A comparison of the size and age of red snapper, Lutjanus campechanus, to the age of artificial reefs in the northern Gulf of Mexico

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Abstract: Size and age of red snapper, Lutjanus campechanus, were sampled from April through November 2010 and compared with the age of the artificial reef at the site of capture. Red snapper were sampled using hook-and-line, fish trap, and SCUBA diver visual surveys. In the laboratory, all captured red snapper were weighed (0.1 g), measured (mm), and otoliths removed for aging. Mean ± SD age of red snapper showed significant differences compared across reef age, with older reefs showing older fish: 2006 reefs = 3.6 ± 1.2 years, 2009 reefs = 2.0 ± 1.7 years, 2010 reefs = 1.7 ± 1.0 years (ANOVA, $F_{2, 1025} = 194.23$, $P < 0.0001$). A significant positive correlation between fish age and reef age was detected ($r^2 = 0.37$, $P < 0.0001$). Depth, distance to other reefs, and potential habitat differences based on growth rate comparisons did not significantly affect the age of red snapper on artificial reefs. This scenario of young fish – new reef and old fish - old reef supports the contention that artificial reefs in the northern Gulf of Mexico are helping in the production and not simply attracting of red snapper.

Abstract—Size and age ofred snapper,*Lutjanus campechanus,* were sampled from April through November 2010 and compared with the age of the artificial reef at the site of capture. Red snapper were sampled using hook-and-line, fish trap, and SCUBA diver visual surveys.In the laboratory, all captured red snapper were weighed (0.1 g), measured (mm), and otoliths removed for aging.Mean ± SD age of red snapper showed significant differences compared across reef age, with older reefs showingolder fish: 2006 reefs = 3.6 ± 1.2 years, 2009 reefs = 2.0 ± 1.7 years, 2010 reefs = 1.7 ± 1.0 years (ANOVA,$F_{2,\ 1025}$ = 194.23, P< 0.0001). A significant positive correlation between fish age and reef age was detected (r^2 = 0.37, P< 0.0001). Depth, distance to other reefs, and potential habitat differences based on growth rate comparisons did not significantly affect the age of red snapper on artificial reefs. This scenario of young fish – new reef and old fish - old reef supports the contention that artificial reefs in the northern Gulf of Mexico are helping in the production and not simply attracting of red snapper.

Introduction

Red snapper(*Lutjanus campechanus*, Poey,1860) hashistorically been a species targeted by both sport and commercial fishers in the Gulf of Mexico (Camber, 1955). Due to intense fishing pressure, the estimated population abundance has decreased and the stock was considered overfished (Schirripa and Legault, 1999; SEDAR7, 2005; SEDAR, 2009). Regulations decreasing the total allowable catch and shortening the recreational season have been enacted over the last several decades to reduce the harvest of this species,for the purpose of increasing the stock.

Red snapper are a reef associated fish, using reef habitat for both shelter and prey resources (Outz and Szedlmayer, 2003; Szedlmayer and Lee, 2004;Piko and Szedlmayer, 2007; Gallaway et al., 2009). However, the substrate in the northern Gulf of Mexicois predominately mud and sand, with comparatively few natural reef areas(Parker et al., 1983;Kennicutt et al.,1995;Dufrene, 2005). The lack of naturally occurring reefs has stimulated the deployment of artificial reefsby the state of Alabama, private fishers, and scientists to increase the availability of reef habitat(e.g. decommissioned military tanks and concrete pyramids). Several permit areas have been established off the coast of Alabama, where an estimated15,000 artificial reefs have been deployed (Minton and Heath, 1998).The deployment of new reefs each year continues to add or replace reefs lost to major tropical storms.

Several studies have examined red snapper age and growth in the northern Gulf of Mexico (Nelson and Manooch, 1982; Szedlmayer and Shipp, 1994; Patterson et al., 2001a; Wilson and Nieland, 2001; Mitchell et al., 2004; Gazey et al., 2008). The results were most often used for annual growth comparisons and population assessments, while a few have examined ontogenetic shifts in habitat and diet with fish age (Szedlmayer and Conti, 1999; Rookeret al.,2004; Szedlmayer and Lee, 2004). Red snapper are most often aged by countingopaque bands on otoliths, with annual depositional rates validated in several studies (Baker and Wilson 2001; Patterson et al., 2001a; Wilson and Neiland 2001; Allman et al., 2005; Szedlmayer and Beyer,2011). Red snapper can be aged by reading whole otoliths if <7 years, butolder fish require otolith sectioning (Szedlmayer and Beyer, 2011). Red snapperare a long-lived species and can reach maximum ages near 50 years (Szedlmayer and Shipp, 1994; Render, 1995; Patterson et al., 2001a; Wilson and Nieland, 2001).

