unexplored (Workman et al. 2002). The importance of reef spacing for juveniles may be linked directly to the resource mosaic hypothesis, which predicts (in part) that as reef spacing decreases, access to prey that inhabit the soft-bottom area around the reefs also decreases (Frazer and Lindberg 1994). Some studies have shown that juvenile Red Snapper (60–299 mm SL) feed heavily on fish and reef-associated prey items (Ouzts and Szedlmayer 2003; Szedlmayer and Lee 2004), whereas other studies have shown that Red Snapper diets are also composed of non-reef-associated prey, such as shrimp and crabs, that are found in soft-bottom habitat around the natural or artificial reef structures where the Red Snapper reside (Peabody 2004; McCawley and Cowan 2007). Juveniles may feed heavily on non-reef-associated demersal prey, thereby creating areas of intense prey depletion ("foraging haloes") around the reef structures, and prey depletion increases as reef spacing decreases because of the greater overlap of foraging activity (Lindberg et al. 1990; Frazer and Lindberg 1994; Campbell et al. 2011). The feeding haloes may have negative effects on abundance, growth, and residence time of juvenile Red Snapper on artificial reefs because the fish may be forced to forage outside of the halo area, making them more susceptible to predation (Lindberg et al. 1990). Frazer and Lindberg (1994) believed that more widely spaced reefs should result in decreased halo overlap, leading to an increased density of potential prey species in soft-bottom habitat and increased foraging opportunities for Red Snapper. Because the resource mosaic hypothesis has possible consequences for reef spacing, managers of artificial reefs need to understand whether the existence of foraging haloes should inform their decisions on reef spacing and placement (McDonough 2009).

Red Snapper movement is tightly linked with the resource mosaic hypothesis and the importance of reef spacing. Various studies have examined Red Snapper movement, with some showing extensive long-range (265–352-km) movements of adults (Watterson et al. 1998; Patterson et al. 2001b), although the occurrence of hurricanes may have played a role in the distances traveled by tagged fish. Other studies suggest that Red Snapper show fidelity to structures such as artificial reefs and exhibit limited movement once they have recruited to those structures (Szedlmayer and Schroepfer 2005; Diamond et al. 2007; Topping and Szedlmayer 2011a). Knowledge of the small-scale movements of Red Snapper in proximity to reef structures,

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

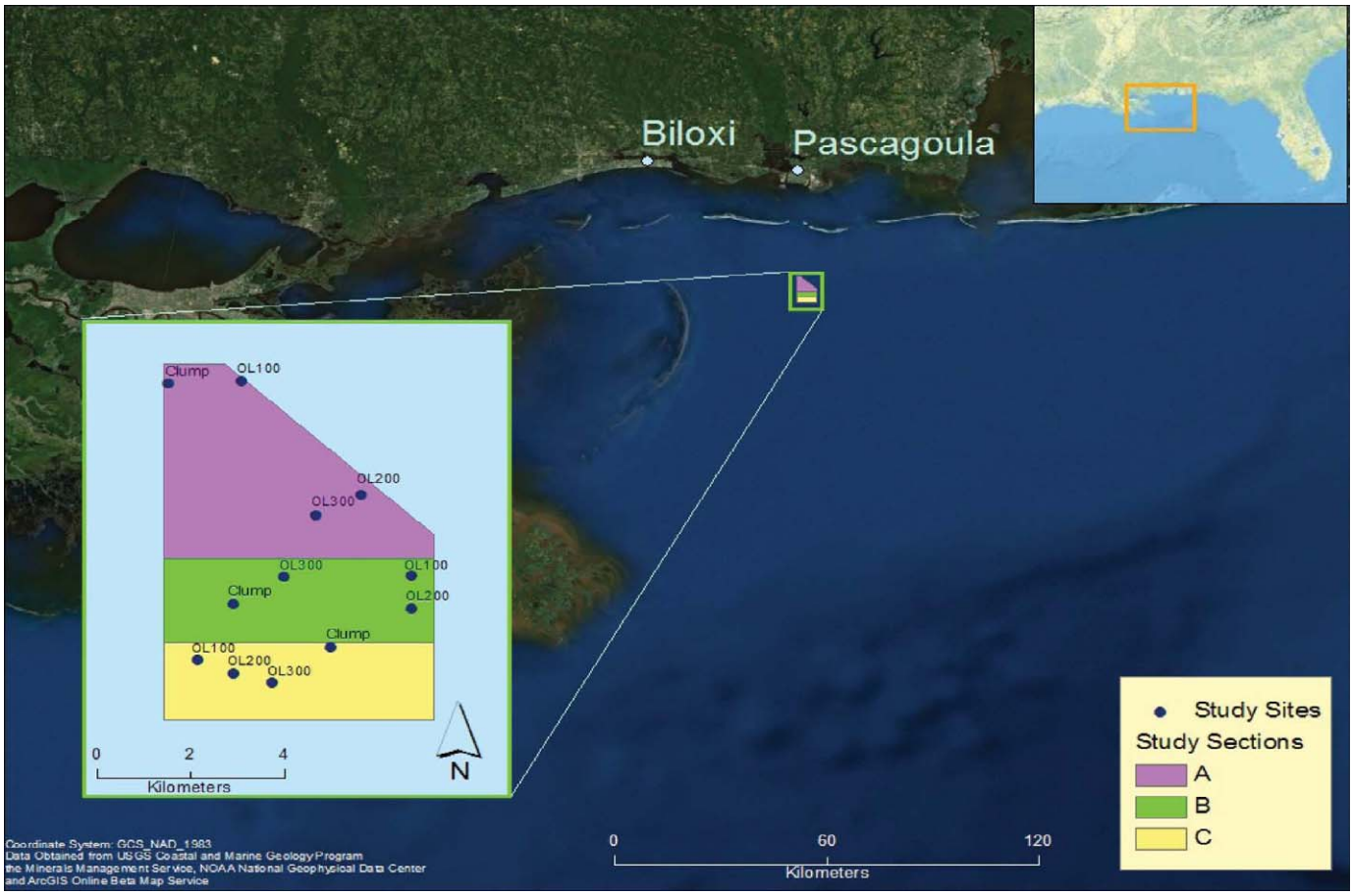


FIGURE 1. Location of Artificial Reef Site Fish Haven 13 in the northern Gulf of Mexico (November 2009). Depth ranges were 20–24 m for section A, 24–26 m for section B, and 26–27 m for section C. See Methods for definition of the reef patterns (clump, OL100, OL200, and OL300).

however, may be necessary to understand the importance of reef spacing in terms of management objectives. Topping and Szedlmayer (2011a) found that 75% of tagged Red Snapper stayed within 30 m of reef structures over 24-h tracks, whereas Schroepfer and Szedlmayer (2006) reported that 87% of tagged Red Snapper stayed within 200 m of the release site. Chapin et al. (2009) obtained similar results: four tagged age-0 Red Snapper moved 206 m away from their original release site, indicating a willingness of juveniles to move relatively short distances from reef structures. Juveniles' willingness to move away from reef structures may be linked to their ability to find their way back to those structures. Workman et al. (2002) found that juvenile Red Snapper exhibited homing capabilities, as fish returned to their capture sites after being displaced. These previous studies indicate that properly spaced artificial reef structures allow for increased Red Snapper foraging opportunities by taking advantage of small-scale movements of the fish while also limiting potential foraging overlap. The studies also highlight the need for further research examining the reef spacing distances that are necessary to maximize the artificial reef management objectives specific to Red Snapper.

