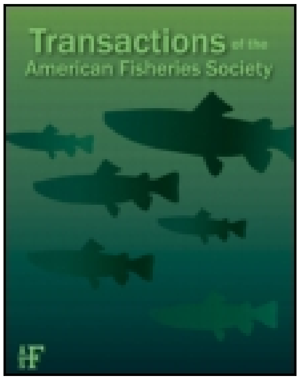

Transactions of the American Fisheries Society
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/utaf20

Evaluating the Performance of Vertical Longlines to Survey Reef Fish Populations in the Northern Gulf of Mexico

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Version of record first published: 01 Oct 2012.

To cite this article: Kevan C. Gregalis, Lela S. Schlenker, J. Marcus Drymon, John F. Mareska & Sean P. Powers (2012): Evaluating the Performance of Vertical Longlines to Survey Reef Fish Populations in the Northern Gulf of Mexico, Transactions of the American Fisheries Society, 141:6, 1453-1464

To link to this article: http://dx.doi.org/10.1080/00028487.2012.703154

Transactions of the American Fisheries Society 141:1453–1464, 2012

ISSN: 0002-8487 print / 1548-8659 online
DOI: 10.1080/00028487.2012.703154

ARTICLE

Evaluating the Performance of Vertical Longlines to Survey Reef Fish Populations in the Northern Gulf of Mexico

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Abstract
A common critique of many stock assessments is the lack of fishery-independent abundance indices and age composition data. Such data streams are essential in evaluating population trajectories that are derived largely from harvest and age composition of landings. For example, high scientific uncertainty in the most recent stock assessment of Gulf of Mexico red snapper *Lutjanus campechanus* resulted from a conflict between trends in fishery-dependent and fishery-independent data. Because sample sizes for the latter data were an order of magnitude lower, resolution of the conflicting trends was even more problematic. Recognizing the need for cost-effective expansion of fishery-independent data in the region, we evaluated the performance of vertical longline surveys for sampling reef fish within a large artificial reef zone in the northern Gulf of Mexico. Specifically, we (1) determined species composition and the length frequency of red snapper (the dominant species captured) as a function of hook size and bait type within our survey area during 2010; (2) evaluated the effect of different soak times on catch for various hook types (a combination of hook size and bait type); and (3) utilized our results to test the effect of artificial reef type on red snapper CPUE and mean size. During March–November 2010, we conducted 532 vertical longline sets, capturing 1,217 red snapper that ranged from 184 to 827 mm FL. Mean FL of red snapper differed among hook sizes, with 3/0 and 8/0 hooks sampling smaller fish than 11/0 hooks. Soak time trials revealed a significant effect of soak time on CPUE, with peak catch rates observed at 5 min. As habitat area increased, the mean size and CPUE of red snapper increased. We conclude that our vertical longline is an effective gear for sampling red snapper, and we recommend protocols to maximize its utility and standardize its use.

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Received October 11, 2011; accepted June 5, 2012

A routine but often ignored recommendation from assessments of many fisheries species is the call for expanded fishery-independent data collection. The inherent differences between fishery-dependent and fishery-independent data can be beneficial in developing stock assessments for exploited species. Fishery-dependent data are essential in quantifying harvest and discards, estimating effort, understanding fisher behavior, and calculating abundance indices. However, because fishers typically sample populations of the target species where fish are most abundant (or are perceived to be most abundant) and within the size range that is most desirable (Rotherham et al. 2007), these data are inherently biased. Although many of these biases can be estimated (e.g., selectivity of fleets), efforts to effectively model fisheries populations have increasingly relied on fishery-independent surveys to provide unbiased, population-level data. Additionally, fishery-independent sampling regimes can provide recruitment indices and wider ecological information about species and sizes that are not normally retained during commercial or recreational fishing (Rotherham et al. 2007).

For many reef fish species, fishery-independent abundance indices are of significant value for stock assessments. Such surveys not only provide data to establish abundance indices but also contribute to a fishery-independent assessment of age composition. This latter element is particularly important for longer-lived species whose exploitation may be largely restricted to limited age-classes. The outcomes of stock assessments are often weighted heavily by age composition data derived from fishery landings—samples that are easier to acquire than those from fishery-independent sources. For example, the most recent update of the red snapper *Lutjanus campechanus* stock assessment (SEDAR 2009) had effective sample sizes of less than 1,000 fish/year for age composition from commercial fisheries and only 10–50 fish/year for fishery-independent indices. Age composition from the commercial fishery revealed heavy exploitation of 3–5-year-old red snapper, resulting in high fishing mortality. The rapid decrease in abundance of age-5 and older red snapper (maximum life span $\sim$ 50 years) may in fact be caused by heavy exploitation (Cowan 2011); however, the pattern could also be caused by behavior of commercial fishers targeting smaller fish or by commercial gear selectivity. Recently, camera surveys conducted in the Gulf of Mexico by the National Marine Fisheries Service have begun to include vertical longline sampling, but these surveys are restricted to natural reefs. For long-lived species in which length is often a poor indication of age, fishery-independent surveys that can be used to establish both an index of abundance and a direct estimate of age composition via collection of hard parts may be the most useful.