Age-0 red snapper begin to use reefs shortly after settling out of the plankton, and seek out available low relief structured habitat(Workman and Foster, 1994; Szedlmayer and Howe, 1997; Szedlmayer and Conti, 1999;Szedlmayer and Lee, 2004). These new recruits quickly outgrowtheir initial benthic habitats and search for larger structured habitats by the fall following the spawning season (Szedlmayer and Conti, 1999; Szedlmayer and Lee, 2004; Szedlmayer,2011). After this initial recruitment, the presence of age-1 and older snapper may limit the immigration of new recruits to reef structure (Bailey et al., 2001; Piko and Szedlmayer, 2007; Gallaway et al., 2009; Mudrak and Szedlmayer, In press).

In the northern Gulf of Mexico,numerous artificial reefs have been placed in offshore waters, with some studies suggesting increased red snapper production (Szedlmayer, 2007; Gallaway et al., 2009; Shipp and Bortone, 2009), while others have suggested only attraction (Cowan et al. 1999; Patterson and Cowan, 2003; Cowan et al., 2010). Results from diet studies have also differed, with some only supporting attraction (McCawley et al.,2006; Wells et al., 2008b), while others supported increased production (Ouzts and Szedlmayer, 2003; Szedlmayer and Lee, 2004; Redman and Szedlmayer, 2009).Residency and movement studies again differed for red snapper, with some showing little site fidelity (Patterson et al., 2001b; Peabody, 2004), whileothers reported long-termresidency on artificial reefs (Szedlmayer and Shipp, 1994; Szedlmayer, 1997; Szedlmayer and Schroepfer, 2005; Schroepfer and Szedlmayer, 2006; Topping and Szedlmayer, In press).

Thus, it is still not clear if artificial reefs produce new red snapper biomass or simply attract fish and make them more vulnerable to fishing mortality. A new approach to this long standing question would be a comparison of resident fish age to artificial reef age. If enhancement is occurring, the reefs will initially attract new recruits, and these recruits will stay and grow as the reef ages, becoming the dominate age class which will then effectively exclude new recruits from immigrating to "their" habitat. In contrast, if the artificial reefs simply attract red snapper, reef age will not be correlated with fish age, with little evidence of competitive exclusion or habitat limitation. In the present study reefs were deployed in 2006, 2009, and 2010 and positions were not released to the public to reduce potential fishing mortality effects on red snapper age distribution. The size and age of red snapper were compared among the three reef ages.

Materials and Methods

Sample sites

The study area was located 20 to 30 km south of Mobile Bay, Alabama (Fig. 1). This area has over 15,000 artificial and a few natural rocky reefs(Minton and Heath, 1998). Artificial reefs

(4.4 x 1.3 x 1.2 m metal cages)were deployed in April 2006 (*n* = 20, 4 year old reefs), April 2009(*n* = 10, 1 year old reefs), and January 2010 (*n* = 10, 0.5 year old reefs). Reef locations were not published which limitedpotential fishing mortality. Depth ranges for 2006 reefs were 27 – 32m, 2009 reefs 18 – 24m, and 2010 reefs 23 – 31m.

All reefs were sampled from April through November 2010. The 2010 reefs were sampled at least five months after deployment to allow adequate time for red snapper immigration.Red snapper were collected with hook-and-lineand fish trap from each reef. Hook-and-line sampling was standardized to 30 min, with two fishers.Fishingtime was suspended when problems occurred (e.g.internally hooked fish)and continued once bothfishers could resume fishing. Hook-and-line fishing used double 6/0 J hooks, 27.2 kg test monofilament line, 45.3 kg test monofilament leader, and whole Gulf menhaden (*Brevoortiapatronus*) as bait.After completion of hook-and-line, additional fish were collected with a baited fish trap (1.2 x 1.5 x 0.6 m; Collins, 1990).In the fish trap both Gulf menhaden and whole squid (*Loligo*spp.) were used as bait. All fish traps were set for 15 min.After collections reached approximately 50 red snapper per reef, additional fish were released with one exception (73 red snapper were kept on 5 May 2010 due to the possibility of area closures as a result of the Deepwater Horizon oil spill). When the minimum target of 30 red snapper per reef was not reached after the first fish trap set, the trap was fished at least one additional time. All red snapper collected from the reef were immediately packed on ice and returned to the laboratory for further processing.

After fish collections were completed, two SCUBA divers completed visual, photographic (Nikon D200) and video (Sony Hi-8) surveys to estimate the remaining red snapper at the sample site. A clear plastic jar containing cut menhaden was used to attract surrounding red snapper into aggregations during the visual survey for increased accuracy of total counts.

Divers completed at least three visual counts, with the highest count used for total abundanceestimates. Poor visibility at some sites limited total abundance estimates. In addition, diver operations were suspended when sharks were present and visual estimates were completed at a later date.

