Predation Effects on Age-0 Red Snapper *Lutjanus campechanus* on Artificial Reefs
in the Northern Gulf of Mexico

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 9, 2011

Keywords: red snapper, predation, recruitment, artificial reef

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Abstract

Small artificial reefs were built in July 2008 ($n = 20$), and 2009 ($n = 20$), 28 km south of Dauphin Island, Alabama, in the northern Gulf of Mexico. Each reef consisted of a polyethylene pallet (1.22 x 1.02 x 0.14 m), to which 10 concrete half-blocks (each 10 x 20 x 41 cm) and a plastic crate (65 x 35 x 28 cm) were attached with 79 kg cable ties. Also, larger steel cage artificial reefs were built in April 2008 ($n = 10$) and 2009 ($n = 10$, 1.2 x 2.4 x 2.4 m). All artificial reefs were secured to the substrate with a 1.2 m ground anchor. Each year, 10 small reefs were placed 15 m away from the larger cage reefs and 10 were placed 500 m away from the larger cage reefs. Each set of reefs (two small and one large) were placed 1.7 km apart.

Reefs were surveyed in August 2008, and August and September 2009. During each survey, two SCUBA divers identified and counted all fish present on the reef and estimated 25 mm length categories. In 2009, all small reefs were videotaped and photographed. In the laboratory, fish in the photographs were identified to species and counted with Image-pro software. A similar procedure was used with a single frame from the Hi8 video.

Significantly lower numbers of age-0 red snapper *Lutjanus campechanus* were detected on small reefs that were near (15 m) the large reefs compared to those that were far (500 m) from the large reefs. In August 2008, the mean ± SD density of age-0 red

snapper on the 500 m reefs was 15.9 ± 12.3 m^{-3} and 0.0 m^{-3} on the 15 m reefs (ANOVA: $F_{1, 36} = 19.54$, $P < 0.05$), in August 2009 it was 23.6 ± 21.0 m^{-3} on the 500 m reefs and 0.1 ± 0.2 m^{-3} on the 15 m reefs (ANOVA: $F_{1, 36} = 10.02$, $P < 0.05$), and in September 2009 it was 77.3 ± 41.2 m^{-3} on the 500 m reefs and 8.6 ± 13.2 m^{-3} on the 15 m reefs (ANOVA: $F_{1, 36} = 21.60$, $P < 0.05$). In addition to red snapper, significantly higher densities of rock sea bass *Centropristis philadelphica,* and pygmy filefish *Stephanolepis setifer* were observed on the 500 m treatment in both August 2009 (rock sea bass t-test: $t_{18} = 2.04$, $P = 0.056$; pygmy filefish t-test: $t_{18} = 2.24$, $P < 0.05$) and September 2009 (rock sea bass t-test: $t_{18} = 2.81$, $P < 0.05$; pygmy filefish t-test: $t_{18} = 2.23$, $P < 0.05$). Mean species richness was also higher on the 500 m treatment in August 2009 (t-test: $t_{18} = 2.37$, $P < 0.05$). Differences in reef fish community structure were detected using nonparametric multidimensional scaling based on Czekanowski's similarity index in all three surveys (ANOSIM $P < 0.05$). The larger reefs attracted larger fish (> 300 mm TL) of several species (e.g., red snapper, gag *Mycteroperca microlepis*, gray triggerfish *Balistes capriscus*, and greater amberjack *Seriola dumerili*). Subsequently, these larger fish probably reduced the recruitment of age-0 red snapper to the small reefs that were close (15 m) to these potential competitors or predators.

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Introduction

Many biological and physical processes can regulate reef fish abundance. Most fishes show type III survivorship, such that a large portion of the population die early in life. These typical high mortalities of early life history stages indicate that many fish populations may be limited during these early stages. For example, high mortality during the larval stage may cause recruitment limitation of adult abundance (Doherty 1982; Victor 1986; Doherty and Fowler 1994). Also, significant limits may occur at the post-settlement stage (Hixon and Carr 1997; Hixon and Jones 2005). For example, Jones (1990) observed that subsequent adult abundance of *Pomacentrus amboinensis* did not increase when recruitment was doubled from one to two recruits per m^2, and indicated that post-recruitment processes may regulate this population. Similarly, Shulman and Ogden (1987) concluded that benthic mortality had a greater effect on population size than a proportional change in settlement for French grunt *Haemulon flavolineatum*.

Predation can significantly influence reef fish post-settlement processes (Carr and Hixon 1995; Beets 1997; Webster 2002; Almany and Webster 2006). New recruits experience their highest rates of mortality within the first 10 days after settlement (Doherty and Sale 1985), and predators are a common source of mortality. For example, Steele and Forester (2002) found high rates of predation, with 92% of blackeye goby *Coryphopterus nicholsii* recruits preyed upon within 24 h of settlement. Similarly, Carr and Hixon (1995) found lower mortality rates in two species of reef fish stocked onto

patch reefs where resident piscivores had been removed. Beets (1997) observed higher recruitment of grunts *Haemulon* spp. on reefs where the predatory squirrelfish *Holocentrus adscensionis* had been removed. Webster (2002) reported higher recruitment and lower mortality for several species of damselfishes (Pomacentridae) on patch reefs where resident predators had been removed. Albins and Hixon (2008) added a single invasive lionfish *Pterois volitans* to patch reefs, and found an average reduction in reef fish recruitment of 79%. In a caging experiment, Heinlein et al. (2010) found a 74% reduction in recruitment, as well as reduced species richness in uncaged plots. Caley (1993) observed higher recruitment and higher species richness of non-predatory fishes on reefs where resident predators had been removed. Thus, high predation at settlement can affect reef fish recruitment, and may even create a bottleneck on reef fish populations.

Predation pressure can be experimentally reduced with the use of exclusion cages (Steele 1997; Steele and Forester 2002; Piko and Szedlmayer 2007), or by predator removal (Carr and Hixon 1995; Beets 1997; Beukers and Jones 1997). However, both of these experimental designs are affected by experimental artifacts. For example, predator removals often result in rapid recolonization of predators (Carr and Hixon 1995), and the addition of a cage can bias an experiment by adding structure to the surrounding habitat (Doherty and Sale 1985). An alternative to predator removal or caging designs is to manipulate predation pressure by placing patch reefs at different distances from a large reef.

Fish living on a reef can affect the environment immediately surrounding the reef. This has been documented with herbivorous fishes in areas where reefs are surrounded by

sea grass beds, and a grazing halo results from their feeding activity (Randal, 1965). Although not as apparent as grazing halos, carnivorous reef fishes have been found to create halos as well. For example, Galván et al. (2008) found a halo around reefs where squat lobsters *Munida gregaria* were completely excluded by predators, and the addition of predator exclusion cages inside the halo resulted in higher abundances of squat lobsters compared to partially caged and open plots. Also, Kurz (1995) found higher predation rates on sand dollars by gray triggerfish *Balistes capriscus* in areas adjacent to artificial reefs, as well as increasing densities of sand dollars as distance from the reef increased. If grazing and predation pressure is higher on plants and invertebrates in areas surrounding a reef, predation pressure is likely higher for small fishes as well. Thus, by isolating patch reefs, predation pressure may be reduced without many of the difficulties or experimental artifacts associated with removal or caging studies.

Previous studies have indicated that reef-fish recruit abundance and diversity on patch reefs increased with increasing distance from larger reefs (Shulman 1985; West et al. 1994; Steele 1997; Bellmaker et al. 2005). Sweatman and Robertson (1994) observed fewer predatory strikes on juvenile surgeonfish *Acanthurus* spp., in jars placed as little as 2 m from a reef than on jars placed at the reef edge. Shulman (1985) observed higher losses of juvenile grunts *Haemulon* spp., tethered at the reef edge than on grunts tethered 20 m from the reef edge, and indicated an increased encounter rate with predators at the reef edge. Thus, the increase in recruitment observed at farther distances from the reef was attributed to a reduction in predation pressure. However, many of the previous studies (Shulman 1985; Connell 1997; Steele 1997; Belmaker et al. 2005) did not examine reef fish recruitment more than 50 m from the larger reefs with larger resident

predators. In the present northern Gulf of Mexico reef system it is well documented that potential predators will forage at least 50 m from the reef (Szedlmayer and Schroepfer 2005; Topping and Szedlmayer In review). Thus, many of these previous studies that examined predation effects at little more than 50 m from the reef structure are not applicable to systems in the northern Gulf of Mexico, and questions remain concerning possible isolation refuge effects for northern Gulf of Mexico fishes.