With this in mind, we undertook a study to determine the effects of reef spacing and horizontal extension on juvenile Red Snapper relative abundance and length. Juvenile Red Snapper were targeted to obtain a better understanding of the functional role of artificial reefs in increasing future numbers of spawning adults; such an understanding will ultimately aid in the rehabilitation of Red Snapper stocks. Results from this study may have important implications for future management and rehabilitation of Red Snapper not only in the northern Gulf of Mexico but throughout the entirety of the species' range.

METHODS

Study area.—The project area for the study was offshore Artificial Reef Site Fish Haven 13 (FH-13), which is located approximately 40 km south of Pascagoula, Mississippi, in the northern Gulf of Mexico (Figure 1). The site encompassed an approximate area of 38 km^2 and ranged in depth from 20 to 27 m. The FH-13 site was split into sections A (18 km^2), B (10 km^2), and C (10 km^2) from north to south, respectively, across depth strata. Depth ranges were 20–24 m for section A, 24–26 m for

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

section B, and 26–27 m for section C. Although 19 rubble piles and 12 decommissioned barges and boats had been placed into FH-13 prior to this study, a majority of the structures were destroyed or heavily damaged by Hurricane Katrina in 2005 and the number of those structures that were still functioning as viable habitat was unknown. Other than those artificial structures, the bottom substrate of FH-13 consisted mostly of sand and mud with little to no vertical relief—characteristics that are typical of most of the continental shelf waters in the northern Gulf of Mexico (Patterson and Cowan 2003; Wells and Cowan 2007). The structures nearest to our study site were two gas platforms (located 1.13 and 0.17 km from FH-13) and artificial structures associated with Artificial Reef Site FH-2 (located 1.38 km from FH-13).

Study design.—Fish sampling began in September 2007 and ended in November 2008. Prior to sampling, pyramid-shaped artificial reef structures with embedded stone outcroppings were deployed within FH-13 (Figure 2). Study reefs were deployed on March 6, 2007, in section A; on March 8, 2007, in section B; and on June 6, 2007, in section C. The artificial reef structures were composed of limestone and Coquina rock panels on cement frames. Each pyramid had a 3.7-m triangular base and measured 2.4 m in height. Approximate weight of each pyramid was 3.2 metric tons.

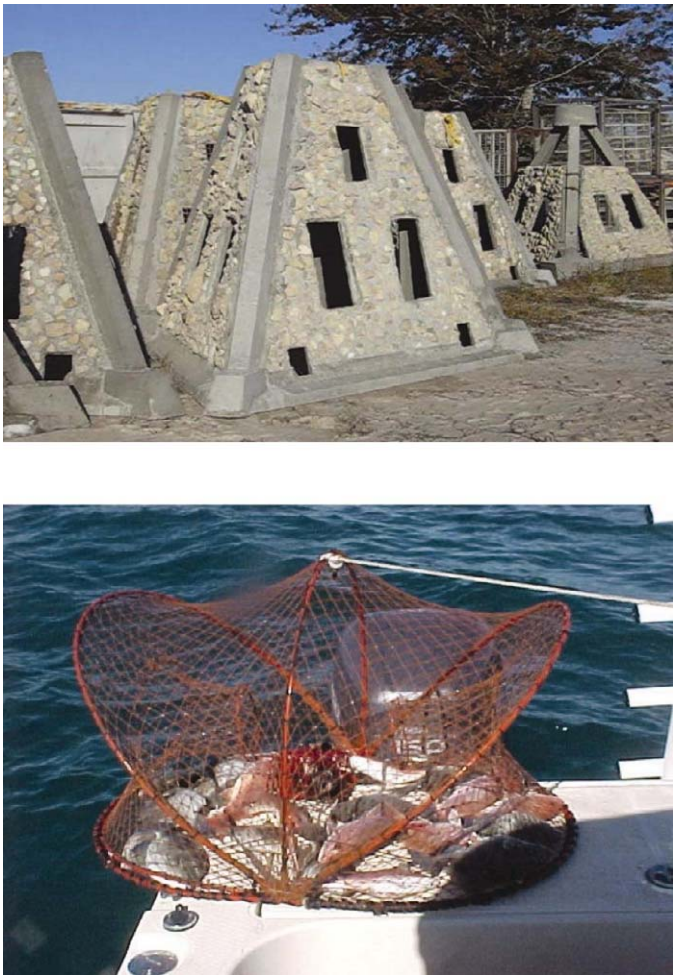


FIGURE 2. Pyramid structures used to construct artificial reef complexes at Artificial Reef Site Fish Haven 13 in the northern Gulf of Mexico (upper panel); and a trap used for collecting Red Snapper during sampling (lower panel; photographs provided by the Mississippi Department of Marine Resources).

Artificial reef structures were deployed in separate, predetermined patterns (treatments) within each section of FH-13 in a randomized complete block design, with designated pyramid dispersion ("clumped" versus "outlier" patterns) and pyramid placement intervals for horizontal positioning (30.5, 61.0, or 91.4 m) from a central clump within the outlier pattern. For the clumped treatment, five closely spaced pyramids (approximately 3–5 m from one another, and all vertically oriented) constituted the experimental unit. For the outlier dispersion pattern, nine pyramids (all vertically oriented) constituted each experimental unit: five of the nine pyramids were clumped (approximately 3–5 m from one another) in a core location, and two groups of two pyramids each were positioned equidistant at 30.5, 61.0, or 91.4 m from the core assemblage location. The Mississippi Department of Marine Resources (MSDMR) chose outlier distances in 100-ft (30.5-m) increments (i.e., 30.5 m = 100 ft; 61.0 m = 200 ft; 91.4 m = 300 ft) in order to encompass practical limits of reef element spacing within individual reef units; hereafter, we will refer to the outlier reef patterns by using those predetermined increment numbers (outlier 100 [OL100], 200 [OL200], and 300 [OL300]; Figure 3). One unit of each pattern (clumped, OL100, OL200, and OL300) was located in each section (sections A–C) of FH-13.