Laboratory analyses

Red snapper size (standard lengthSL; fork length FL; total length TL mm) and total body weight (0.01 g)were measured in the laboratory within 24 h of capture.For red snapper ≥ 250mm TL, otoliths were removed usinga Bosch fine cutelectric saw. For red snapper <250mm TL, otoliths were removed using a small knife. Both left and rightotoliths were removed from each fish, cleaned, and stored in dry plastic vials for later analysis.Opaque bands were counted on all otoliths for age estimates. For fish < 7 years, bands were counted on whole otoliths that were immersed in water under a dissecting scope with transmitted light. If ages were ≥ 7 years, thin otolith sections were prepared and bands were counted at 40x with a compound microscope (Szedlmayer and Beyer,2011). Opaque bands of sectioned otoliths were counted along the dorsal edge of the sulcus acousticus.Bands on each otolith were counted independently four times. After four readings, two readers examined remaining otoliths where counts still differed and attempted to reach a consensus on age. If an agreement on age could not be reached the otolith was rejected. A reference collection of hatchery red snapper that were released in the wild as age-0 and recaptured as age-1 (n = 22) along with a group that was reared in captivityto age-1 (n = 13) were used to validate counting methods ofwild caught age-1 fish. Some of the otoliths of these known age-1 fish showed a “false” annulus(i.e. had 2 opaque bands), but showed age-1 otolith shape patterns (Beyer and Szedlmayer, 2010). Thus, some wild fish < 200 mm caught in this study with two opaque bands were defined as age-1, based on age-1 shape patterns similar to hatchery reared as well as hatchery born but wild reared fish.

Video recordings and digital photographs of the reefs were examined in the laboratory for comparisons and validation of diver visual counts. In the laboratory, photographs that showed the highest number of red snapper for a particular reef were selected for computer counting. All red snapper in photographs were identified and counted using Image-pro software (Image–pro plus vers. 4.5, MediaCybernetics, Silver Spring, MD). Two screens were used to count video recordings. A single frame of the video was displayed on one screen while the video played on the second screen. When a single frame of the video is captured, the quality of the image decreases, but the live video screenallowed identification of all fish in the captured screen. The captured screen could then be marked and counted using Image-pro software.

Data analyses

Catch per unit effort was calculated for both hook-and-line (CPUE = number caught by 2 fishers 30 min^{-1}) andtrap (CPUE = number caught 15 min^{-1}) for each reef. The precision of age estimates between readerswas compared using a linear regression and average percent error (Beamish and Fournier, 1981).Red snapper densities (number per $m^3$of reef) were compared with the number of months the reefs were deployed prior to sampling using Pearson’s correlation coefficient. An analysis of variance (ANOVA) was used to compare the SL, weights, and ages of red snapper among the different reef ages. If significant differences were detected a Tukeytest was used to show specific differences.

Growth rates were examined by linear regressions for red snapper <10 years and compared among old (2006) and new (2009 and 2010) reefsusing an analysis of covariance (ANCOVA). For additional comparisons, Pearson's correlation coefficients were calculated between reef age and red snapper SL, weight, and age; and between proximity to other artificial reefs and red snapper abundance and age. To eliminate possible depth effects, the ages of red snapper collected from the same depth (30 m) were compared among 2006 reefs and 2010 reefs with a t-test. Differences were considered significant at $P \leq 0.05$ and all data were analyzed with Statistical Analysis System software (SAS vers. 9.1, SAS Inst., Inc., Cary, NC)

Results

Red snapper were sampled from April through November 2010 from 37 artificial reefs (2006 reefs$n$=18, 2009 reefs$n$=10, 2010 reefs$n$=9).Diver surveys were completedat later dateson two sites due to shark presence on the original sample date, and not completed on seven reefs due to poor visibility.

Atotal of 1028 red snapper were collected, 439 by hook-and-line, and589by trap. Mean± SD CPUE for hook-and-linewas significantly greater on the 2006 reefs (20.4± 8.5 30 min^{-1}) than on the 2009 (6.3 ± 8.1 30 min^{-1})and 2010 reefs (2.6 ± 4.6 30 min^{-1}; ANOVA:$F_{2, 34}$= 20.38, P< 0.0001). No significant CPUE (number 15 min^{-1}) differences were detected among reef years for trap collections (2006 = 10.6 ± 10.9, 2009 = 16.6 ± 19.9, and 2010 = 14.3 ± 12.7; ANOVA:$F_{2,}$

$_{34}$= 0.61, P= 0.55). The SL and weight of red snapper caught by hook-and-line (429.4 ± 79.8 mm, 2531 ± 1409 g) were significantly greater than those caught by trap (232.6 ± 77.6 mm, 538 ± 726 g; SL t-test,t_{1018} = 39.56,weightt_{1018}= 29.41, P< 0.0001). Red snapper ages were also significantly different between the two sampling methods (hook-and-line = 4.1 ± 1.3 years, trap =1.9 ± 1.1 years;t-test,t_{1024} = 29.68, P< 0.0001).

Diver survey methods significantly affected red snapper counts. Visual survey estimates (mean ± SD = 78.3±54.8)were significantly higher than other methods (photograph counts =30.7± 20.2, video counts =16.5± 10.3; ANOVA,$F_{2, 42}$= 13.37, P<0.0001). Due to these differences, total red snapper densities were estimated by adding captured fish (hook-and-line and trap samples) to visual counts.