Red snapper *Lutjanus campechanus* are abundant on reef structure in the northern Gulf of Mexico, and support an important commercial and recreational fishery (SEDAR7 2005). The red snapper stock in the northern Gulf of Mexico has been classified as overfished (Goodyear 1994; SEDAR7 2005; SEDAR 2009), resulting in severe restrictions on harvest. Proper management of red snapper requires an understanding of life history, and the processes that regulate abundance. Thus, identifying population bottlenecks will aid in managing the fishery.

Red snapper have an interesting life history. Although red snapper can live for over 50 years (Szedlmayer and Shipp 1994; Wilson and Nieland 2001; Nieland and Wilson 2003), they mature as early as age-2 (Woods et al., 2003). Spawning typically occurs between May and October, with a peak in spawning between June and August (Collins et al. 1996; Woods et al. 2003; White and Palmer 2004). Fertilized eggs are buoyant, and hatch in 24 to 27 h (Rabalais et al., 1980). The larvae spend around 26 d in the plankton before settling to benthic habitats (Szedlmayer and Conti 1999; Rooker et al. 2004). At settlement red snapper are approximately 18 mm standard length (Szedlmayer and Conti 1999; Rooker et al. 2004). New recruits reach their highest abundances between July and September (Szedlmayer and Conti 1999; Rooker et al. 2004). Red

snapper first settle to open habitat then move to more structured habitats in the fall of their first year (Szedlmayer and Lee 2004), but also may settle directly to reef structure (Szedlmayer In press). As red snapper grow, they seek out progressively larger structure, and by age-2 red snapper have recruited to higher relief structure such as gas platforms (Neiland and Wilson, 2003; Szedlmayer 2007; Gallaway et al. 2009).

Previous studies have indicated that predators or larger competitors can affect the abundance and distribution of age-0 red snapper. For example, in field caging experiments higher abundances of age-0 red snapper were shown on reefs when predators were excluded using cages, and in captivity age-0 red snapper spent more time associated with complex habitat when a predator, Gulf flounder *Paralichthys albigutta*, was present (Piko and Szedlmayer 2007). Bailey et al. (2001) found that age-0 red snapper were excluded from complex habitat when older red snapper were added to a tank. Based on the life history of red snapper and the potential effects of predators on reef fish recruitment, the proximity of larger artificial reefs with its associated reef fish community may affect new recruitment of juvenile red snapper to low relief nursery structures. This study examines this question of proximity of larger predators and their potential predation or competitive exclusion effects on recruitment of age-0 red snapper through the use of experimental artificial reefs.

Materials and Methods

This study site was 28 km south of Dauphin Island, Alabama in the northern Gulf of Mexico (Figure 1). This area is characterized by sand and mud substrate with only 3% of the sea floor comprised of natural reefs (Parker et al., 1983; Dufrene, 2005). Reefs were built within an artificial reef building zone. This reef zone contains many artificial reefs including natural gas platforms, liberty ships, concrete pyramids, and army tanks (Minton and Heath 1998). All reefs were placed at depths ranging from 18 to 23 m.

Large steel cages (1.2 x 2.4 x 2.4 m) were deployed on 2 April 2008 ($n = 10$) and 14 April 2009 ($n = 10$). These cages provided habitat for larger predatory fishes, compared to the smaller fishes typically observed on the smaller recruitment reefs. Small recruitment reefs (Figure 2) were built on 24 and 28 July 2008 ($n = 20$) and 9-10 July 2009 ($n = 20$). Each small reef consisted of a polyethylene plastic pallet (1.22 x 1.02 x 0.14 m), 10 concrete half blocks (41 x 20 x 10 cm), and a plastic crate (65 x 35 x 28 cm). Small reefs were assembled using 122 cm cable ties with a breaking strength of 79 kg. Four small floats (5.1 x 12.7 cm) were tied to the reef, one on each corner, and floated 1 m above the reef. One larger float (15.2 cm diameter) was tied in the center of the reef, also at a height of one meter. The floats added vertical structure to the reef, and facilitated reef relocations with sonar. The small reefs were anchored by attachment to a 1.2 m ground anchor with 1.3 cm diameter nylon rope. The total volume of the reef was 1.42 m³.

The small reefs provided habitat for age-0 red snapper and other small (mostly < 200 mm) reef fishes. One small reef was anchored 15 m from the large reef and one small reef was anchored 500 m from the large reef. Each replicate included one large reef and two small reefs, and all replicates were placed 1.7 km apart.

In 2008, all reefs were surveyed on 6 and 15 August 2008, but subsequently destroyed by hurricane Gustav in the first week of September. In 2009, reefs were surveyed on 4 and 6 August, and again on 9 and 10 September. A third survey was attempted on 19 November 2009, but was not completed due to high turbidity as well as damage to the reefs caused by tropical storm Ida.

During each survey two SCUBA divers visually identified, counted, and estimated size classes within 25 mm intervals, of all fishes on individual small reefs. Divers also estimated the size and abundance of common species inhabiting the large reefs. In 2009, divers also videotaped (Sony Hi8) and photographed (Nikon D200) each reef with its associated fishes. In the laboratory, photographs that showed the highest number of age-0 red snapper for a particular reef were selected for computer counting. Each fish in the photograph was identified to species and counted using Image-pro software. Any fish in the photograph that could not be accurately identified to species was counted and included in a category labeled unknown. Two screens were used to analyze the video. 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 was captured, the quality of the image decreased. The second screen allowed the counter to simultaneously view the fish in the captured frame for counting using Image-pro software and on the moving video for accurate identification.

Data analysis

All fish counts were converted to densities per m³. Red snapper age was estimated based on length. During the August surveys all red snapper less than the 115 mm TL size class were classified as age-0. In September, all red snapper less than the 141 mm TL size class were classified as age-0 (Szedlmayer and Lee 2004). All tomtate, *Haemulon aurolineatum*, < 89 mm TL size class were considered age-0. A few fast moving and large schooling species (blue runner *Caranx crysos*, round scad *Decapterus punctatus*, greater amberjack *Seriola dumerili*, and longspine porgy *Stenotomus caprinus*) were excluded from all reef comparisons due to difficulty in counting and their transient behavior.

Age-0 and age-1 red snapper densities obtained from the visual surveys were compared between treatments using a two-way analysis of variance (ANOVA). The mean densities of other common species were compared between treatments using a t-test. Differences in mean species richness were compared between treatments separately for each survey using a t-test. Pearson correlation coefficient was calculated for age-0 and age-1 red snapper densities on the 500 m treatments. A one-way ANOVA was used to compare age-0 red snapper densities across years for August surveys. Age-0 red snapper densities estimated from photograph and video counts were compared between treatments using a t-test. The three counting methods (diver, photograph, and video) of age-0 red snapper densities and mean species richness were compared using a one-way ANOVA. If significant differences were detected with ANOVA's, specific differences were shown using a Student-Newman-Keuls test.

Fish community patterns between reef types were also compared with non-metric multidimensional scaling (MDS; Szedlmayer & Able 1996; Lingo & Szedlmayer 2006; Redman and Szedlmayer 2009). Species abundance data were square-root transformed to reduce the weight of highly abundant species (Field et al., 1982). Czekanowski's similarity coefficients were calculated among all individual surveys of each reef and mapped as MDS ordination plots:

$$S_{jk} = 100 \left\{ 1 - \frac{\sum |y_{ij} - y_{ik}|}{\sum y_{ij} + y_{ik}} \right\}$$

where S_{jk} is the similarity between the jth and the kth reefs, y_{ij} is abundance of the ith species on the jth reef, and y_{ik} is the abundance of the ith species on the kth reef (Field et al. 1982; Yoshioka 2008). Circles describing the grouping between treatments were hand drawn onto MDS ordination plots. One-way analysis of similarities (ANOSIM) permutation tests were used to test for significant differences in the reef community (rather than individual species) between reef types for each survey (Clarke & Green 1988). All statistical tests were considered significant at $P \leq 0.05$.

Results

Red Snapper

In August 2008 and 2009, age-0 red snapper were significantly more abundant on the 500 m reefs compared to the 15 m reefs as shown by a significant interaction effect (2008 ANOVA: $F_{1, 36} = 19.54$, $P < 0.001$, Figure 3; 2009 ANOVA: $F_{1, 36} = 10.02$, $P = 0.003$, Figure 4). Similarly, in September 2009 age-0 red snapper were more abundant on the 500 m reefs compared to the 15 m reefs (ANOVA: $F_{1, 36} = 21.60$, $P < 0.001$, Figure 5). No significant differences were detected for age-1 red snapper abundances between reef types (August 2008 Figure 3; August 2009 Figure 4; September 2009 Figure 5). Comparisons of age-0 and age-1 red snapper abundance on the 500 m reefs showed a significant negative correlation in August 2008 ($r = -0.67$, $P = 0.03$), but significant correlations were not detected for the other two surveys (August 2009, $r = -0.59$, $P = 0.07$; September 2009, $r = -0.10$, $P = 0.78$). Overall age-0 red snapper abundance did not significantly differ between August 2008 (mean $\pm$ SD = 8.0 ± 11.8 m^{-3}) and August 2009 (mean $\pm$ SD = 11.8 ± 18.8 m^{-3}; ANOVA: $F_{1, 38} = 0.6$, $P = 0.44$).