Data from fishery-independent surveys can best be used when accompanied with measures of gear performance and assessments of survey variables. In instances when survey variables have been examined, catch characteristics have been demonstrated to differ as a function of gear type (Wells et al. 2008), hook size (Ralston 1982, 1990), soak time (Løkkeborg and Pina 1997; Ward et al. 2004), and bait type (Alós et al. 2009). In 2010, we began a random stratified vertical longline survey to assess the population status of reef fishes in the northern Gulf of Mexico. During this first year of the survey, several changes were made to optimize gear configuration prior to the establishment of a long-term monitoring program. We focused our analysis on red snapper due to the economic and social importance of the red snapper fishery. Given the need for (1) increased fishery-independent indices of abundance and (2) hard parts for fishery-independent age assessment, the objectives of this study were to describe species composition (via comparison with video surveys) and the length frequency of red snapper captured on hook sizes and bait types commonly used in the vertical longline commercial fishery; to test the effect of soak time on common gear configurations; and to utilize our survey to evaluate the effect of habitat on red snapper abundance in the northern Gulf of Mexico.

METHODS

Our study consisted of two distinct components: (1) use of vertical longline gear to conduct a broad-scale survey of reef fish populations in the Alabama Artificial Reef Zone (AARZ) and (2) soak time trials of the vertical longline gear to determine an appropriate set time. Although the survey was designed to be the basis for a long-term fishery-independent monitoring program in the region, the survey also allowed us to evaluate the gear's performance by comparing species composition and length frequency between the vertical longline and video (via a remotely operated vehicle [ROV]) and by examining length frequency of fish caught on various hook types (hook type = a combination of hook size and bait type) in comparison with video-derived estimates. Because our broad-scale survey used a standardized time, we evaluated the effect of soak time as a separate component of the study.

Study area.—All sampling occurred during March–November 2010, thereby encompassing both the Deepwater Horizon explosion (April 20, 2010) and the red snapper recreational fishing season in the Gulf of Mexico (weekends from October 1 to November 21, 2010). Sampling took place in the AARZ, a large offshore area that encompasses most of the inner continental shelf off the coast of Alabama (Figure 1).

For the broad survey, the AARZ was divided into a grid with 2- × 2-km cells and was stratified into three depth zones: shallow, 18.3–36.6 m (60–120 ft); mid-depth, 36.6–54.9 m (120–180 ft); and deep, 54.9–91.4 m (180–300 ft). Sampling cells within the grid were selected to proportionally allocate effort to the total bottom area covered by each depth zone (50% of effort in the shallow zone, 33% in the mid-depth zone, and 17% in the deep zone). Before each of three vertical longline sampling periods commenced, grid cells were randomly selected ($n = 12$ cells/period; 36 total). When possible ($\sim$60% of the time), grid cells were surveyed with side-scan sonar and the structure within each cell was identified and enumerated. Bottom contacts were categorized as either qualifying structure (area > 4 m^2; vertical