Age-1 red snapper first recruited to the 2010 reefs in the early summer, and numbers increased through the fall. Mean ± SD numbers of red snapper m^{-3} of reef structure increased as reef age increased (Pearson's r = 0.48, P = 0.008), and were significantly greater on 2006 reefs (22 ± 13) than on 2009 reefs (12 ± 6) and 2010 reefs (8 ± 7; ANOVA,$F_{2, 27}$= 4.25, P<0.025).

All red snapper caught (n= 1028) were used in the final age comparisons. Initial agreement between the 1st and 2nd independent readings was 62.2% (639/1028). A 3rd and 4th reading increased the accepted otoliths to 92.3% (949/1028).Average percent error was calculated for both sets of independent readings (Table 1). An age consensus was reached on all remaining otoliths (n = 79) by simultaneous examination by two readers. The reference collection of age-1 hatchery (n = 35, laboratory and wild reared) red snapper showed25.7 % with two opaque bands, suggesting that counting opaque bands for age-1 fish may not be reliable. Among fish that were < 200 mm SL and showed two opaque bands (n= 72), allwere identified as age-1 based on shape, thickness, and location of the opaque bands (Szedlmayer and Beyer, 2010; Szedlmayer, personal observ.).

Mean ± SD red snapper SL, weight, and age were significantly different among 2006 reefs (373.29 ± 107.83 mm SL,1883.1 ± 1388.1 g, 3.6 ± 1.2 years),2009 reefs (250.20 ± 114.71 mm SL,852.0 ± 1464.4 g, 2.0 ± 1.7 years) and2010 reefs (222.25 ± 78.04 mm SL, 480.1 ± 710.6 g, 1.7 ± 1.0 years; ANOVA,$F_{2,\ 1025} = 194.23$, $P < 0.0001$; Table 2;Fig.2 and 3).Reef age was positively correlated with red snapper age (Pearson's$r = 0.61$, $P < 0.0001$), standard length ($r = 0.71$, $P < 0.0001$), and weight ($r = 0.47$, $P = 0.0035$).Comparisons of linear growth rates for fish <10 years showed no significant differences between old (2006) and new (2009 and 2010) reefs (ANCOVA,$F_{3,\ 1018} = 2.98$, $P = 0.085$, power > 0.99).

The depths of the 2006 reefs were significantly greater than the depths of the 2009 reefs (*t*-test,$t_{26} = 16.32$, $P < 0.0001$). Due to this depth difference, red snapper were also compared among the 2006 and 2010 reefs($n = 8$) from the same depth (30 m). These comparisons still detected significantly larger and older red snapper on 2006 reefs (mean ± SD = 368.73 ±105.02 mm SL, 1820.8 ± 1326.3 g, 3.60 ± 1.20 years) compared to2010 reefs (236.19± 85.24 mm SL, 578.0 ± 814.1 g, 1.91 ± 1.10 years,*t*-test,$P < 0.0001$).

Comparisons of red snapper abundance and age on artificial reefs from this study,to theproximity ofother known reefs failed to detect a significant effect. Also, no significant correlations were detectedbetween abundance (Pearson's $r = -0.061$, $P = 0.721$), or mean age of red snapperand distance to other reefs(Pearson's $r = 0.160$, $P = 0.345$).

Discussion

Evidence for production

This study showed significantly older red snapper were associated with older artificial reefs. Previous studies have compared artificial reef age with density and size estimates of resident reef fishes but have not examined reef fish age. For example, there were significantly higher densities of reef fishes and larger Sparids (*Diplodussargus*,*Diplodusbellottii*, and *Diplodus vulgaris*) at older habitats(Lindberg et al., 2006; Santos et al., 2011). Since length varies directly with age with these species up to age 3 (Gordoa and Molí, 1997), it is likely that the age also increased with reef age similar to the present study.

This relation between reef age and fish age supports previous studies that indicated red snapper production from artificial reefs (Szedlmayer and Shipp, 1994; Szedlmayer, 2007; Gallaway et al., 2009). The increased production is likely due to an increase in available reef habitat, which has been shown as a controlling factor affecting the density and growth of red snapper (Szedlmayer and Shipp, 1994; Szedlmayer and Conti, 1999; Gazey et al., 2008). Red snapper recruited to the newly deployed reefs rapidly as juveniles (approximately age-1) andthen resided on these reefs for several years based on red snapper ages in the present study and long term residency shown in previous studies (Schroepfer and Szedlmayer 2006; Topping and Szedlmayer, In press). If these reefs were only attracting red snapper, fish age and reef age would not be correlated. Red snapper would freely move back and forth among reefs and show random age distributions at each reef site. If artificial reefs are enhancing the population and experiencing no fishing pressure, Powers et al. (2003) estimated that these reefs could increase production by 6.45 kg wet wt 10 m^{-2} in the first year. Since the reefs used in the present study were unpublished, fishing mortality was limited and following Powers et al. (2003) had the potential to increase production.