Other Species

In August 2009, rock sea bass *Centropristis philadelphica* were marginally more abundant on the 500 m compared to the 15 m reefs (t-test: $t_{18} = 2.04$, $P = 0.056$), but by September 2009, they were significantly more abundant on the 500 m reefs (t-test: $t_{18} = 2.81$, $P = 0.012$, Figure 6). Pygmy filefish *Stephanolepis setifer* were significantly more

abundant on the 500 m compared to the 15 m reefs in both August and September 2009 (August t-test: $t_{18} = 2.24$, $P < 0.05$; September t-test: $t_{18} = 2.23$, $P < 0.05$; Figure 7). In contrast to most other species, in September 2009 age-0 tomtate were significantly more abundant on the 15 m reefs (mean $\pm$ SD = 172.1 $\pm$ 225.5 m^{-3}) compared to the 500 m reefs (mean $\pm$ SD = 2.8 $\pm$ 4.4 m^{-3}; t-test: $t_{18} = -2.37$, $P < 0.05$). Age-0 recruits (generally < 76 mm) of several other species, including vermilion snapper *Rhomboplites aurorubens*, lane snapper *Lutjanus synagris*, cubbyu *Pareques umbrosus*, cocoa damselfish *Pomacentrus variabilis*, snowy grouper *Epinephelus niveatus*, sand perch *Diplectrum formosum*, and wrasse *Halichoeres* spp., were observed on small reefs in 2009. However, no significant differences in mean abundances were detected between the 15 m and 500 m treatments ($P > 0.05$). In August 2009, mean species richness was significantly higher on the 500 m (mean $\pm$ SD = 4.2 $\pm$ 1.1 m^{-3}) compared to the 15 m reefs (mean $\pm$ SD = 2.7 $\pm$ 1.6 m^{-3}; t-test: $t_{18} = 2.37$, $P < 0.05$).

Large reefs

Predators capable of consuming newly settled reef fishes (TL > 200 mm) were observed on all of the large reefs. In addition to large fishes, in 2009 age-0 tomtate, vermilion snapper, and round scad were observed recruiting onto 6 of the 10 large reefs. Age-0 cocoa damselfish were also observed recruiting onto at least one of the large reefs, but due to the small size of this species it may have been missed during SCUBA visual surveys on other large reefs. No age-0 red snapper were observed on the large reefs in August 2008 or August 2009. However, fewer than 20 age-0 red snapper were observed on two large reefs in September 2009.

Multivariate Analysis

Based on Czekanowski's coefficient, significant differences were detected in reef fish communities between the two treatments in August 2008 (ANOSIM: $R = 0.342$, $P < 0.001$; Figure 8). There was also a significant difference in fish communities in August 2009 (ANOSIM: $R = 0.327$, $P < 0.001$; Figure 9). Fish communities were significantly different in September 2009 as well (ANOSIM: $R = 0.497$, $P < 0.001$; Figure 10).

Survey Methods

Similar to SCUBA diver visual surveys, Image-pro aided counts of age-0 red snapper from photographs showed significantly higher abundances on the 500 m compared to the 15 m reefs in both August 2009 (t-test: $t_{18} = 2.43$, $P < 0.05$) and September 2009 (t-test: $t_{18} = 5.36$, $P < 0.001$; Table 1). Video counts also showed significantly higher age-0 red snapper abundances on the 500 m compared to the 15 m reefs in August 2009 (t-test: $t_{16} = 3.33$, $P < 0.01$) and September 2009 (t-test: $t_{17} = 4.98$, $P < 0.001$; Table 1). Comparisons among the three methods showed significantly more age-0 red snapper from diver visual surveys, compared to video derived counts in September 2009 (ANOVA: $F_{2, 56} = 4.35$, $P < 0.05$; Figure 11). This same pattern was detected for species richness, with visual surveys showing significantly higher mean species richness, compared to photographs and video surveys in August 2009 (ANOVA: $F_{2, 55} = 21.91$, $P < 0.001$) and September 2009 (ANOVA: $F_{2, 56} = 27.27$, $P < 0.001$; Figure 12).

Discussion

There was a clear and consistent effect of distance between small reefs and large reefs that affected age-0 red snapper abundance on the smaller recruitment reefs. This study assumed that the 15 m treatment was well within the range of the predatory fishes living on the steel cage reefs, while the 500 m treatment was beyond the usual range of resident predators on the steel cage reefs. This assumption is supported by previous tracking studies of adult red snapper that located fish at distances of between 5 and 66 m from a reef continuously over 24 h periods (Szedlmayer and Schroepfer 2005; Topping and Szedlmayer In review). This assumption was also supported by diver observations of resident fishes on the large reef swimming over to the 15 m small reefs during visual surveys. In addition, although not quantified, when any age-0 red snapper were observed on the 15 m reefs, they tended to hide well within the holes and refuges of the reef structure, while observation on the 500 m showed age-0 red snapper moving freely above and around the reef structure.

Red Snapper

Age-0 red snapper were always more abundant on the 500 m treatment. In fact, no age-0 red snapper were observed on the 15 m treatment in August 2008, and only one age-0 red snapper was observed on the 15 m treatment in August 2009, this illustrates a strong effect on new recruits by the proximity to larger predators and competitors. These results agree with the conclusions of Shulman (1985), West et al. (1994), Steele (1997), and Bellmaker et al. (2005), who all found that predators reduced recruitment near larger

reefs. It was only in September 2009 that age-0 red snapper began to appear in low numbers on the 15 m treatment. This suggested that by this time the age-0 red snapper had grown beyond the gape size of smaller potential predators living on the steel cages, such as tomtate, pigfish *Orthopristis chrysoptera*, and age-1 red snapper, and the age-0 recruits were also probably more competent swimmers making them better able to evade larger predators, and aggression from other fishes (Gerking 1994).

It is apparent that age-0 red snapper have a strong affinity for structure and in the absence of predators or competitors, will settle directly onto low relief habitat. During this study tomtate, vermilion snapper, cubbyu, and cocoa damselfish were observed recruiting to the 15 m treatment, or directly onto the steel cage itself. So, the nearly complete exclusion of new recruits was only observed in red snapper.

Several mechanisms may be responsible for the pattern of reduced age-0 red snapper on the 15 m compared to the 500 m reefs. Age-0 red snapper may suffer predation mortality shortly after settlement by the predators inhabiting the larger steel cage. Direct observation of predation on recruits attempting to settle onto the near reefs is difficult to obtain. However, Bellmaker et al. (2005) moved patch reefs that had previously been located away from a continuous reef closer to a continuous reef with a resident fish community. This resulted in an aggregation of predators, and numerous predatory strikes were observed and suggested that predators were consuming many of the recruits that had attempted to settle onto the near reefs. Another possibility is that older conspecifics are driving off any new recruits that attempt to settle onto the 15 m treatment. This behavior was observed in the laboratory study conducted on red snapper by Bailey et al. (2001). It is also possible that new recruits may be able to detect

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predators or conspecifics on the steel cage reefs, and simply choose to settle elsewhere. Sweatman (1988) found evidence that reef fish recruits may use chemical cues to preferentially choose settlement sites based on the presence or absence of conspecifics or competitors. Ultimately all three mechanisms are probably operating, but it is difficult to partition these factors in the present study.

Nearly 45% of the variation in age-0 red snapper abundance on the 500 m reefs in August 2008 was negatively correlated to the abundance of age-1 red snapper. A similar negative pattern was apparent in August 2009, but was not significant. In September 2009 no density patterns between age-0 and age-1 were apparent, probably because age-0 fish had grown to larger sizes. Sale (1976) also found enhanced recruitment of *Pomacentrus wardi* on reefs where adult conspecifics had been removed. If conspecifics are responsible for the exclusion of age-0 red snapper, this may be an example of density dependence. Other studies have found evidence of density dependence in reef fishes. For example, Forrester (1995) found that adult *Coryphopterus glaucofraenum* caused a density dependent reduction in the recruitment of juveniles. Stimson (1990) also found an inverse relationship between adult density and subsequent recruitment in *Chaetodon miliaris*. Tupper and Boutilier (1995) found that older conspecifics reduced survival of cunner *Tautogolabrus adspersus*, with no new recruits surviving on reefs with the highest densities of conspecifics. In the present study it is difficult to conclude that older conspecifics were causing density dependant recruitment in red snapper, because of the large number of other predators on the larger cage reefs. Either way, predator free nursery structures may be a limiting resource for age-0 red snapper.