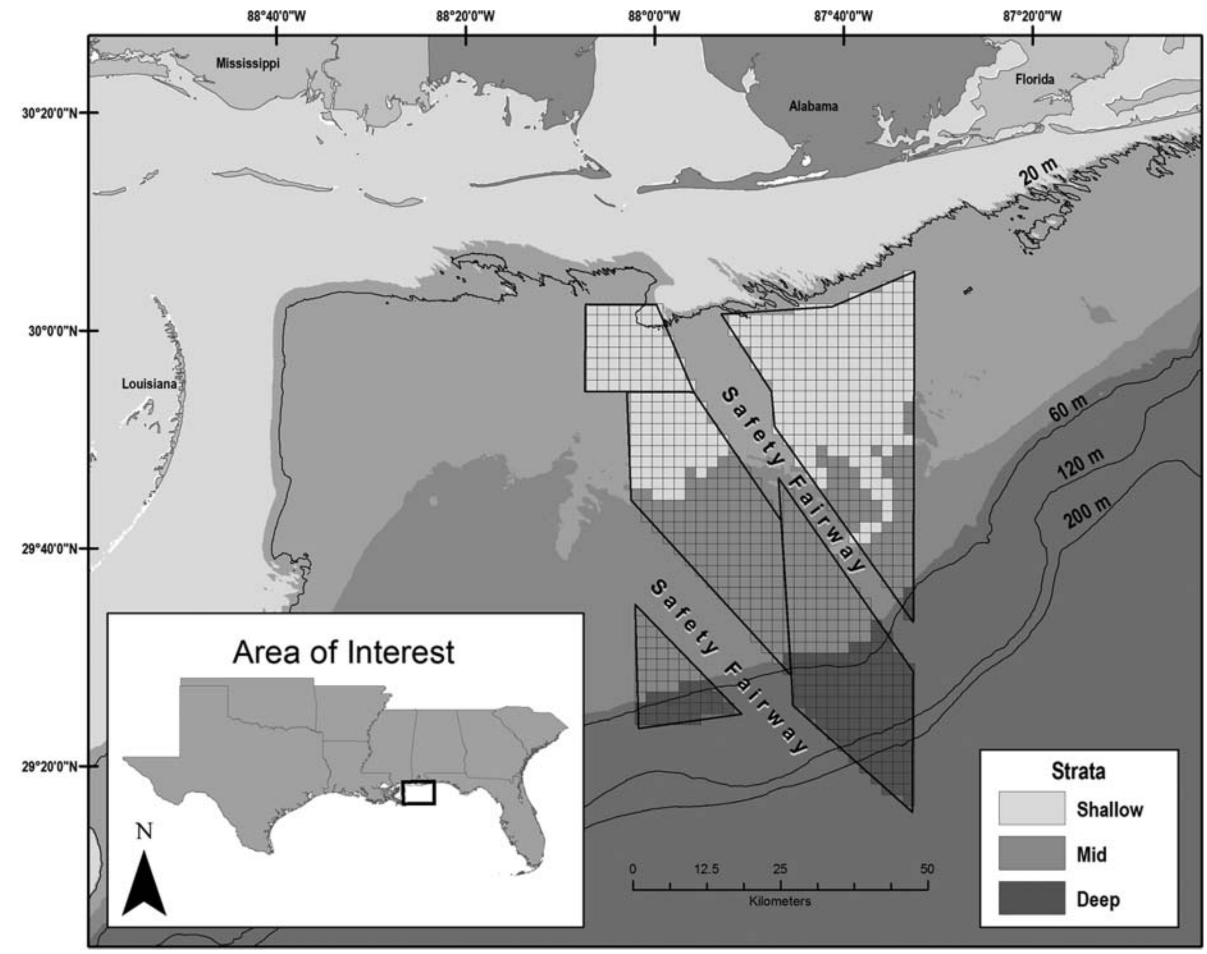

FIGURE 1. Map of the Alabama Artificial Reef Zone in the Gulf of Mexico, showing our vertical longline survey design. Shading within the grid indicates the three depth zones (see Methods).

relief > 0.5 m) or nonqualifying structure (area < 4 m^2; vertical relief < 0.5 m). After categorization, two qualifying structures were randomly selected from within each grid cell and designated for sampling ($n = 3$ replicates/site). Additionally, one area without structure was haphazardly selected per depth stratum ($n = 3$ areas/period). For grid cells that were not side-scanned, two artificial reefs within each cell were chosen at random from the pool of public artificial reef locations maintained by the Alabama Marine Resources Division, and the area without structure was located within the cell and confirmed by use of a vessel bottom sounder (i.e., fish finder).

Video observations.—Prior to deployment of the vertical longline gear, an ROV was haphazardly deployed at a subset of sample sites ($n = 15$) to record video that could be used to characterize the fish assemblage. Video was recorded using a SeaBotix five-thruster LBV300-5 ROV. This ROV was rated to 300 m and was equipped with two cameras: (1) a high-definition, 1,080-line color camera coupled with (2) a standard-definition, 520-line color camera. The ROV was also equipped with single-beam scanning sonar (Micron Sonar; Tritech International), which had a 100-m detection range and 360° viewing capabilities to locate target objects. The ROV was maneuvered 1–2 m from the bottom at a speed of approximately 0.25 m/s. The ROV umbilical cable (250 m) was attached to a 4.5-kg depression weight, which was used to reduce the umbilical cable's catenary. The terminus of the depression weight was maintained on the seafloor, followed by 20 m of unweighted umbilical cable. Fish measurements were estimated by using a pair of Digi-Key 2.5-mW red lasers that were aligned in parallel and separated by a distance of 3 cm as a frame of reference (Caimi and Tusting 1987). Video imagery from the ROV was recorded to a handheld high-definition recorder and was analyzed in the laboratory using ImagePro software. For each survey, fish that were recorded by the ROV were identified to the lowest possible taxon.