Several studies suggest that red snapper populations were overfished and that habitat limitation was not the most important controlling factor (Schrippa and Legault, 1999; Patterson et al., 2001b; Cowan et al., 2010). Clearly there was significant fishing mortality of red snapper in the northern Gulf of Mexico (Gillig et al., 2000). However, if fishing mortality was the limiting factor for red snapper and habitat was not important, we would not expect significant reef age effects on fish age (i.e. all reefs whether fished or not would show similar age distributions). Red snapper enter the fishery around age 2, (recreational size minimum = 406 mm, commercial = 330 mm), with the catch predominately consisting of 2 to 4 year old fish. If fishing mortality was limiting red snapper, these ages would have been harvested and not show significant increases on older reefs. However, these ages represented 59 % (n =602) of the total catch, indicating that fishing mortality was not limiting red snapperabundance on the reefs in the present study.

Onesubstantial difference between the present study that suggests habitat limitation and previous studies that suggested fishing mortality limitation was the use of fishery independent data compared to fishery dependent data. While other studies mainly used fishery dependent data of red snapper caught by sport and commercial fishers (Szedlmayer and Shipp, 1994; Baker and Wilson, 2001; Patterson et al., 2001a; Wilson et al., 2001), this study used fishery independent methods from unpublished artificial reef sites. These fishery independent methods could also sample smaller red snapper that were unavailable from fishery dependent methods. In addition, fishing mortalityat reef sites in the present study was probably greatly reduced,because reef locations were unpublished which limited fisher access.

Several alternate factors, aside from reef age, could have affected the size and age of red snapper caught. First, larger fish on the older reefs may have resulted from differential habitat value among reef ages, but growth rate differences among different reef ages were not detected. Thus reefs in this study were providing similar resources. Second, the mean depth of the 2006 reefs was 30 m while the mean depth of the 2009 reefs was 20 m, and previous studies have indicated that larger, older red snapper were more common in deeper offshore waters compared to shallower nearshore waters (Render, 1995; Mitchell et al., 2004). However, in this study reefs from the same depth (30 m) still showed significantly larger and older red snapper on the 2006 reefs compared to the 2010 reefs. Third, distance from natural or artificial reefs has been shown to be an important factor affecting the density of reef fishes (Jessee et al., 1985; Sogard, 1989;Strelcheck et al., 2005; Shipley and Cowan, 2010). In this study, no significant relations were detected between reef proximity and red snapper ages and abundance. Forth, older reefs may provide better habitat and older red snapper are transient and migrate to these higher quality habitats.However, recent telemetry studies have showed long term residence of red snapper to the present or similar study sites up to 1099 d (Schroepfer and Szedlmayer 2006;Topping and Szedlmayer, In press)

Comparison of collection methods

This study supports previous studieson the importance of using several collection methods to adequately estimate size and age distribution of red snapper on artificial reefs (Myers and Hoenig, 1997; McClanahan and Mangi, 2004; Szedlmayer, 2007; Wells et al., 2008a;Gallaway et al., 2009). Hook-and-line and fish traps were size selective, with hook-and-line consistently catching larger red snapper than the fish trap.

Visual diver counts were used to estimate the remaining red snapper still present on the reef after hook-and-line and trap sampling. The video and photograph methods had significantly lower counts than diver visual surveys. These differences were mostly due to fish swimming throughout the water column that were not within the field of view of the cameras. The use of a bait jar was intended to attract fish closer to reduce these differences, but only had limited success. Comparisons of remote underwater baited cameras have reported similar results, with visual SCUBA surveys showing the greatest abundance and diversity (Tessier et al., 2005; Langlois et al., 2006). Due to lower counts from photographs and video recordings, the diver visual counts were used in the red snapper density estimates for each reef. However, the photographs and video recordings were important in verifying species identification.

Artificial reef succession and red snapper densities

Many studies have shown that artificial habitats are rapidly settled by reef fishes (Solonsky, 1985; Walsh, 1985; Leitão et al., 2008; Redman and Szedlmayer, 2009; Szedlmayer, 2011; Mudrak and Szedlmayer, in press). In a four year study of an artificial reef system in the U. S. Virgin Islands, most reef fishes that immigrated to reefs were juveniles which then stayed on the reefs through adulthood(Ogden and Ebersole, 1981). Also, fish will re-colonize reefs back to pre-event densities following a catastrophic event in which the abundance of fish was decreased (Bohnsack, 1983). Two years after a red tide event off the coast of Florida, the invertebrate and demersal fish communities were similar to those before the red tide (Dupont et al., 2010). The artificial reefs used in this study showed similar patterns where new reefs fill up quickly over the first year then reach a carrying capacity with little change in density over the next few years.