Other Species

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Rock sea bass and pygmy filefish were significantly more abundant on the 500 m treatment. However, most of the individuals observed in this study were not new recruits, but neither species grow to large sizes, e.g., in this study the largest rock sea bass = 13 cm and pygmy filefish = 12 cm. Thus, not only juvenile fishes but adults of smaller reef fishes may also benefit from the reduced predation or competition in habitats located outside of the influence of larger reefs.

Age-0 tomtate showed the opposite pattern as red snapper, with higher abundances on the 15 m treatment. Divers observed tomtate recruits on the large reefs, sometimes more than 1,000, despite the presence of numerous predators. It appears that higher counts of tomtate on the 15 m reefs result from a preference to settle in the proximity of a large reef, and they simply spilled over from the larger reef to the 15 m smaller reef. In September 2009 when this pattern was detected, tomtate settled onto reefs at much higher densities than red snapper. These densities may be high enough to satiate predators and allow tomtate to survive despite heavy predation. These patterns may suggest a different survival strategy for tomtate compared to red snapper. Red snapper may actively select predator free habitat, while tomtate seek out reef habitat regardless of the presence of predators. Such differences in life history are known for other reef fishes. While some species such as *Pomacentrus amboinensis* settle directly onto adult habitats (McCormick and Makey 1997), others such as Nassau grouper *Epinephelus striatus* and gag *Mycteroperca microlepis* utilize nursery habitats before moving to larger reefs later in life (Eggleston 1995; Ross and Moser 1995). Under this scenario, the large reef and nearby small reef are easier to find than the isolated small reef, resulting in higher densities of tomtate on the 15 m reefs.

Higher abundances of tomtate on the 15 m reefs contradicts the results of Shulman (1985), Steele (1997), and Bellmaker et al. (2005) who all found increases in recruitment with increasing distance from a reef. This difference may result from a difference in scale. The above studies looked at fine scale differences, with the farthest reefs less than 50 m from the large reef, while the present study placed small reefs 500 m from the large reef. However all of these previous studies were conducted in different locations with different species, and tomtate in the northern Gulf of Mexico may simply be an exception to an otherwise common pattern.

In August 2009 mean species richness was higher on the 500 m reefs. Bellmaker et al. (2005) and Shulman (1985) also observed higher diversity on small reefs placed farther away from a large reef than on small reef placed closer to the large reef. Caley (1993) observed higher species richness in non-piscivorus reef fish recruits on reefs where resident predators had been removed. Again this pattern could be caused by avoidance of habitats with resident predators by recruits, or predators may be reducing species richness by occasionally eating members of rare species.

Survey Methods

All three survey techniques used in this study were able to detect significantly higher densities of age-0 red snapper on the 500 m treatment. On average the visual surveys gave the highest counts, photographs gave the next highest counts, and video tapes always gave the lowest abundances. Tessier et al. (2005) also obtained higher counts with visual surveys than with video techniques. Willis et al. (2000) obtained higher abundance estimates and higher precision with video surveys than with visual surveys. However, Willis et al. (2000) used an unmanned and baited video technique

rather than a diver operated video camera. This attracted fish from the surrounding area, and counteracted any avoidance response that the fish may have to divers. In any photograph or video survey, there will always be fish on the reef that are out of range and undetectable. However, as fish abundance increases, diver counts become more difficult. Thus, as a trade off, photographs can provide more precise counts for comparative purposes without the difficulty of counting swimming fish, but will be less accurate compared to diver visual counts of total reef fish abundance.

Visual surveys also showed higher mean species richness than photographs or video recordings. Tessier et al. (2005) also recorded higher numbers of species using visual surveys than with video techniques. The visual survey was also able to detect rare and cryptic species such as twospot cardinalfish *Apogon pseudomaculatus* and belted sandfish *Serranus subligarius* which were not detected in photographs or video counts. The visual survey was also the only method that was able to detect the single age-0 red snapper on the 15 m treatment in August 2009. In conclusion, visual surveys are needed for rare or cryptic species and measures of species richness, while photographs were more applicable for comparative measures of relative abundances.

Management Implications

The results of this study can be used to improve the construction and placement of artificial reefs. West et al. (1994) concluded that low relief artificial reefs would most benefit juvenile rockfish *Seabastes* spp., if they were built in areas without adjoining adult habitat. Likewise, this study indicate that if artificial reefs are built in order to provide habitat for juvenile red snapper, they should not be built in areas immediately adjacent to existing adult habitat. Also, artificial reefs meant to provide habitat for adult

fish should not be built within 500 m of important juvenile red snapper habitat, such as the relic shell beds identified by Szedlmayer and Conti (1999). However, the higher densities of age-0 tomtate observed on the 15 m treatment in this study indicates that this trend is not universal to all reef fishes, and different reef building strategies may be needed for other species.

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Table 1. Mean abundance of age-0 red snapper / m^3 from photographs and video recordings of juvenile recruitment reefs in 2009. Different letters indicate significant differences ($P < 0.05$).

| | | Treatment | |
| | | 15 m | 500 m |
Survey Method	Survey Month	Mean ± SD	Mean ± SD
Photographs	August	0.00 ± 0.00 a	12.04 ± 15.69 b
	September	6.76 ± 9.80 a	52.67 ± 25.24 b
Video Tape	August	0.00 ± 0.00 a	7.51 ± 6.77 b
	September	1.88 ± 3.05 a	21.06 ± 11.15 b
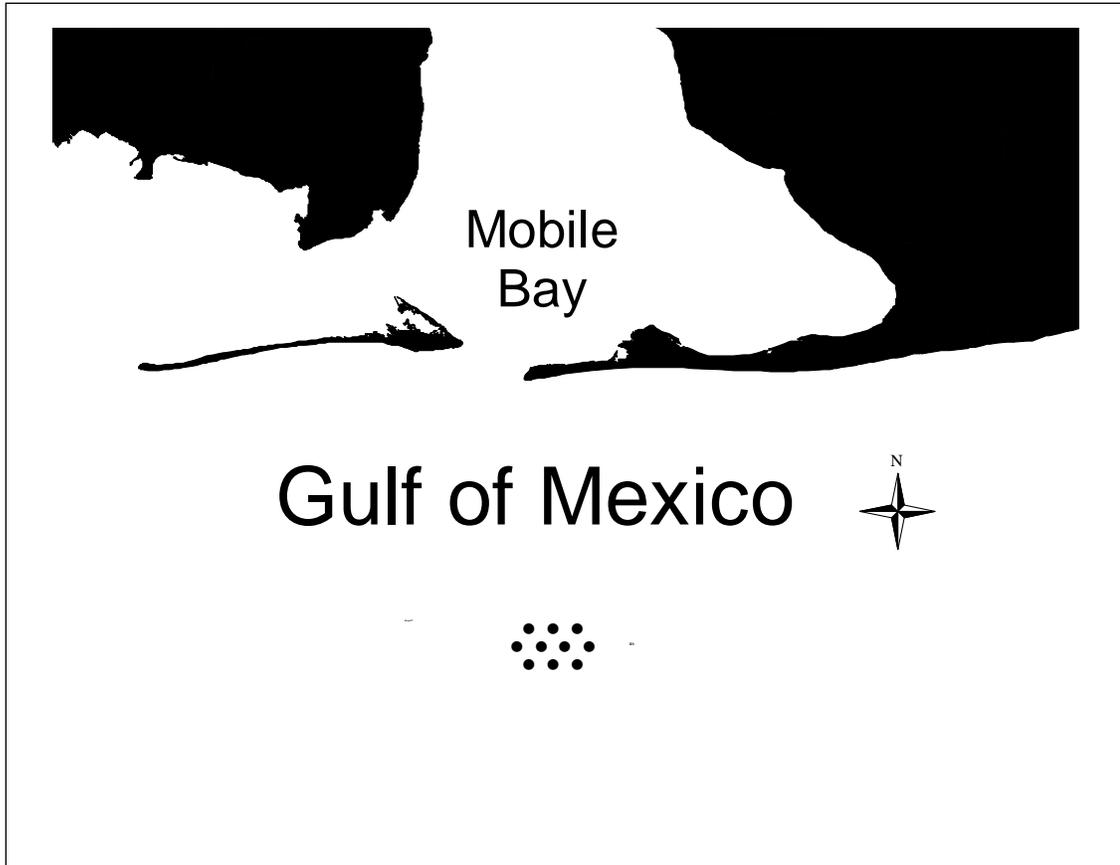
Figure 1. Map of the study site. Reefs were deployed approximately 28 km south of