Vertical longline configuration.—Two gear configurations were used for this study. The first gear configuration was fished during March and April and consisted of a bandit reel, mainline, backbone, gangions, and a sash weight. We sampled by using two reels mounted to the gunnel amidships (one on the port

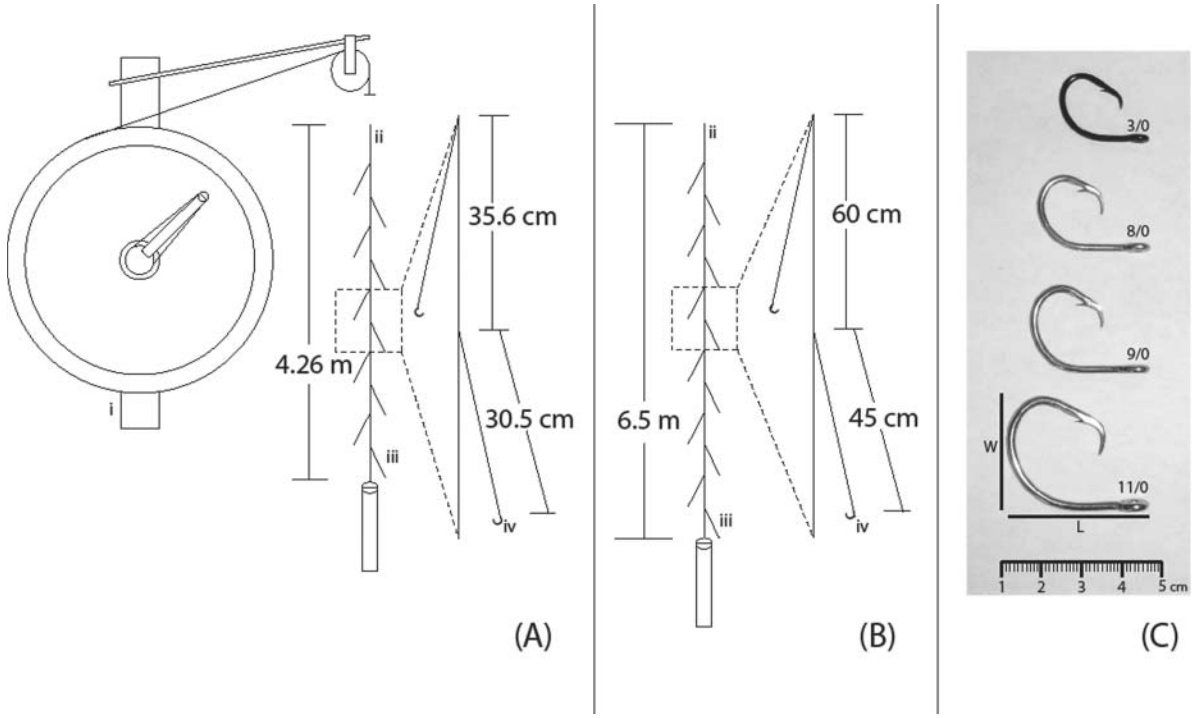

FIGURE 2. Gear configuration for vertical longlines used during **(A)** March–April 2010 and **(B)** May–November 2010; and **(C)** size range of hooks used in the current study (i = bandit reel; ii = backbone; iii = sash weight; and iv = gangion).

side and one on the starboard side). The mainline was 1.5-mm stainless cable (218-kg [480-lb] test; 152 m in length) mounted to an electric reel (1 m/revolution). The tag end of the cable had a 6/0 Rosco snap swivel crimped onto the end. The backbone was 4.26 m in length and consisted of 181-kg-test (400-lb-test) red monofilament, with ten 2.3-mm swivel sleeves that were crimped 35.6 cm apart. The top of the backbone had a crimped loop to attach the 6/0 Rosco snap swivel from the mainline, and a 2/0 Rosco snap swivel was crimped by a second loop at the bottom to attach a 4-kg sash weight. The crimps used at the top and bottom of the backbone were 2.3-mm double copper crimp sleeves. Five 9/0 circle hooks and five 11/0 circle hooks (Mustad Series 39960D) were fished during March and April. Gangions were made out of 45-kg-test (100-lb-test) clear monofilament with a hook (9/0 or 11/0) at one end and a 2/0 snap swivel at the other, each tied with a grouper knot; no crimps were used in gangion construction. Including the hook and the snap swivel, the gangions were 30.5 cm in length. A gangion was connected to the backbone by attaching the snap swivel to the swivel sleeve. In total, 10 gangions were connected to the backbone (Figure 2A).

To increase the number of hooks that were fished and the range of hook sizes, a second gear configuration was fished during May–November. Electric reels were foregone due to the simplicity of manual reels. The reels selected were manual hand-crank reels (1 m/revolution) mounted to the port and starboard gunnels as described above. Spooled onto the reel was a 152-m length of 181-kg-test (400-lb-test) clear monofilament with a 6/0 Rosco snap swivel crimped onto the tag end. All crimps used in gear construction (except the gangions) were 2.3-mm double copper crimp sleeves. The backbone was constructed from 136-kg-test (300-lb-test) red monofilament and measured 6.5 m in length. The top of the backbone had a crimped loop that was used to attach the 6/0 Rosco snap swivel to the mainline. Below the loop, 12 swivel sleeves were crimped every 60 cm, and a 2/0 Rosco snap swivel was crimped to a loop at the bottom to attach a 4-kg sash weight. Gangions were made by using a 4/0 Rosco snap swivel crimped to a section of 91-kg-test (200-lb-test) camouflage monofilament with a hook crimped to the end. The crimps that were used to attach the hook and the snap swivel were 1.9-mm mini double copper crimp sleeves. The total length of the gangion, including the snap swivel and hook, was 45 cm. Gangions were connected to the backbone by connecting the snap swivel to the swivel sleeve. Twelve gangions were attached to each backbone; four 3/0 circle hooks (Mustad Series 39950BL), four 8/0 circle hooks, and four 11/0 circle hooks (Mustad Series 39960D) were used for each drop (Figure 2B). In summary, across both studies the 8/0 and 9/0 hooks were chosen because they are the most commonly used hook sizes in the regional handline fishery, whereas the 3/0 and 11/0 hooks were selected as one size smaller and one size larger than the 8/0 and 9/0 hooks, respectively. The absolute size of all four hook sizes (3/0, 8/0, 9/0, and 11/0; Figure 2C) was calculated as the product of the length and width of the hook.