The reefs in the present study supported higher densities of red snapper compared to previous studies. In a demolition study of nine offshore oil platforms, mean density was 0.24 red snapper m^{-3} (Gitschlag et al., 2000). In another study of platforms that used stationary hydroacoustics and visual diver counts, the mean density was 0.16 red snapper m^{-3} (Stanley and Wilson, 1997). The total red snapper density estimates in the present study were substantially higher than these platform estimates and ranged from 1.6 – 47.9, with a mean of 15.7red snapper m^{-3}. One difference between the present study and these previous studies on platforms, were substantial differences in the size of the structures, since the platforms encompass the entire water column. The volume of the platforms ranged from 1037 – 29,860 m^3 (Gitschlag et al., 2000) and 19,800 m^3 (Stanley and Wilson, 1997), whereas all reefs in the current study had a volume of 6.9 m^3. However, even if the volume estimates of the platforms were reduced by two-thirds (upper water column habitat not typically used by red snapper), mean platform red snapper densities of 0.73 m^{-3} (Gitschlag et al., 2000) and 0.47 m^{-3} (Stanley and Wilson, 1997) would still be considerably less than present metal cage estimates.

These differences in the density of red snapper among artificial habitats may be due to increased habitat complexity of cage reefs, providing better protection from predation for younger red snapper, additional prey resources, and fewer resident larger predators compared to platforms. The densities of lemon damselfish (*Pomacentrusmoluccensis*) found on highly complex coral reefs with predators were similar to reefs where predators were excluded, indicating that these corals provided protection for the species (Beukers and Jones, 1997). Similarly, higher densities of young (age-0 and age-1) red snapper were shown with increasing complexity of reef structure (Lingo and Szedlmayer, 2006; Piko and Szedlmayer, 2007) and absence of predators (Mudrak and Szedlmayer, in press) . With large structures, such as platforms, complexity probably decreases and the abundance of potential predators probably increases compared to the smaller artificial reefs used in the present study.Therefore, these larger reefs do not support as many red snapper per unit volume as the more complex smaller structures. For example, an inverse relation was shown between red snapper abundance and the density of offshore platforms, possibly due to an increased exposure of young red snapper to predator aggregations around the platform (Gallaway et al., 1999).The higher densities of red snapper on the reefs used in the present study indicate that these reefs are providing red snapper protection from predation, and increasing the overall carrying capacity.

Conclusions

Significant differences in red snapper ages among the different reef ages provides support for increased red snapper production from artificial reefs.However, at some point the number of artificial habitats placed off the coast of Alabamawill surpass the habitat limitation and the addition of more artificial structures will no longer increase the population. Future research examining the carrying capacities of artificial habitats is needed and would provide information on when an overall environmental carrying capacity for red snapper has been reached.

Additional fishery independent studies using similar methods as in the present study throughout the northern Gulf of Mexico would be useful for making better management decisions regarding catch limits for red snapper.

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Table 1Average percent error for both sets of independent readings. Included are the percentages of agreement for each difference (1st and 2nd reading $r^2 = 0.83$, $P < 0.0001$; 3rd and 4th reading $r^2 = 0.96$, $P < 0.0001$).

	First and Second Reading	Third and Fourth Readings
Average percent error	7.85	1.41
Standard deviation	0.12	0.05
0	62.16 %	92.32 %
± 1	35.89 %	7.39 %
± 2	1.95 %	0.29 %
≥ 3	0 %	0 %

Table 2Comparison of red snappermean ± SD standard length, weight, and age for each reef year using ANOVA and a Tukeytest. Different letters are used to indicate significant differences ($P \leq 0.05$).

Reef Year	SL (mm)	Weight (kg)	Mean Age
2006	373.29 ± 107.83 (a)	1.883 ± 1.388 (a)	3.54 ± 1.24 (a)
	(*n* = 581)	(*n* = 581)	(*n* = 587)
2009	250.20 ± 114.71 (b)	0.852 ± 1.464 (b)	1.98 ± 1.70 (b)
	(*n* = 280)	(*n* = 280)	(*n* = 280)
2010	222.25 ± 78.04 (c)	0.480 ±0.711 (c)	1.72 ± 1.00 (c)
	(*n* = 161)	(*n* = 161)	(*n* = 161)