Dauphin Island Alabama U.S.A., at depths of 18 to 23 m.
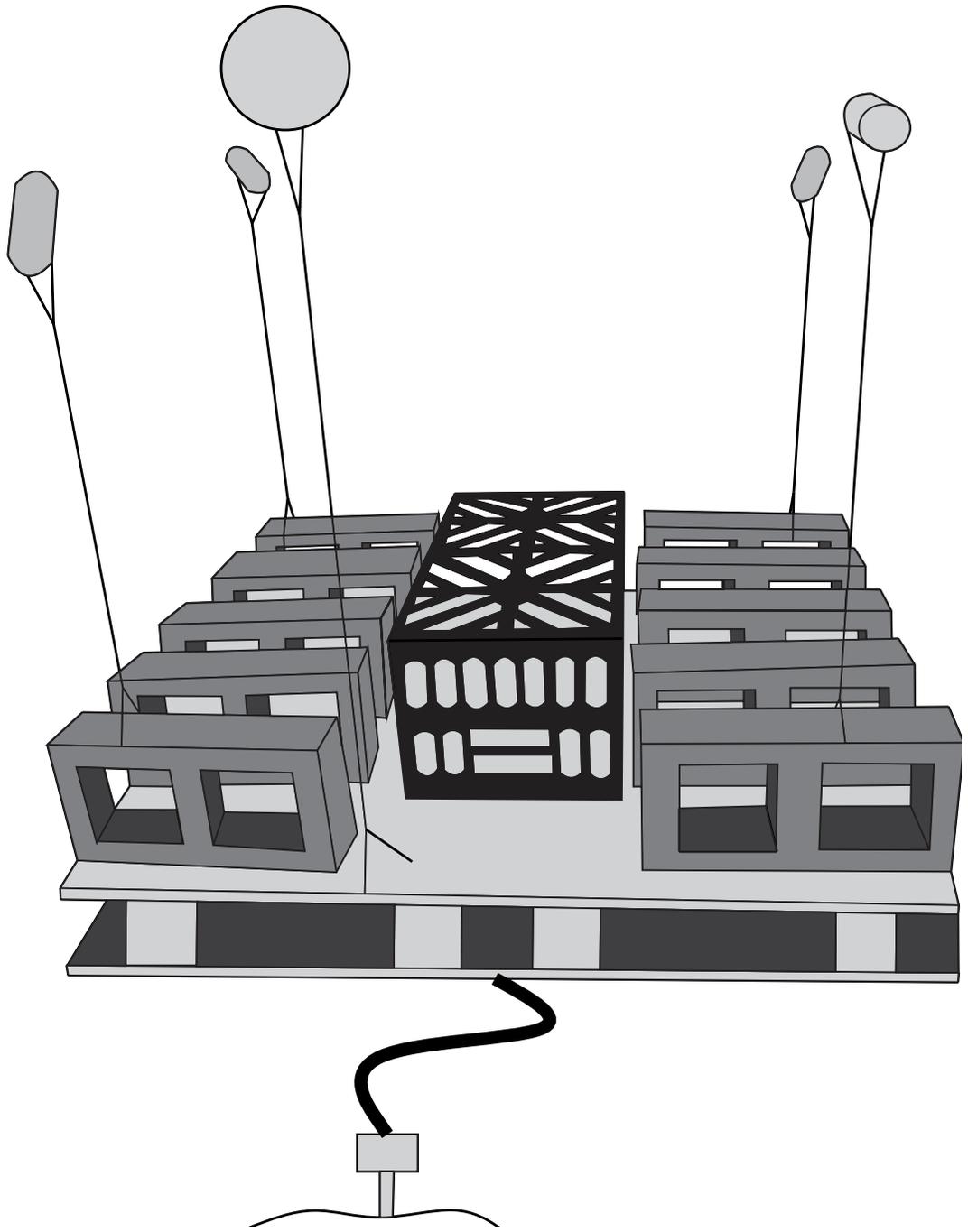
Figure 2. Design of the small juvenile recruitment reefs.
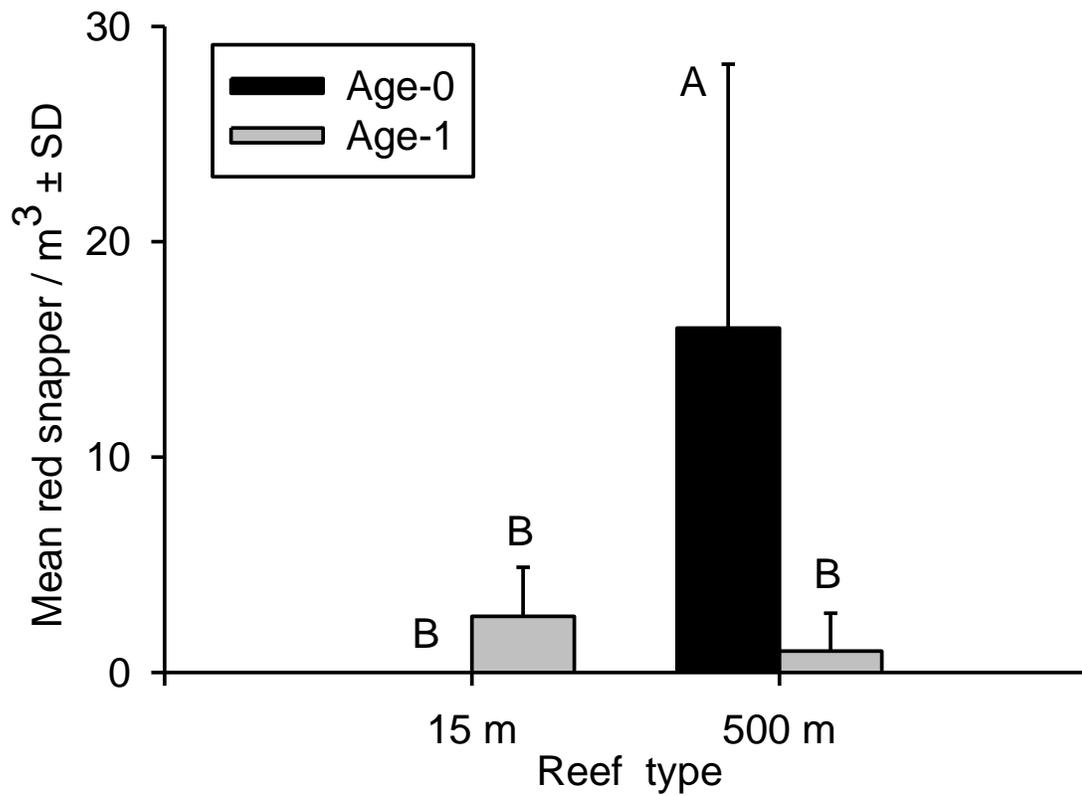
Figure 3. Mean red snapper abundance / m³ from visual SCUBA surveys of the juvenile recruitment reefs in August 2008. Different letters indicate significant differences ($P <$ 0.05).
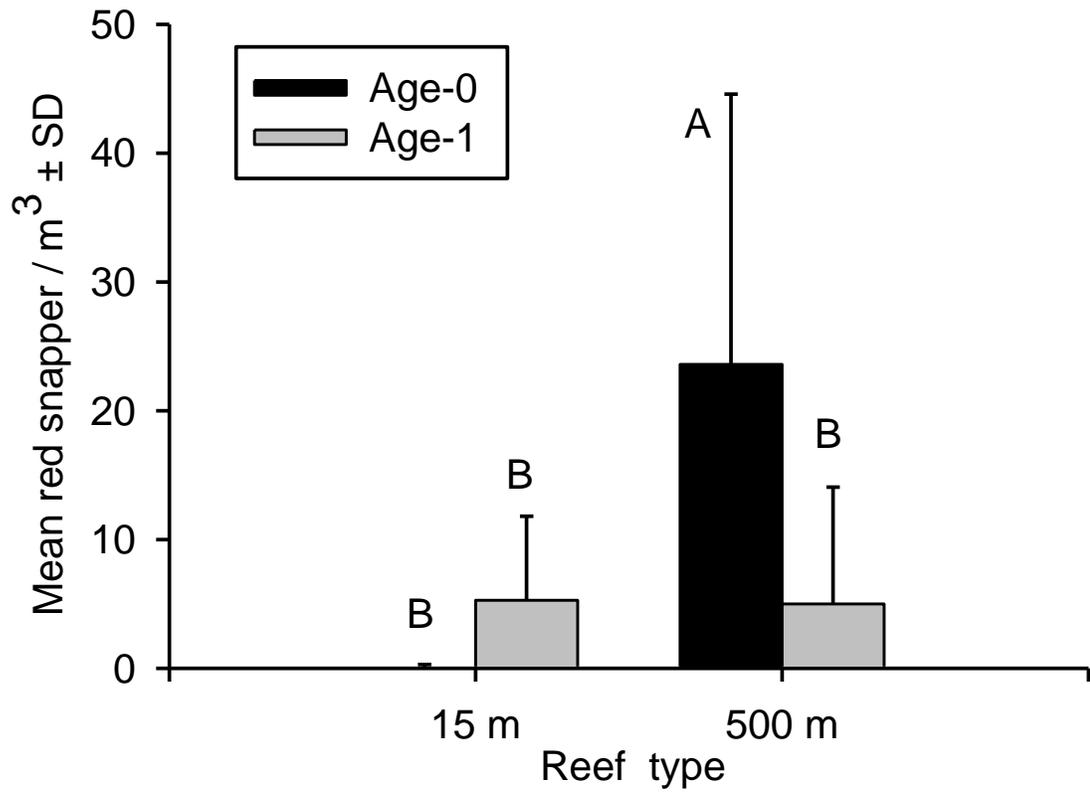
Figure 4. Mean red snapper abundance / m³ from visual SCUBA surveys of juvenile