Fish traps were used for fish collections. Traps were 0.97 m long, 0.67 m wide, and 0.64 m high (Figure 2). Funnel mouth size for each trap measured 175 × 115 mm, with smaller mouth openings biased toward the collection of juvenile Red Snapper. Trap mesh size was 6.5 cm^2. Locations for sampling were determined by randomly selecting section A, B, or C. After the section was chosen, three artificial reef patterns within the section were selected randomly. Sampling began at approximately 0900 hours for all study trips. Four traps baited with cut bait (Gulf Menhaden *Brevoortia patronus*) were set at each of the three artificial reef patterns and were allowed to soak for 2 h. A 2-h soak time was chosen based on results from an MSDMR study in which baited traps identical to those used in our study were set on similar artificial reefs for different periods of time (Kerwin Cuevas, MSDMR, unpublished data). Catch rates were modeled and analyzed after multiple trap deployments at each time interval, and results indicated peak catch rates at the 2-h soak interval. Small amounts of bait were observed in a majority of our traps after the 2-h sets, indicating that the traps were most likely attracting and retaining fish throughout the entire 2-h soak time. All traps were set on the main clump of five central pyramids. All fish that were collected in traps were identified to species and measured for TL. Data on the absolute number of Red Snapper collected were used to estimate CPUE (number of Red Snapper/trap soak-hour)

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

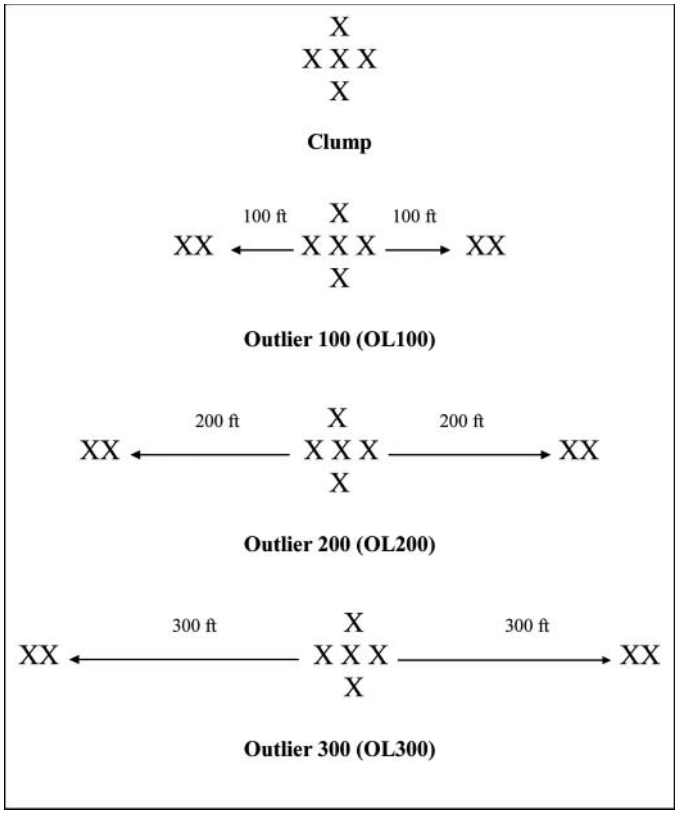


FIGURE 3. Artificial reef patterns deployed between March 6 and June 6, 2007, within each section of Artificial Reef Site Fish Haven 13 in the Gulf of Mexico (100 ft = 30.5 m; 200 ft = 61.0 m; 300 ft = 91.4 m).

as an index of relative abundance for use in analysis. For the purpose of this study, juvenile Red Snapper were considered to be prerecruits if they were smaller than 406 mm TL (the legal recreational size limit), and only data from fish smaller than that length were used in analysis.

Data analysis.—As the experimental model for this study represented a randomized complete block design, analysis was run using a repeated-measures mixed linear model (MIXED procedure in the Statistical Analysis Systems [SAS]; SAS 2008). The number of days between sampling trips was the temporal repeated measure, and reef patterns (nested within sections) were the subjects that were repeatedly sampled. Section (block) was modeled as a random effect, and a spatial power covariance structure was found to be the most appropriate covariance structure for the model. The Kenward–Roger df adjustment was used to determine df for the analysis.

The model directly assessed the effect of reef pattern and season (independent variables) on Red Snapper CPUE (fish/trap soak-hour; dependent variable), and the total number of Red Snapper collected among the four traps was used to develop the CPUE estimate for each sample site. Normal probability plots and Shapiro–Wilk values generated from the UNIVARIATE procedure in SAS (SAS 2008) were used to test assumptions of normality. The CPUE data were significantly nonnormal; thus, a $\log_e$ transformation of the CPUE data was performed to satisfy the normality assumptions. Sampling occurred during three seasons: spring (March–May), summer (June–August), and fall (September–November). No sampling occurred in December, January, or February due to poor sampling conditions. Model parameter estimates were generated using restricted maximum likelihood, and an α value of 0.05 was used for all analyses. In the case of significant results from the mixed model, least-squares analysis (LSMEANS in SAS) was used for pairwise comparisons, and the significance level was adjusted by using the Bonferroni correction to maintain the predetermined experimental error rate.

The TLs (mm) of Red Snapper were compared among the different reef patterns. Lengths were tested for normality by using normal probability plots and Shapiro–Wilk values generated from the UNIVARIATE procedure in SAS. Length data were significantly nonnormal, and a $\log_e$ transformation was applied to normalize the data. Analysis was conducted with the same repeated-measures mixed linear model (MIXED procedure in SAS) as used for the CPUE analysis, and the model directly assessed the effect of reef pattern and season (independent variables) on Red Snapper TL (dependent variable). Parameter estimates were generated in the same manner as for the CPUE analysis, and least-squares mean TL and SE estimates were generated and back-transformed for reporting.

RESULTS

Sampling for this project began on September 28, 2007, and ended on November 20, 2008. Twenty-six trips were made to FH-13, and reef patterns within each section were sampled fairly evenly (Table 1). In total, 927 Red Snapper were collected, and Red Snapper CPUE was determined for each pattern on every individual trip. Estimates of CPUE at each individual pattern differed among trips. Results from the best-fit mixed model (Akaike's information criterion corrected for small sample size [AIC_c] = 101.0) indicated that CPUE did not vary significantly among the reef patterns (reef pattern: $F_{3, 69.2} = 1.00$, $P = 0.396$), but CPUE did differ significantly among seasons (season: $F_{2, 69.5} = 6.56$, $P = 0.002$). Inclusion of section as a random effect in the model did not improve model likelihood, as the estimate was close to zero (estimate = 0.026; SE = 0.033). The geometric least-squares parameter estimates of mean CPUE for the clumped pattern (mean CPUE = 1.22 fish/trap soak-hour; SE = 0.33), OL100 pattern (1.38 fish/trap soak-hour; SE = 0.32), OL200 pattern (1.57 fish/trap soak-hour; SE = 0.43), and OL300 pattern (1.11 fish/trap soak-hour; SE = 0.28) were similar (Figure 4).