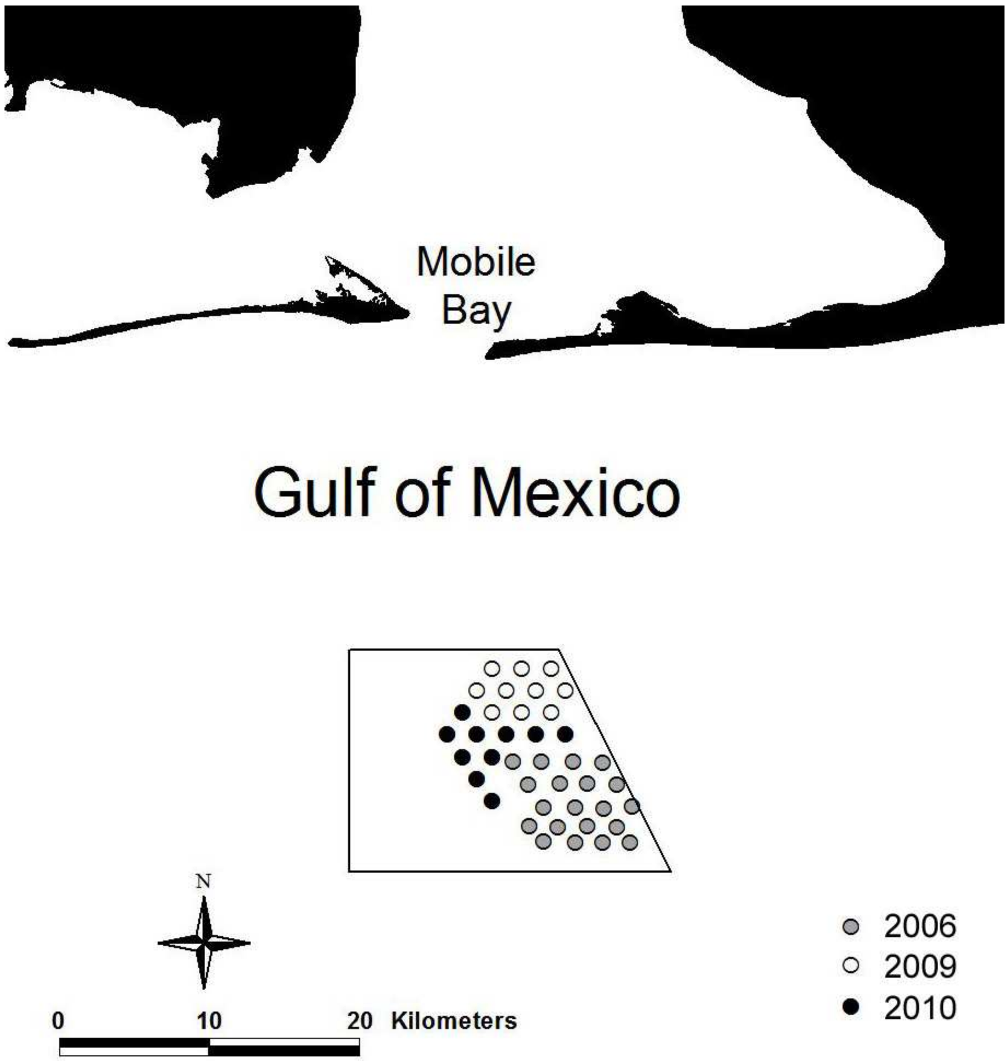

Figure 1 Locations of artificial reefs. Reef years are indicated by different shading.
322x348mm (72 x 72 DPI)