recruitment reefs in August 2009. Different letters indicate significant differences
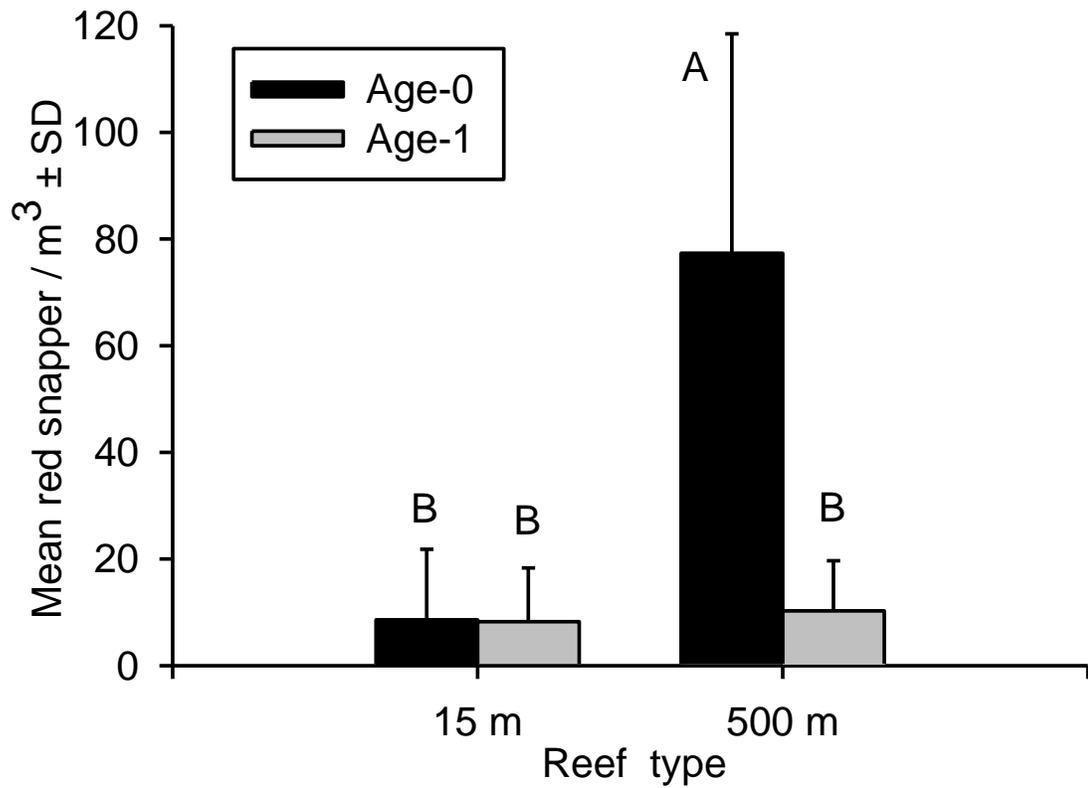
($P<0.05$).

Figure 5. Mean red snapper abundance / m³ from visual SCUBA surveys of juvenile

recruitment reefs in September 2009. Different letters indicate significant differences (P