Vertical longline sampling.—After a 30-min period had elapsed from the end of the ROV flight (to allow fish to return to an undisturbed state), a backbone with affixed gangions was attached to each bandit reel and the hooks were baited with either Atlantic mackerel *Scomber scombrus* or squid *Loligo* spp. in an alternating manner. Bait size was standardized across all hook types. The mean weight of the bait pieces was 18.53 g (SD = 2.98) for Atlantic mackerel and 5.87 g (SD = 1.38) for squid. Gangion attachment points were numbered 1–10 (or 1–12), with number 1 starting at the sash weight end. Hook sizes were randomly assigned to the attachment points on the backbone. A third backbone with attached gangions was prepared in the same way and was placed on the deck for the third replicate. An equal number of randomly chosen hooks were baited with one of the two different bait types. A coin toss determined whether the first drop was on the port or starboard side, after which the backbone was lowered over the gunnel and dropped to the bottom to begin fishing.

After the soak, the gear was brought to the surface and the status of each hook was recorded (species caught, bait present, or bait absent). The backbone was detached from the mainline and brought to an area near the stern for data recording. All fish that were present were removed from their respective hooks starting at hook 1, and fish length (SL, FL, and stretch TL) and weight (kg) were recorded. Fish were placed on ice for further processing at the laboratory. The second reel fished backbone 2 just after backbone 1 was brought to the surface. Backbone 3 was baited and attached to the first reel so that it could be quickly dropped once backbone 2 was at the surface. Thus, each site was fished with three backbones, each soaked for 5 min, with a uniquely randomized order of hook sizes and bait types.

Age and growth.—Ages were determined for red snapper that were collected during the broad-scale portion of the vertical longline survey. Sagittal otoliths were removed and processed according to the methods described by VanderKooy and Guidon-Tisdel (2003). Each otolith was weighed to the nearest gram. Using a Hillquist thin-section saw, material from the left otolith was removed starting from the anterior side until the core was reached. The sectioned otolith was polished and mounted on a glass slide with Loctite 349 light-sensitive glue and was left to set overnight under an ultraviolet light. The otolith was then sectioned to approximately 0.50 mm. Each otolith section was polished and covered with a thin coat of liquid cover slip to smooth out any remaining scratches. Opaque zones (annuli) were counted from the core to the margin in the medial direction. The right otolith was used when the left otolith was not available or when there was a disagreement between otolith readers. Each otolith was aged independently by two readers, and the estimated ages were compared. If the readers' initial estimates did not agree, the readers jointly examined the otolith in question. If the resulting ages still differed, the otolith was read by a third reader. If the third reader's estimate did not agree with one of the initial readers' estimates, the otolith was excluded from analysis (Johnson et al. 2010).

Soak time trials.—In addition to the sampling performed during our broad-scale surveys, during June and November 2010 we conducted vertical longline sets in which we varied the soak time of the gear. For these trials, sites were haphazardly selected from the pool of public artificial reef locations that were maintained by the Alabama Marine Resources Division. During the June sampling trip, we used soak times of 1, 3, and 5 min fished at 12 sites ($n = 3$ replicates/site). During the November trials, we used soak times of 1, 3, 5, 7, and 10 min fished at 10 sites ($n = 3$ replicates/site). Soak times were equally and randomly allocated across sampling effort during both cruises.

Statistics.—Univariate statistics were used to (1) describe gear performance by hook type, (2) test the effect of habitat type on the catch rates and mean size of red snapper by using data collected in our broad-scale survey, and (3) test the effect of soak time on catch rates and mean size of red snapper from a portion of our data. All data were tested for normality and homogeneity of variance. For the complete set of data, red snapper lengths were separated into 50-mm size-bins and by age. For each hook size, two-sample Kolmogorov–Smirnov (KS) tests (Sokal and Rohlf 1995) were used to test for differences in red snapper size distribution as a function of bait type. If no difference was detected, the two bait types were pooled for each hook size (Erzini et al. 1998), and length frequency distributions were compared among hook sizes by using two-sample KS tests.