Least-squares pairwise comparisons (Bonferroni adjusted) indicated that mean CPUE differed significantly between spring and summer ($P = 0.001$) but not between spring and fall ($P = 1.000$) or between summer and fall ($P = 0.175$). For season, the geometric least-squares parameter estimate of mean CPUE was greatest for summer (mean CPUE = 1.74 fish/trap soak-hour;

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

TABLE 1. Dates of individual sampling events, along with section, reef patterns, and season sampled, in Artificial Reef Site Fish Haven 13 located in the Gulf of Mexico offshore of Mississippi (Fa = fall; Sp = spring; Su = summer; see Methods for definition of reef patterns). Due to gear restrictions, only two reef patterns were sampled on the October 26, 2007, sampling trip.

Date of sampling	Section sampled	Reef patterns sampled	Season
Sep 28, 2007	B	Clumped, OL100, OL300	Fa
Oct 26, 2007	A	Clumped, OL100	Fa
Mar 6, 2008	B	Clumped, OL100, OL200	Sp
Mar 12, 2008	A	Clumped, OL100, OL300	Sp
Apr 2, 2008	B	OL100, OL200, OL300	Sp
Apr 22, 2008	A	Clumped, OL100, OL300	Sp
Apr 30, 2008	B	Clumped, OL200, OL300	Sp
May 28, 2008	C	Clumped, OL100, OL300	Sp
May 30, 2008	C	OL100, OL200, OL300	Sp
Jun 3, 2008	B	Clumped, OL100, OL300	Su
Jun 6, 2008	B	Clumped, OL100, OL300	Su
Jun 16, 2008	C	Clumped, OL100, OL300	Su
Jun 19, 2008	C	Clumped, OL100, OL200	Su
Jun 24, 2008	C	Clumped, OL100, OL200	Su
Jul 2, 2008	A	Clumped, OL100, OL200	Su
Jul 8, 2008	C	Clumped, OL100, OL200	Su
Jul 10, 2008	B	Clumped, OL100, OL200	Su
Jul 16, 2008	A	Clumped, OL100, OL300	Su
Jul 17, 2008	B	Clumped, OL100, OL300	Su
Aug 7, 2008	A	Clumped, OL200, OL300	Su
Aug 21, 2008	B	OL100, OL200, OL300	Su
Sep 18, 2008	B	Clumped, OL200, OL300	Fa
Oct 3, 2008	A	Clumped, OL200, OL300	Fa
Nov 5, 2008	A	Clumped, OL200, OL300	Fa
Nov 6, 2008	C	Clumped, OL200, OL300	Fa
Nov 20, 2008	B	OL100, OL200, OL300	Fa

SE = 0.38), whereas the spring season had the lowest estimated mean CPUE (1.06 fish/trap soak-hour; SE = 0.24). Estimated mean CPUE for fall (1.19 fish/trap soak-hour; SE = 0.73) did not differ significantly from the spring or summer mean CPUE estimates (Figure 5).

Collected Red Snapper TLs ranged from 120 to 501 mm, with a mean of 225 mm (SE = 2.24). Of the 927 Red Snapper that were captured, 18 exceeded the legal length limit of 406 mm TL. Results from the mixed model ($AIC_c = 84.4$) indicated that mean TL differed among the four reef patterns ($F_{3, 903} = 5.39$, $P = 0.001$) and among seasons ($F_{2, 903} = 6.22$, $P = 0.001$). The inclusion of section as a random effect in the model did not improve model likelihood, as the estimate was close to zero (estimate = 0.007; SE = 0.008).

The least-squares pairwise comparisons (Bonferroni adjusted) of Red Snapper TL indicated that TL differed significantly between the clumped pattern and the OL100, OL200, and OL300 patterns ($P = 0.001$ in each case; Figure 6). The

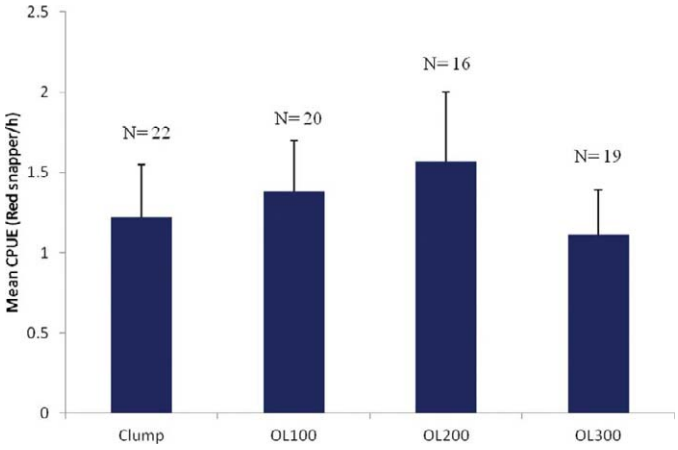


FIGURE 4. Mean (+ SE) CPUE (Red Snapper/trap soak-hour) at each reef pattern (described in Figure 3; N = number of site visits used to generate mean CPUE estimates) for Red Snapper captured with trap nets during September 2007–November 2008 from Artificial Reef Site Fish Haven 13 in the Gulf of Mexico.

analysis also indicated a significant difference in Red Snapper TL between the OL200 and OL300 patterns ($P = 0.001$). Geometric least-squares parameter estimates of mean TL indicated that the OL200 pattern had the greatest mean TL (235 mm; SE = 5.14), whereas the clumped pattern had the lowest mean TL (198 mm; SE = 3.10). The mean TL estimate for OL100 was 227 mm (SE = 3.30), and the mean for OL300 was 215 mm (SE = 4.79; Figure 6).

Results from least-squares pairwise comparisons (Bonferroni adjusted) indicated that Red Snapper TL differed significantly between fall and spring ($P = 0.001$) and between fall and summer ($P = 0.001$) but not between spring and summer ($P = 1.000$; Figure 7). Geometric least-squares parameter estimates of mean TL indicated that the greatest mean TL was associated

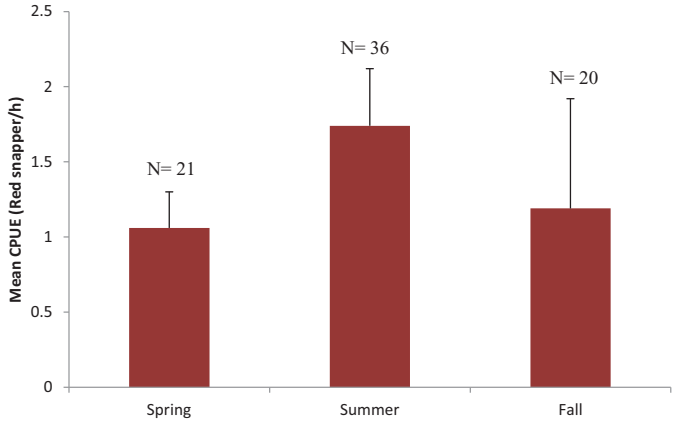


FIGURE 5. Mean (+ SE) CPUE (Red Snapper/trap soak-hour) by season (N = number of site visits used to generate mean CPUE estimates) for Red Snapper captured with trap nets during September 2007–November 2008 from Artificial Reef Site Fish Haven 13 in the Gulf of Mexico. Sampled seasons were spring (March–May), summer (June–August), and fall (September–November).