< 0.05).
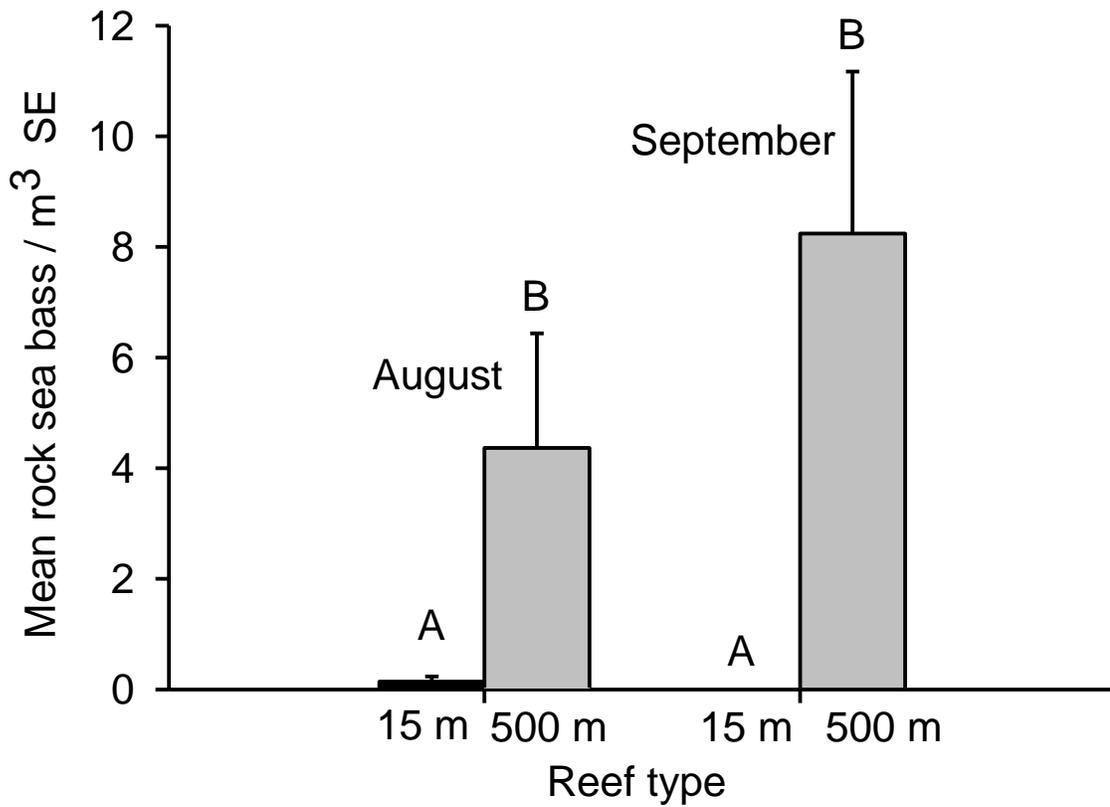
Figure 6. Mean rock sea bass abundance / m³ from visual SCUBA surveys of juvenile recruitment reefs in 2009. In August, different letters indicate marginally significant differences ($P = 0.056$). In September, different letters indicate significant differences ($P < 0.05$).
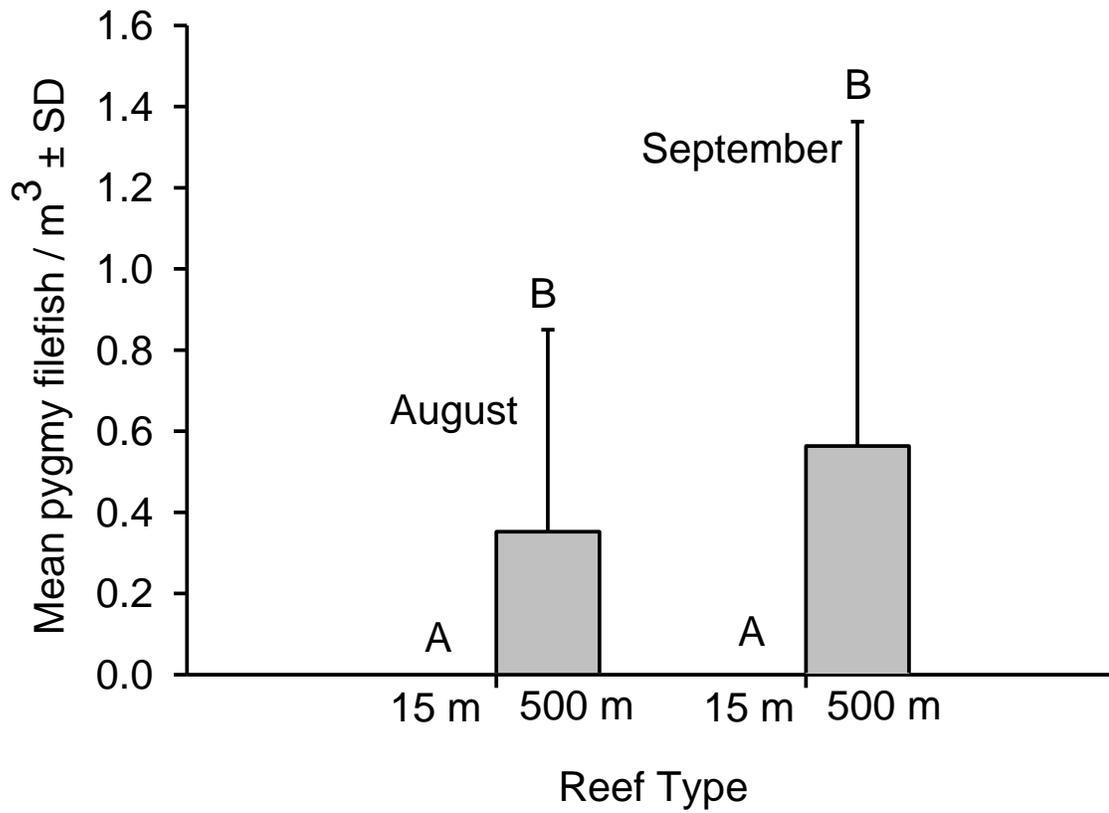
Figure 7. Mean pygmy filefish abundance / m³ from visual SCUBA surveys of the juvenile recruitment reefs in 2009. Different letters indicate significant differences within each survey month ($P < 0.05$).
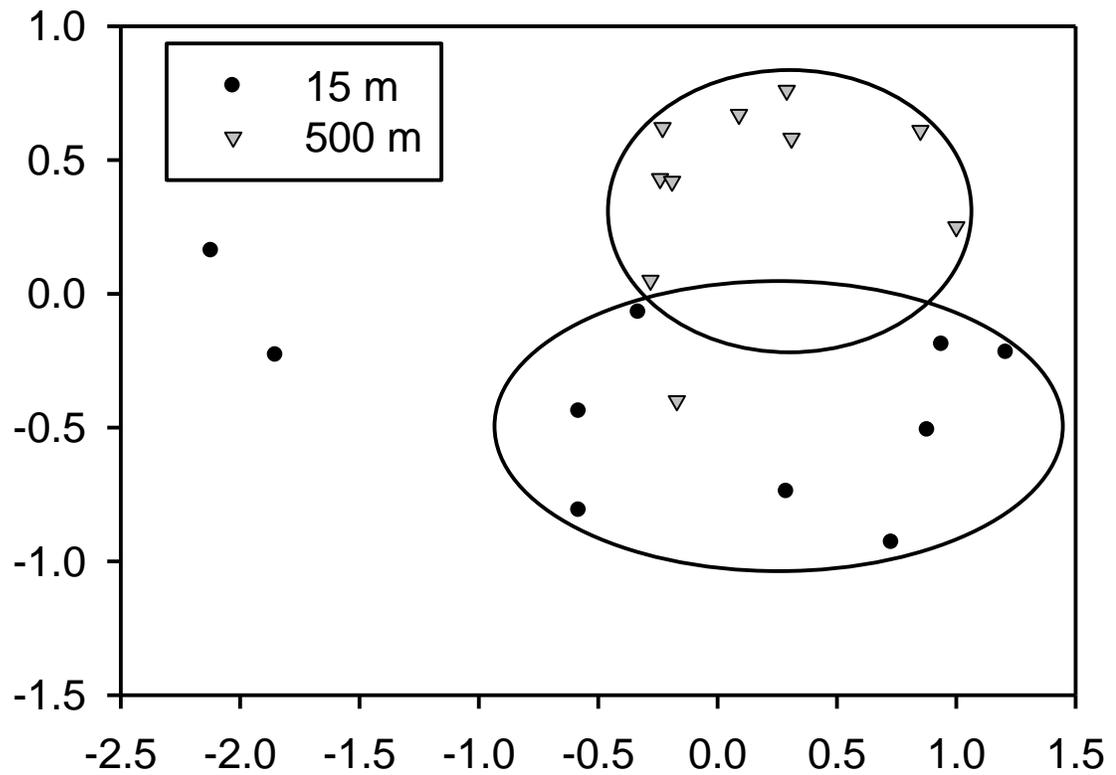
Figure 8. Multidimensional scaling plot of Czekanowski's similarity index showing differences in resident reef fish communities between treatments in August 2008. Axes are unitless.
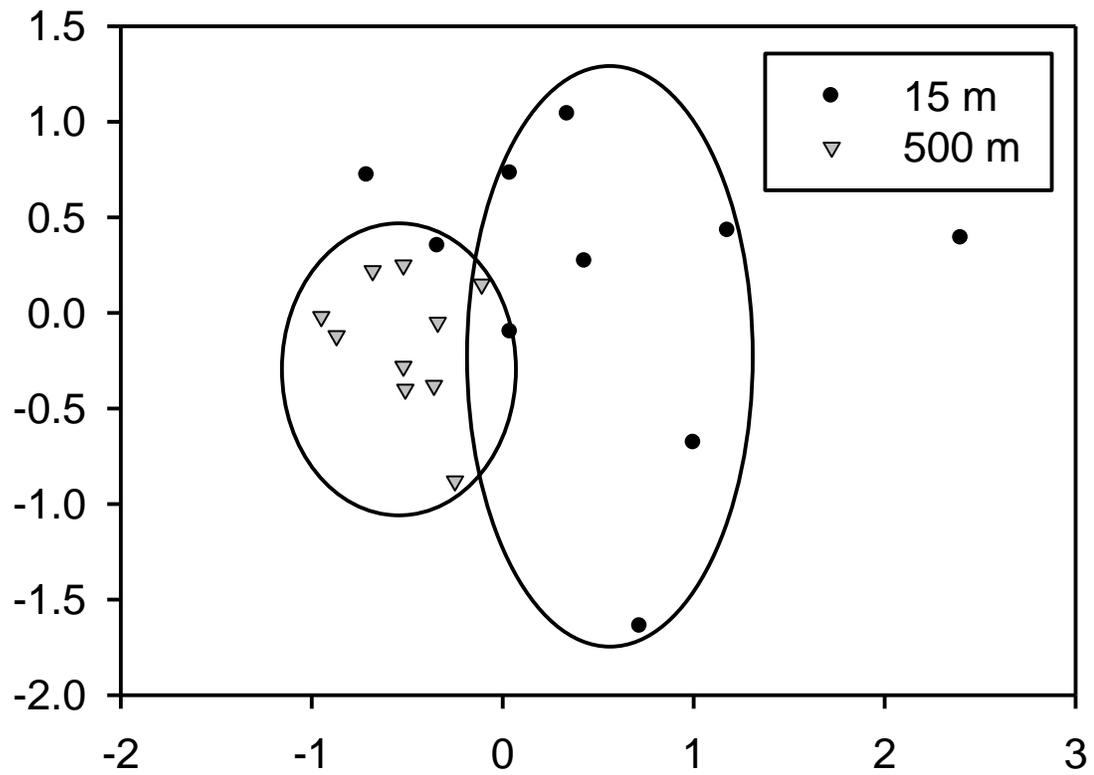
Figure 9. Multidimensional scaling plot of Czekanowski's similarity index showing

differences in resident reef fish communities between treatments in August 2009. Axes