The vast majority of habitats sampled during the study were artificial structures due to (1) the high number of artificial structures deployed in the AARZ and (2) the fact that the natural bottom is further offshore (>70 m) and limited in bottom coverage. To illustrate the utility of our fishery-independent data collection, we examined the effect of structure type on the CPUE and mean size of red snapper. For this analysis, we chose the two most common structure types in the AARZ: prefabricated reef pyramids and military tanks. The majority of reef pyramids in the AARZ are either Florida limestone artificial reefs or Florida special artificial reefs. These structures are approximately 2.5 m tall with a 3-m triangular base and weigh approximately 2,500 kg. The military tanks are M60s with a hull approximately 7 m long and 3.5 m wide; the tanks stand 3.2 m high and weigh over 35,000 kg. We used a nested ANOVA to test for the effect of habitat type (reef pyramid, military tank, or no structure) on catch rates of red snapper, with hook type nested within the main effect. Hook type ($n = 6$ levels) incorporated the six unique combinations of hook size ($n = 3$ levels) and bait type ($n = 2$ levels) to account for the variability in catch rates among hook types without explicitly testing their interactive effects. For these tests, we used only the second gear configuration, and we restricted our analyses to the number of sites at which habitat fell within our three categories of no structure ($n = 20$ sites), reef pyramid ($n = 72$ sites), and military tank ($n = 27$ sites). A similar nested ANOVA was performed to test for the effect of habitat type on mean size of red snapper. Finally, we used a nested ANOVA to test for the effect of soak time on the CPUE and mean size of red snapper, and hook type

TABLE 1. Species composition of vertical longline samples by hook size. Species are listed in order of decreasing abundance.

Species	Hook size 3/0	8/0	9/0	11/0	Total
Red snapper *Lutjanus campechanus*	240	307	168	502	1,217
Gray triggerfish *Balistes capriscus*	36	27	6	17	86
Vermilion snapper *Rhomboplites aurorubens*	6	8	6	7	27
Sharksucker *Echeneis naucrates*	7	11	0	6	24
Tomtate *Haemulon aurolineatum*	1	0	2	4	7
Atlantic sharpnose shark *Rhizoprionodon terraenovae*	0	0	3	4	7
Red porgy *Pagrus pagrus*	3	1	0	1	5
Rock sea bass *Centropristis philadelphica*	0	1	3	1	5
Red drum *Sciaenops ocellatus*	0	0	2	3	5
Scamp *Mycteroperca phenax*	2	0	0	1	3
Almaco jack *Seriola rivoliana*	0	0	0	2	2
Red grouper *Epinephelus morio*	0	1	0	1	2
Warsaw grouper *Epinephelus nigritus*	0	0	1	1	2
Gag *Mycteroperca microlepis*	0	0	0	1	1
Cobia *Rachycentron canadum*	1	0	0	0	1
Hardhead catfish *Ariopsis felis*	0	0	0	1	1
Blackline tilefish *Caulolatilus cyanops*	1	0	0	0	1
Round scad *Decapterus punctatus*	0	0	1	0	1
Little tunny *Euthynnus alletteratus*	0	0	0	1	1
Silky shark *Carcharhinus falciformis*	0	0	0	1	1
Lane snapper *Lutjanus synagris*	0	0	0	1	1

was treated as a nested variable. This analysis was performed on 12 sets completed at 12 sites. Only sets with completely orthogonal hook type treatments were used. Post hoc comparisons were performed with Student-Newman-Keuls tests. All analyses employed an α of 0.05.

RESULTS

Catch Summary

Overall, 532 vertical longline sets were completed during March–November 2010 on the two different gear configurations. Vertical longline sampling yielded 1,217 red snapper along with 20 additional species (Table 1). Red snapper were the numerically dominant species, comprising 87% of the total catch. Gray triggerfish, vermilion snapper, and sharksuckers were caught less frequently, and all other species represented no more than 1% of the catch. Red snapper ranged in size from 184 to 827 mm FL, and mean monthly size varied from 385 mm FL (SE = 9.1) in June to 431 mm FL (SE = 7.7) in September. Mean monthly CPUE for red snapper ranged from 0.186 to 0.333 fish·hook^{-1}·5 min^{-1} (excluding data from soak time manipulations).

Species Composition

Species selectivity of the vertical longline was measured for a subset of ROV flights (n = 15) conducted between March and November 2010; over this period, 25 species were observed (Table 2). Species composition varied little among the 15 sites and consisted primarily of smaller, reef-associated fishes, such as the tomtate, rock sea bass, bank sea bass, gray snapper, and lane snapper. On average, 5.7 species (SE = 0.6) were seen on each ROV video, and red snapper were present on all 15 videos. In all 15 instances, red snapper were observed with the ROV and were captured by the vertical longline.