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

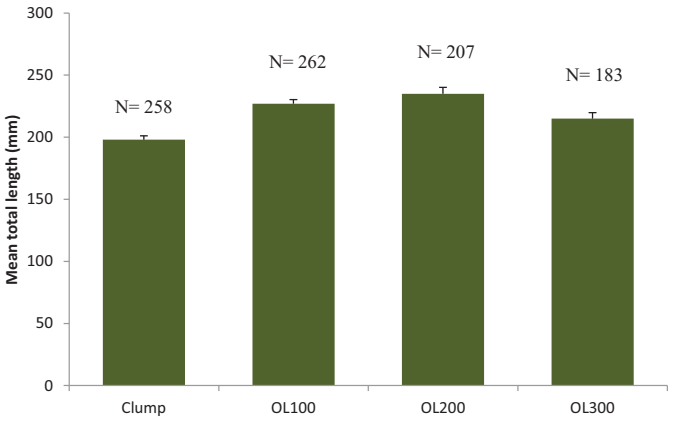


FIGURE 6. Mean (+ SE) total length (mm) at each reef pattern (described in Figure 3; N = total number of Red Snapper sampled at each pattern) for Red Snapper captured with trap nets during September 2007–November 2008 from Artificial Reef Site Fish Haven 13 in the Gulf of Mexico.

with fall (mean TL = 253 mm; SE = 4.35). Mean TLs for spring (203 mm; SE = 2.30) and summer (201 mm; SE = 4.48) did not differ significantly (Figure 7).

DISCUSSION

Artificial reefs have previously been studied to determine structural characteristics and placement strategies that maximize fisheries benefits (Gregg 1995; Herrera et al. 2002; Strelcheck et al. 2005), but few studies have specifically examined the importance of reef spacing and placement for Red Snapper (Campbell et al. 2011; Shipley and Cowan 2011). The present study's focus on reef spacing effects on juvenile Red Snapper is particularly important because recruitment variability and year-class strength of Red Snapper are most likely determined during early life stages (Geary et al. 2007). Ninety-eight percent of the

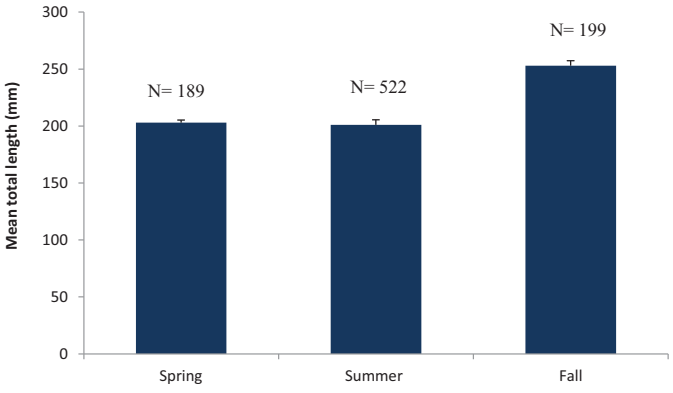


FIGURE 7. Mean (+ SE) total length (mm) in each season (N = total number of Red Snapper sampled during each season) for Red Snapper captured with trap nets during September 2007–November 2008 from Artificial Reef Site Fish Haven 13 in the Gulf of Mexico. Sampled seasons were spring (March–May), summer (June–August), and fall (September–November).

Red Snapper captured during this study (909/927 fish) were under the legal recreational length limit of 406 mm TL, and the mean length of captured Red Snapper was 225 mm TL. Wells and Cowan (2007) found that juvenile Red Snapper prefer and recruit to high-relief structures at 200 mm TL (or at age 1), and Nieland and Wilson (2003) reported that juvenile Red Snapper disappear from shrimp trawls at age 1, migrating to higher-relief structures to seek refuge from predators. In an area that typically lacks structure with substantial vertical relief, the artificial reefs examined in this study could be providing important refuge for juvenile Red Snapper that might otherwise be lost as bycatch in Gulf of Mexico trawling operations.

Results from the mixed model analysis indicated that reef pattern did not significantly affect Red Snapper CPUE, as the mean CPUE estimates differed by less than 1 fish/trap soak-hour among the reef patterns. It is possible that the artificial reef patterns used for this study were not different enough in structure or function to significantly affect juvenile Red Snapper CPUE. Spacing of individual reef elements within a reef complex can encompass a large number of options, of which only a few were examined in this study. Although no pattern in CPUE was found, various factors may have hindered our ability to detect a significant effect of reef pattern on Red Snapper relative abundance (i.e., if an effect actually occurred). Difficulties primarily related to setting traps on or close to the sampled reef patterns, even when accounting for important factors such as currents and wave action, may have prevented us from discovering a reef spacing effect on juvenile Red Snapper CPUE if such an effect existed. Further studies with different spacing of individual reef units and multiple sampling methods are most likely necessary to determine whether or how reef spacing affects the relative abundance of juvenile Red Snapper.

The finding of a significant seasonal effect on juvenile Red Snapper CPUE was not surprising, but identification of summer as the season producing the greatest CPUE differed from the results of other studies. Strelcheck (2001) and Patterson (1999) found that CPUE of Red Snapper decreased during spring and summer and increased during fall. However, both of those studies involved Red Snapper of greater mean size than were observed in our study. The presence of larger Red Snapper on the study reefs during the fall season may be one reason for the observed seasonal differences in CPUE. Bailey (1995) found that the presence of larger subadult Red Snapper (360–367 mm) negatively influenced the presence of young-of-the-year Red Snapper by limiting the refuge and foraging opportunities of the smaller fish. Workman et al. (2002) found that the presence of age-1 Red Snapper on study reefs limited the recruitment of age-0 Red Snapper onto those structures. Mudrak and Szedlmayer (2012) also found that age-0 Red Snapper tended to avoid reefs that were used by adult conspecifics; those authors recommended that reefs built specifically for juvenile habitat should not be placed in proximity to existing adult habitat. In our study, the fall season was associated with the greatest mean

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

TL, and therefore the presence of larger Red Snapper during fall and early spring may have had a negative effect on juvenile Red Snapper CPUE.