are unitless.
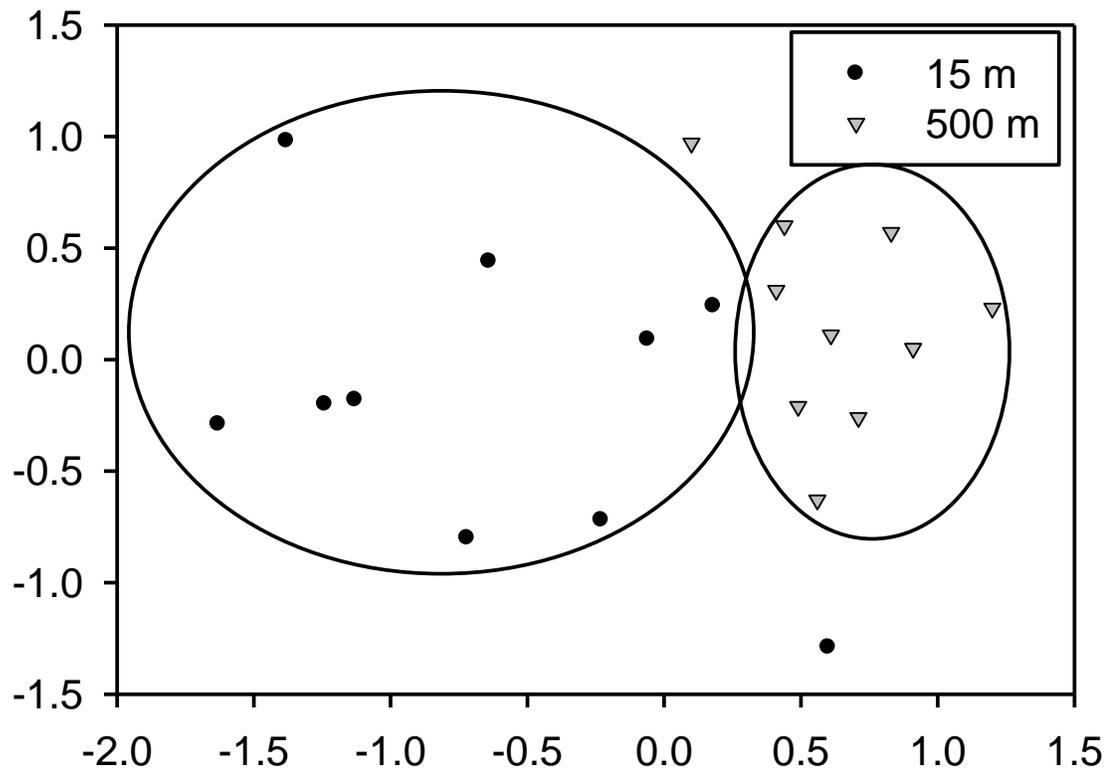
Figure 10. Multidimensional scaling plot of Czekanowski's similarity index showing

differences in resident reef fish communities between treatments in September 2009.

Axes are unitless.
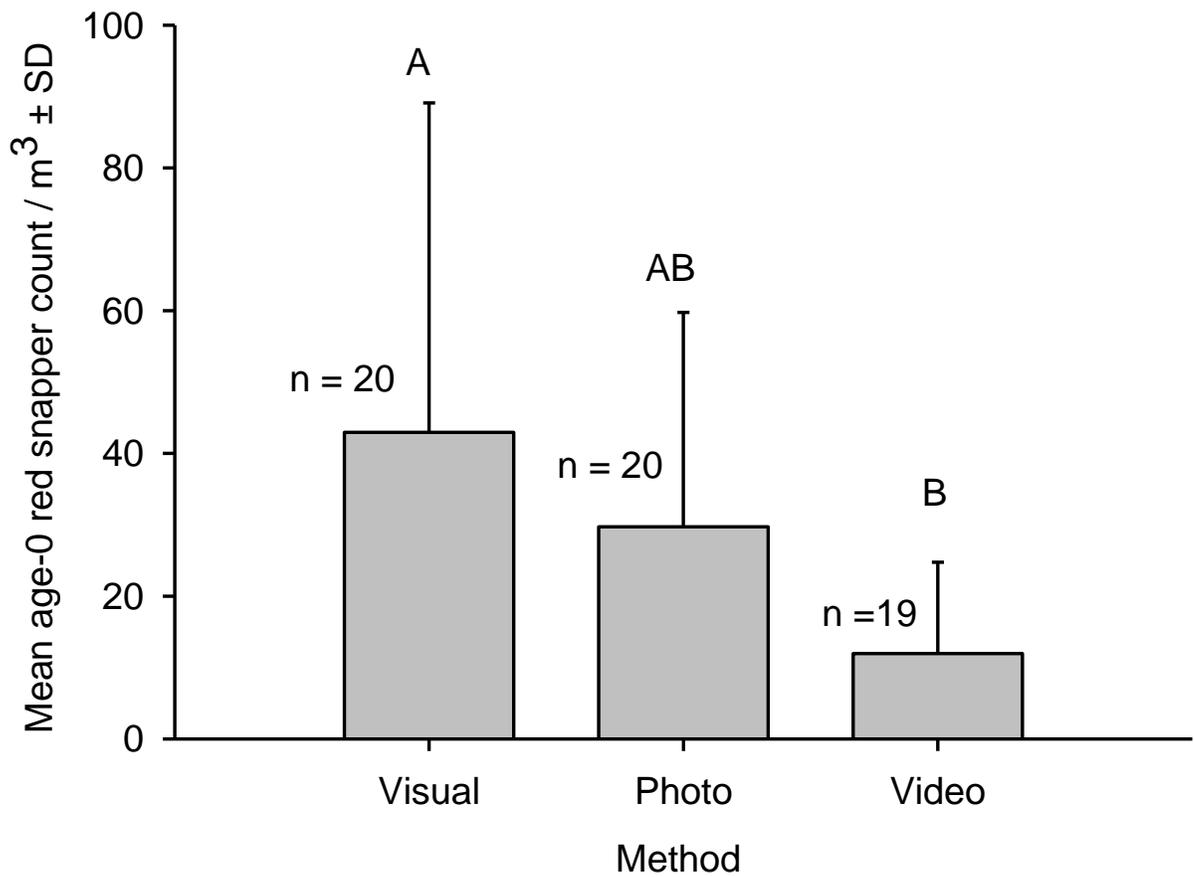
Figure 11. Comparison of mean age-0 red snapper abundance / m³ among each survey method in September 2009. Different letters indicate significant differences ($P < 0.05$).
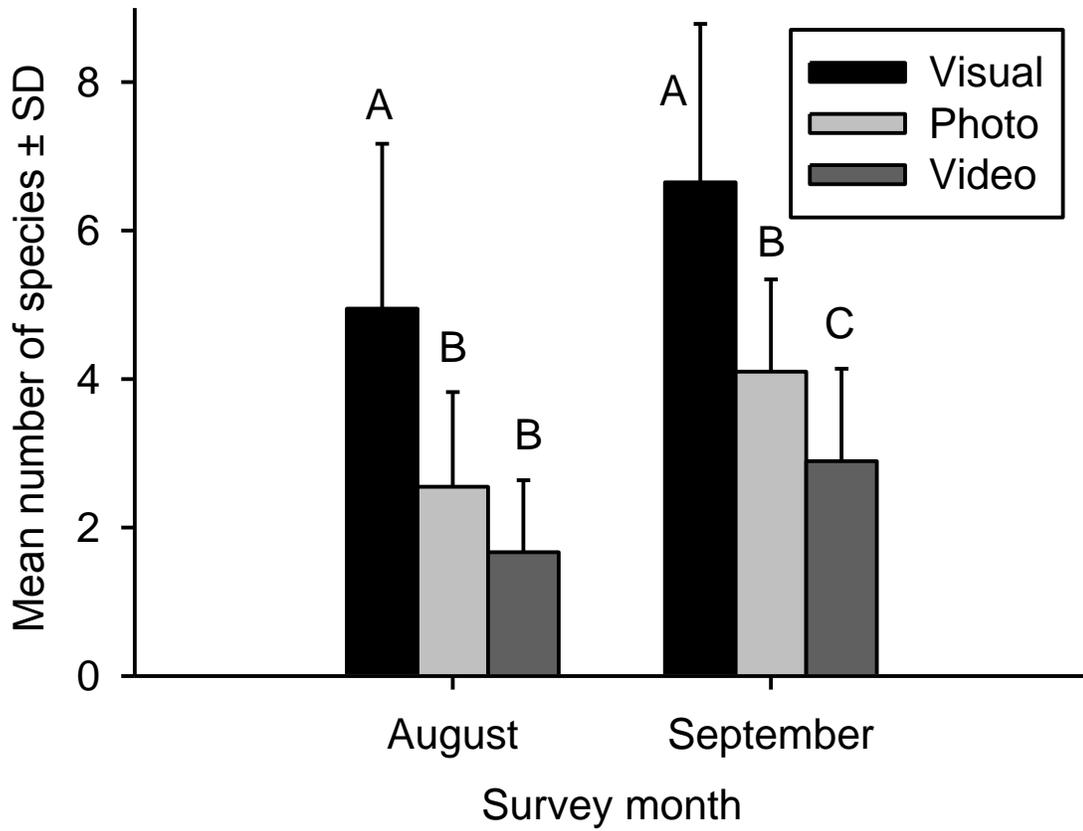
Figure 12. Comparison of mean species richness among each survey method in 2009.

Different letters indicate significant differences within each survey month ($P < 0.05$).