Length Frequency

The complete set of catch data and the data from the ROV lasers were examined for red snapper length frequency analysis. For hook data, length frequency varied as a function of hook size and bait type (Figure 3). For 3/0, 8/0, and 9/0 hooks, no differences were observed in length distribution as a function of bait, so data from the two bait types were combined for further analysis. Length distributions differed between 11/0 hooks baited with Atlantic mackerel and those baited with squid, so the two distributions were analyzed separately. Two-sample KS tests revealed that 3/0 hooks sampled a similar size distribution of red snapper as did 8/0 hooks and 11/0 hooks baited with squid. Similarly, both 8/0 and 9/0 hooks were indistinguishable from 11/0 hooks baited with squid. The 11/0 hooks baited with Atlantic mackerel sampled slightly larger fish than all other hook types, including 11/0 hooks baited with squid. Length frequency generated from the ROV lasers identified a distribution

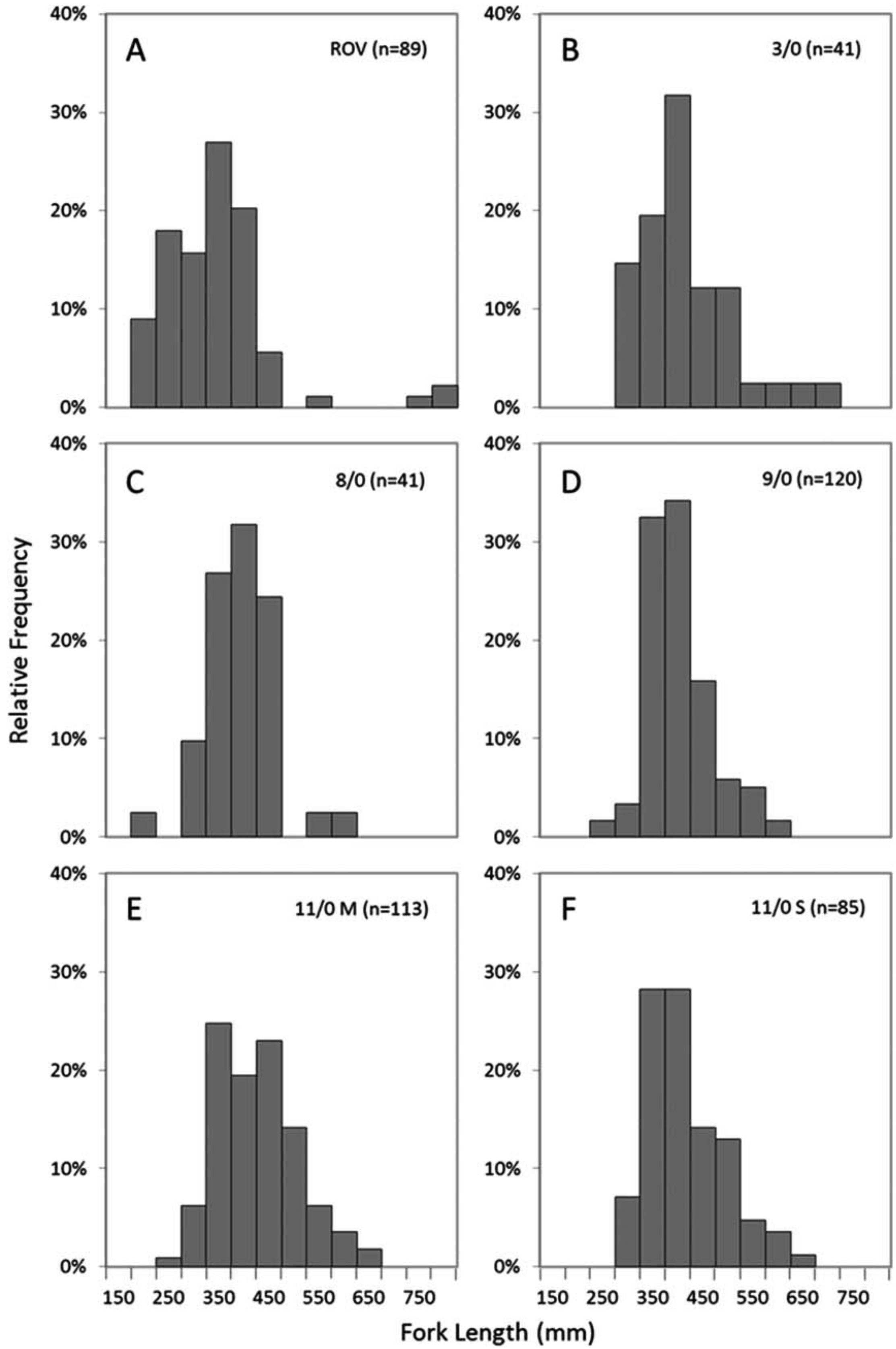

FIGURE 3. Length frequency of red snapper sampled by the **(A)** remotely operated vehicle (ROV), **(B)** 3/0 hooks, **(C)** 8/0 hooks, **(D)** 9/0 hooks, **(E)** 11/0 hooks baited with Atlantic mackerel (M), and **(F)** 11/0 hooks baited with squid (S; n = number of replicates).