Various studies have also examined the effects of hurricanes on Red Snapper movement. Watterson et al. (1998) and Patterson et al. (2001b) found greater dispersal of tagged adult Red Snapper at large during hurricanes, although studies by Szedlmayer and Schroepfer (2005) and Topping and Szedlmayer (2011b) indicated that the extent of hurricane-caused dispersal was related to reef size, with larger reef structures having lower dispersal of fish. Turpin and Bortone (2002) found a greater abundance of larger Red Snapper on study reefs after Hurricane Erin and Hurricane Opal; this result may have been attributable to (1) inshore movement of larger Red Snapper after the disturbances or (2) displacement and mortality of smaller individuals. Two hurricanes, Gustav (August 31, 2008) and Ike (September 11, 2008), impacted our study area; it is possible that juvenile Red Snapper were displaced from our study reefs either by heavy wave action and strong currents or by larger Red Snapper moving into the study area after the disturbances caused by the hurricanes.

Perhaps the most important result of this study was the statistically significant difference in Red Snapper TL among reef patterns, with the OL200 pattern having the greatest estimated mean TL. Significant differences in TLs of same-age juveniles between reef patterns may be an indication of increased benefits (foraging opportunities or prey abundance) that are specific to reef spacing and horizontal extension. Powers et al. (2003) and Wells (2007) observed that larger sizes of individual fish at particular reefs were possibly indicative of increased refuge from predation and an increased access to reef-associated prey resources, which in turn may lead to increased production by enhancing growth and protection of individuals that use the reefs.

The effect of reef spacing on Red Snapper length may be directly linked to Red Snapper foraging strategies and principles of optimal foraging theory and the resource mosaic hypothesis (McCawley 2003). As Red Snapper forage on prey inhabiting the soft-bottom areas around reef structures, areas of intense prey depletion (i.e., foraging haloes) can form (McCawley and Cowan 2007). If reefs are placed too close together, their associated foraging haloes may overlap and negatively affect one another by causing a disproportionate depletion of resources, leading to possible declines in juvenile Red Snapper fitness and abundance (Frazer and Lindberg 1994; Westmeyer et al. 2007; McDonough 2009; Campbell et al. 2011). Red Snapper that are associated with closely spaced reefs may be forced to travel farther from the reef to forage at increased energetic cost, which in turn increases the risk of predation and decreases the probability that those Red Snapper will return to the reef.

In this regard, the OL200 pattern may provide an adequate amount of spacing to minimize foraging halo overlap and in turn might increase the foraging opportunities for juvenile Red Snapper in the study area. Frazer and Lindberg (1994) looked at different reef spacing of similar-sized prefabricated concrete reefs and found that widely spaced (60 m) reef units presented a more beneficial resource for fish (e.g., Red Snapper) that forage off reefs by providing increased access to prey in soft-bottom areas. Although the greatest mean TL of Red Snapper was observed for the OL200 pattern, similar to the results of Frazer and Lindberg (1994), logistical constraints associated with our study make it difficult to draw definitive conclusions from our results. For example, our sample size was restricted by active weather in the northern Gulf of Mexico and by sampling time constraints, and the relatively small number of pyramid structures limited the number of replicates per treatment. In addition, results from this study were based on roughly 1 year of data collection and may not accurately reflect changes associated with the stabilization of Red Snapper populations on the reefs through time. Thus, although the OL200 pattern appears to offer some energetic benefit to Red Snapper over the other three reef patterns, a more robust examination involving a larger sample size and occurring over a number of years is likely needed to accurately determine whether there is an effect of reef pattern on Red Snapper TL.

Red Snapper TL differed significantly among seasons, with the greatest mean TL observed during the fall season. Collection of larger juvenile Red Snapper in the fall seems reasonable because the fish had more time to grow, but as mentioned earlier the greater mean TL during fall may have resulted from the movement of larger Red Snapper onto the artificial reefs during our study. Szedlmayer and Schroepfer (2005) found that Red Snapper were resident on artificial reefs for several seasons, and those authors did not detect any seasonal migration away from their study reefs; however, various other studies have shown probable seasonal movements of Red Snapper. Wells (2007) found that seasonal size differences at specific reef habitats were likely a result of seasonal emigration and immigration of different size-groups of Red Snapper. Topping and Szedlmayer (2011b) found significant differences among seasons in the proportion of large (>500 mm TL), tagged Red Snapper that were emigrating, and the largest proportion of fish emigrating was observed during summer. Decreased CPUEs of large Red Snapper during spring and summer, as detected in studies by Patterson (1999) and Strelcheck (2001), may also indicate seasonal movements. The possible movement of larger fish onto our study reefs during fall, potentially in response to hurricane disturbances (Watterson et al. 1998; Patterson et al. 2001b; Turpin and Bortone 2002), or the emigration of larger fish away from the reefs during summer could account for the greater mean TL and lower mean CPUE of Red Snapper during the fall season.

Conclusions

Findings of this study are significant and promising, as few studies have looked at the importance of independent reef unit spacing as it pertains to the relative abundance and length of reef-associated juvenile Red Snapper. The knowledge that

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

juveniles will recruit to high-relief structures, such as the prefabricated artificial structures used in this study, gives fisheries managers viable options for different reef programs that are tailored to different species and needs. The rapid colonization of the artificial reef structures by Red Snapper gives a strong indication that the reefs are offering fitness benefits, such as shelter from predation or increased foraging opportunities, to these important reef fish.

The OL200 pattern appears to offer some added benefit to juvenile Red Snapper in the study area, as indicated by the significantly greater mean TL of juveniles sampled at OL200 than at the other reef patterns. However, project limitations, such as a relatively small sample size and a short period of data collection, restrict the scope of our results and conclusions. Greater mean TL may indicate energetic benefits related to the specific reef spacing of the OL200 pattern, but continued research that examines important physiological and ecological aspects of Red Snapper on these study reefs (e.g., diet, prey availability, and interactions with other species) over a number of years is needed to obtain more accurate and robust results and to address some of the questions that could not be definitively answered by the present study.

Reef spacing is just one of the physical components of artificial reef complexes that may affect the recruitment of Red Snapper and other reef fishes to the structures. Consequences of resource depletion caused by the overlap of foraging haloes are a critical reason why the management of artificial reefs should include consideration of reef spacing to minimize halo overlap. The results of this study provide an important and informative first step toward understanding the relationship between juvenile Red Snapper and artificial reefs off the coast of Mississippi and will hopefully aid in the continued rehabilitation of Red Snapper stocks throughout the Gulf of Mexico.