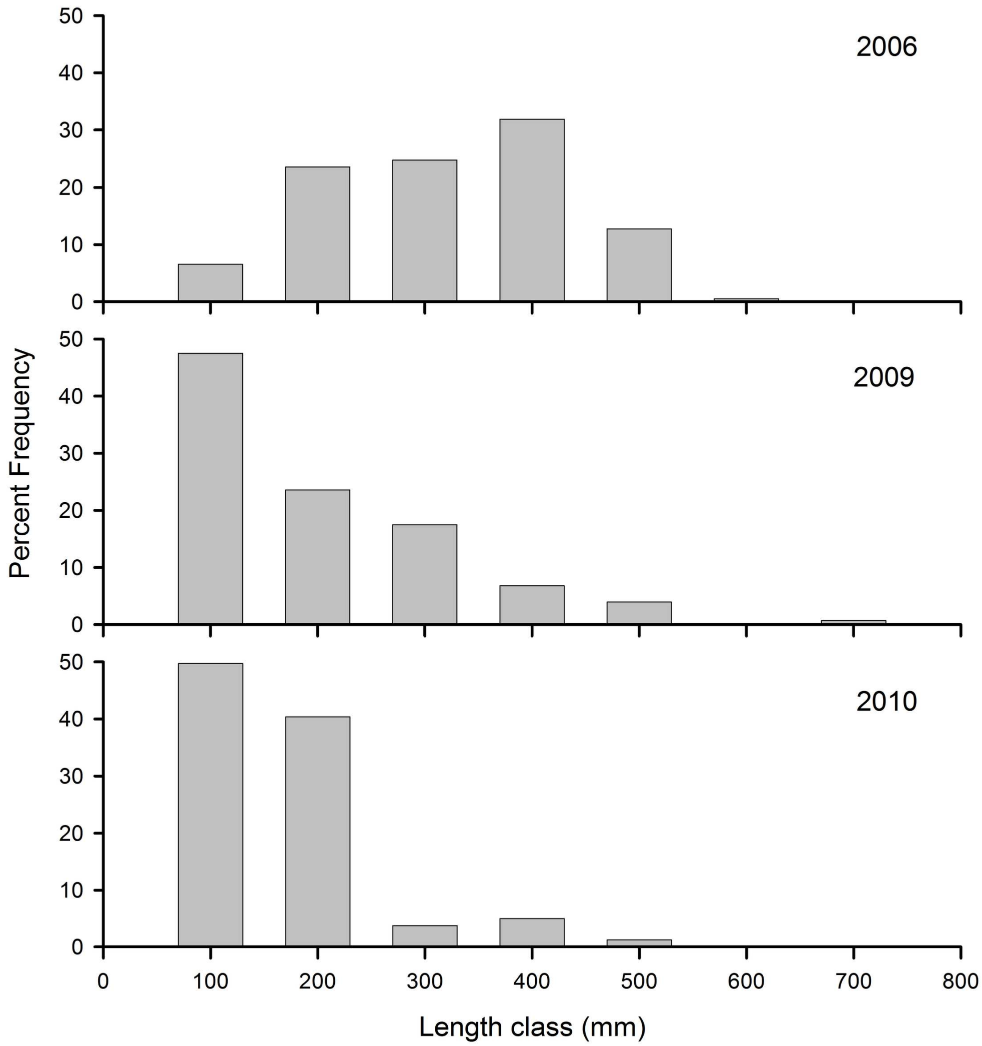

Figure 2 Red snapper SL (mm) percent frequency by reef year, separated into 100 mm categories (e.g. 100 = 100 – 199 mm).
189x202mm (300 x 300 DPI)

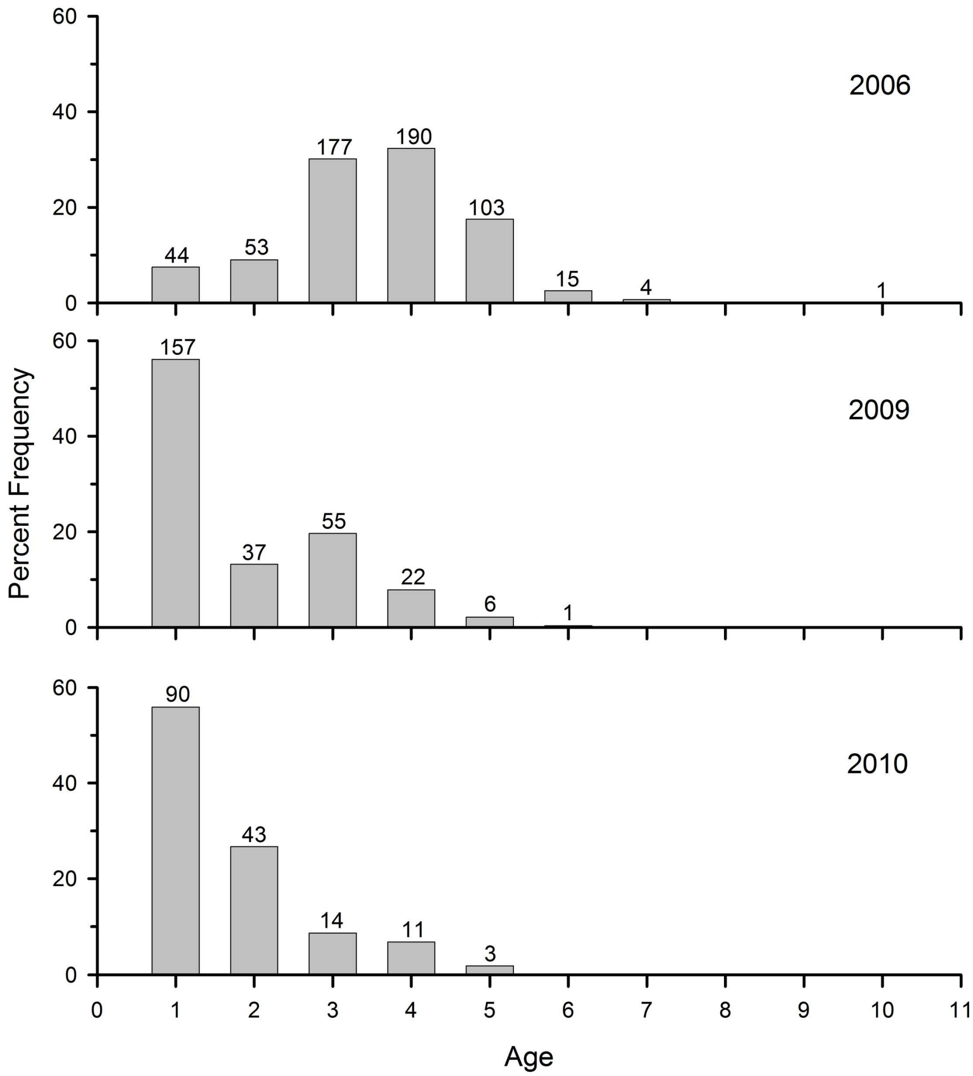

Figure 3 Percent frequency of red snapper age (years) by reef year. Total number of fish caught for each age class indicated by numbers above bars.
193x212mm (300 x 300 DPI)