ACKNOWLEDGMENTS

Thanks are extended to Leandro (Steve) E. Miranda, Eric D. Dibble, and the faculty and staff of Mississippi State University for their guidance and input during this project and during the writing process. We especially appreciate Kerwin Cuevas, Jimmy Sanders, Erik Broussard, Brandon Hall, and all other MSDMR members who accompanied us out on the water and assisted us in the office. Without their help, this project would not have been possible. Finally, we thank charter boat captains Tom Becker, Jay Trochesset, and Kenny Barhanovich for providing use of their boats to access and sample our study site and for relating their invaluable personal experiences to aid in this study.

REFERENCES

Allman, R. J., L. A. Lombardi-Carlson, G. R. Fitzhugh, and W. A. Fable. 2002. Age structure of Red Snapper (*Lutjanus campechanus*) in the Gulf of Mexico by fishing mode and region. Proceedings of the Gulf and Caribbean Fisheries Institute 53:482–495.

Bailey, H. K., IV. 1995. Potential interactive effects of habitat complexity and sub-adults on young-of-the-year Red Snapper (*Lutjanus campechanus*) behavior. Master's thesis. University of South Alabama, Mobile.

Bohnsack, J. A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bulletin of Marine Science 44:631–645.

Bohnsack, J. A., and D. L. Sutherland. 1985. Artificial reef research: a review with recommendations for future priorities. Bulletin of Marine Science 37: 11–39.

Bortone, S. A., T. Martin, and C. M. Bundrick. 1994. Factors affecting fish assemblage development on a modular artificial reef in a northern Gulf of Mexico estuary. Bulletin of Marine Science 55:319–332.

Campbell, M. D., K. Rose, K. Boswell, and J. Cowan. 2011. Individual-based modeling of an artificial reef fish community: effects of habitat quantity and degree of refuge. Ecological Modelling 222:3895–3909.

Chapin, A. M., S. T. Szedlmayer, and R. P. Phelps. 2009. Survival and movement of hatchery-reared Red Snapper on artificial habitats in the northern Gulf of Mexico. Fisheries Management and Ecology 16:28–36.

Collins, L. A., J. H. Finucane, and L. E. Barger. 1980. Description of larval and juvenile Red Snapper, *Lutjanus campechanus*. U. S. National Marine Fisheries Service Fishery Bulletin 77:965–974.

Cowan, J. H., Jr., C. B. Grimes, W. F. Patterson III, C. J. Walters, A. C. Jones, W. J. Lindberg, D. J. Sheehy, W. E. Pine III, J. E. Powers, M. D. Campbell, K. C. Lindeman, S. L. Diamond, R. Hilborn, H. T. Gibson, and K. A. Rose. 2011. Red Snapper management in the Gulf of Mexico: science- or faith-based? Reviews in Fish Biology and Fisheries 21:187–204.

Diamond, S. L., M. D. Campbell, D. Olson, Y. Wang, J. Zeplin, and S. Qualia. 2007. Movers and stayers: individual variability in site fidelity and movements of Red Snapper off Texas. Pages 163–187 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Franks, J. S., J. R. Hendon, and N. M. Garber. 2004. Red Snapper (*Lutjanus campechanus*) associated with a small artificial structure in the Mississippi Sound, a northern Gulf of Mexico estuary. Proceedings of the Gulf and Caribbean Fisheries Institute 55:853–864.

Frazer, T. K., and W. J. Lindberg. 1994. Refuge spacing similarly affects reef-associated species from three phyla. Bulletin of Marine Science 55:388–400.

Gallaway, B. J., J. G. Cole, R. Meyer, and P. Roscigno. 1999. Delineation of essential habitat for juvenile Red Snapper in the northwestern Gulf of Mexico. Transactions of the American Fisheries Society 128:713–726.

Gallaway, B. J., W. J. Gazey, J. G. Cole, and R. G. Fechhelm. 2007. Estimation of potential impacts from offshore liquefied natural gas terminals on Red Snapper and Red Drum fisheries in the Gulf of Mexico: an alternative approach. Transactions of the American Fisheries Society 136:655–677.

Garber, A. F., M. D. Tringali, and K. C. Stuck. 2004. Population structure and variation in Red Snapper (*Lutjanus campechanus*) from the Gulf of Mexico and Atlantic coast of Florida as determined from mitochondrial DNA control region sequence. Marine Biotechnology 6:175–185.

Geary, B. W., J. J. Mikulas Jr., J. R. Rooker, A. M. Landry Jr., and T. M. Dellapenna. 2007. Patterns of habitat use by newly settled Red Snapper in the northwestern Gulf of Mexico. Pages 25–38 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Gillig, D., W. L. Griffin, and T. Ozuna Jr. 2001. A bioeconomic assessment of Gulf of Mexico Red Snapper management policies. Transactions of the American Fisheries Society 130:117–129.

Gregg, K. L. 1995. Comparisons of three manufactured artificial reef units in Onslow Bay, North Carolina. North American Journal of Fisheries Management 15:316–324.

Herrera, R., F. Espino, M. Garrido, and R. J. Haroun. 2002. Observations on fish colonization and predation on two artificial reefs in the Canary Islands. ICES Journal of Marine Science 59(Supplement):69–73.

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Jordan, L. K. B., D. S. Gilliam, and R. E. Spieler. 2005. Reef fish assemblage structure affected by small-scale spacing and size variations of artificial patch reefs. Journal of Experimental Marine Biology and Ecology 326:170–186.

Lindberg, W. J., T. K. Frazer, and G. R. Stanton. 1990. Population effects of refuge dispersion for adult stone crabs (Xanthidae, *Menippe*). Marine Ecology Progress Series 66:239–249.

Lukens, R. R. 1980. The succession of ichthyofauna on new artificial reefs in the northern Gulf of Mexico. Master's thesis. University of Southern Mississippi, Hattiesburg.

Lukens, R. R., J. D. Cirino, J. A. Ballard, and G. Geddes. 1989. Two methods of monitoring and assessment of artificial reef materials. Gulf States Marine Fisheries Commission, Special Report 2-WB, Ocean Springs, Mississippi.

McCawley, J. R. 2003. Diet and prey demand of Red Snapper, *Lutjanus campechanus*, on Alabama artificial reefs. Master's thesis. University of South Alabama, Mobile.

McCawley, J. R., and J. H. Cowan Jr. 2007. Seasonal and size specific diet and prey demand of Red Snapper on Alabama artificial reefs. Pages 77–104 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

McDonough, M. 2009. Oil platforms and Red Snapper movement and behavior. Master's thesis. Louisiana State University, Baton Rouge.

Mitchell, K. M., T. Henwood, G. R. Fitzhugh, and R. J. Allman. 2004. Distribution, abundance, and age structure of Red Snapper (*Lutjanus campechanus*) caught on research longlines in the U.S. Gulf of Mexico. Gulf of Mexico Science 22:164–172.

Mudrak, P. A., and S. T. Szedlmayer. 2012. Proximity effects of larger resident fishes on recruitment of age-0 Red Snapper in the northern Gulf of Mexico. Transactions of the American Fisheries Society 141:487–494.

Nieland, D. L., and C. A. Wilson. 2003. Red Snapper recruitment to and disappearance from oil and gas platforms in the northern Gulf of Mexico. Pages 73–81 *in* D. R. Stanley and A. Scarborough-Bull, editors. Fisheries, reefs, and offshore development. American Fisheries Society, Symposium 36, Bethesda, Maryland.

Ouzts, A. C., and S. T. Szedlmayer. 2003. Diel feeding patterns of Red Snapper on artificial reefs in the north-central Gulf of Mexico. Transactions of the American Fisheries Society 132:1186–1193.

Parsons, G. R., and D. G. Foster. 2007. Swimming performance and behavior of Red Snapper: their application to bycatch reduction. Pages 59–75 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Patterson, W. F., III. 1999. Aspects of the population ecology of Red Snapper, *Lutjanus campechanus*, in an artificial reef area off Alabama. Doctoral dissertation. University of South Alabama, Mobile.

Patterson, W. F., III, and J. H. Cowan Jr. 2003. Site fidelity and dispersion of Red Snapper associated with artificial reefs in the northern Gulf of Mexico. Pages 181–193 *in* D. R. Stanley and A. Scarborough-Bull, editors. Fisheries, reefs, and offshore development. American Fisheries Society, Symposium 36, Bethesda, Maryland.

Patterson, W. F., III, J. H. Cowan Jr., C. A. Wilson, and R. L. Shipp. 2001a. Age and growth of Red Snapper, *Lutjanus campechanus,* from an artificial reef area off Alabama in the northern Gulf of Mexico. U.S. National Marine Fisheries Service Fishery Bulletin 99:617–627.

Patterson, W. F., III, J. C. Watterson, R. L. Shipp, and J. H. Cowan Jr. 2001b. Movement of tagged Red Snapper in the northern Gulf of Mexico. Transactions of the American Fisheries Society 130:533–545.

Peabody, M. B. 2004. The fidelity of Red Snapper (*Lutjanus campechanus*) to petroleum platforms and artificial reefs in the northern Gulf of Mexico. Master's thesis. Louisiana State University, Baton Rouge.

Powers, S. P., J. H. Grabowski, C. H. Peterson, and W. J. Lindberg. 2003. Estimating enhancement of fish production by offshore artificial reefs: uncertainty exhibited by divergent scenarios. Marine Ecology Progress Series 264:265–277.

Saillant, E., and J. R. Gold. 2006. Population structure and variance effective size of Red Snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico. U.S. National Marine Fisheries Service Fishery Bulletin 104: 136–148.

SAS (Statistical Analysis Systems). 2008. SAS online doc 9.2. SAS Institute, Cary, North Carolina.

Schroepfer, R. L., and S. T. Szedlmayer. 2006. Estimates of residence and site fidelity for Red Snapper *Lutjanus campechanus* on artificial reefs in the northeastern Gulf of Mexico. Bulletin of Marine Science 78:93–101.

Sherman, R. L., D. S. Gilliam, and R. E. Spieler. 2002. Artificial reef design: void space, complexity, and attractants. ICES Journal of Marine Science 59(Supplement):196–200.

Shipley, J. B., and J. H. Cowan Jr. 2011. Artificial reef placement: a Red Snapper, *Lutjanus campechanus,* ecosystem and fuzzy rule-based model. Fisheries Management and Ecology 18:154–167.

Strelcheck, A. J. 2001. The influence of reef design and nearest-neighbor dynamics on artificial reef fish assemblages. Master's thesis. University of South Alabama, Mobile.

Strelcheck, A. J., J. H. Cowan Jr., and A. Shah. 2005. Influence of reef location on artificial-reef fish assemblages in the northcentral Gulf of Mexico. Bulletin of Marine Science 77:425–440.

Szedlmayer, S. T., and J. D. Lee. 2004. Diet shifts of juvenile Red Snapper (*Lutjanus campechanus*) with changes in habitat and fish size. U.S. National Marine Fisheries Service Fishery Bulletin 102:366–375.

Szedlmayer, S. T., and R. L. Schroepfer. 2005. Long-term residence of Red Snapper on artificial reefs in the northeastern Gulf of Mexico. Transactions of the American Fisheries Society 134:315–325.

Szedlmayer, S. T., and R. L. Shipp. 1994. Movement and growth of Red Snapper, *Lutjanus campechanus,* from an artificial reef area in the northeastern Gulf of Mexico. Bulletin of Marine Science 55:887–896.

Topping, D. T., and S. T. Szedlmayer. 2011a. Home range and movement patterns of Red Snapper (*Lutjanus campechanus*) on artificial reefs. Fisheries Research 112:77–84.

Topping, D. T., and S. T. Szedlmayer. 2011b. Site fidelity, residence time and movements of Red Snapper *Lutjanus campechanus* estimated with long-term acoustic monitoring. Marine Ecology Progress Series 437:183–200.

Turpin, R. K., and S. A. Bortone. 2002. Pre- and post-hurricane assessment of artificial reefs: evidence for potential use as refugia in a fishery management strategy. ICES Journal of Marine Science 59(Supplement):74–82.

Watterson, J. C., W. F. Patterson III, R. L. Shipp, and J. H. Cowan Jr. 1998. Movement of Red Snapper, *Lutjanus campechanus,* in the north central Gulf of Mexico: potential effects of hurricanes. Gulf of Mexico Science 16: 92–104.

Wells, R. J. D. 2007. The effects of trawling and habitat use on Red Snapper and the associated community. Doctoral dissertation. Louisiana State University, Baton Rouge.

Wells, R. J. D., and J. H. Cowan Jr. 2007. Video estimates of Red Snapper and associated fish assemblages on sand, shell, and natural reef habitats in the north-central Gulf of Mexico. Pages 39–57 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Westmeyer, M. P., C. A. Wilson III, and D. L. Nieland. 2007. Fidelity of Red Snapper to petroleum platforms in the northern Gulf of Mexico. Pages 105–121 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Wilson, C. A., and D. L. Nieland. 2001. Age and growth of Red Snapper, *Lutjanus campechanus,* from the northern Gulf of Mexico off Louisiana. U.S. National Marine Fisheries Service Fishery Bulletin 99:653–664.

Workman, I., A. Shah, D. Foster, and B. Hataway. 2002. Habitat preferences and site fidelity of juvenile Red Snapper (*Lutjanus campechanus*). ICES Journal of Marine Science 59(Supplement):43–50.

Downloaded From: https://bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use