TABLE 2. Species composition at 15 Gulf of Mexico sites compared between the remotely operated vehicle (ROV) and vertical longline gear (VLL). Species are listed in alphabetical order.

Species	ROV	VLL
Amberjacks *Seriola* spp.	X	
Angelfishes *Holacanthus* spp.	X	
Bank sea bass *Centropristis ocyurus*	X	
Bigeye *Priacanthus arenatus*	X	
Blackbar drum *Pareques iwamotoi*	X	
Blue runner *Caranx crysos*	X	
Cubbyu *Pareques umbrosus*	X	
Dwarf sand perch *Diplectrum bivittatum*	X	
Gag	X	
Gray snapper *Lutjanus griseus*	X	
Gray triggerfish	X	X
Groupers *Epinephelus* spp.	X	
High-hat *Pareques acuminatus*	X	
Jackknife-fish *Equetus lanceolatus*	X	
Little tunny		X
Lane snapper	X	
Red grouper	X	
Red porgy	X	X
Red snapper	X	X
Rock sea bass	X	X
Scamp	X	
Soapfishes *Rypticus* spp.	X	
Atlantic spadefish *Chaetodipterus faber*	X	
Tomtate	X	
Vermilion snapper	X	

that was distinct from those of all hook types (Table 3). Lasers from the ROV identified both the smallest and largest individuals and, hence, a larger range of red snapper than any hook type (Figure 3; Table 4). In addition, the mean size of red snapper measured via the ROV lasers was substantially smaller than the mean size of red snapper sampled on any of the hook types.

TABLE 3. Results (*P*-values) of pairwise Kolmogorov–Smirnov tests for differences in red snapper length frequency distribution between the remotely operated vehicle (ROV) and hook types on vertical longline gear (11/0 hooks were baited with Atlantic mackerel [M] or squid [S]; the two bait types were combined for all other hook sizes). Values in bold italics are significant (α = 0.05).

Gear	ROV	3/0 hook	8/0 hook	9/0 hook	11/0 hook M
3/0 hook	***<0.01***				
8/0 hook	***<0.01***	0.83			
9/0 hook	***<0.01***	***0.01***	***0.03***		
11/0 hook M	***<0.01***	***<0.01***	***<0.01***	***<0.01***	
11/0 hook S	***<0.01***	0.68	0.69	0.08	***<0.01***

Age and Growth

Ages were determined from 390 red snapper that were sampled during the broad-scale portion of our survey (March–November 2010). With the exception of a single 6-year-old fish, age ranged from 1 to 5 years. Fish of age 3 (n = 172) and age 4 (n = 143) made up greater than 80% of all fish aged. Across all five hook types (3/0, 8/0, 9/0, 11/0 baited with Atlantic mackerel, and 11/0 baited with squid), the median age of fish was 3 years; however, mean age increased from 3 years on 3/0 and 8/0 hooks to 3.4 years on 9/0 hooks, 11/0 hooks baited with Atlantic mackerel, and 11/0 hooks baited with squid (Table 4). The single age-6 fish was caught on the largest hook size (an 11/0 hook baited with squid).

Soak Time

Analysis of an orthogonal subset of data for which soak times were manipulated revealed that the number and mean size of sampled red snapper varied as a function of soak time. The CPUE was significantly higher during the 5-min soak than during the 1- and 10-min soaks (ANOVA: $F_{2,71} = 3.36$, P = 0.04). The CPUE of red snapper increased from 0.167 fish/hook at 3 min to 0.375 fish/hook at 5 min and then declined to 0.139 fish/hook at 10 min (Figure 4A). Mean size of red snapper varied as a function of soak time (ANOVA: $F_{2,32} = 6.26$, $P < 0.01$); mean size was 441 mm FL at 3 min, 361 mm FL at 5 min, and 472 mm FL at 10 min (Figure 4B). For both analyses (i.e., CPUE and mean size as the response variables), the nested variable of hook type was not significant.

Habitat Type

Analysis of the subset of data for which habitat type was classified (i.e., reef pyramid, military tank, or no structure) revealed that the number and size of red snapper varied as a function of habitat type. Red snapper CPUE was significantly higher at sites with structure than at sites without structure (ANOVA: $F_{1,133}$ = 10.138, $P < 0.01$). In addition, red snapper CPUE was higher at military tank structures (CPUE = 0.264 fish·hook^{-1}·5 min^{-1}) than at reef pyramids (CPUE = 0.222 fish·hook^{-1}·5 min^{-1}; $P < 0.01$; Figure 5A). Similarly, mean size of red snapper increased with increasing habitat size (Figure 5B). For both of the analyses (i.e., CPUE and mean fish size as the response variables), the nested variable, hook type, was not significant.

DISCUSSION

For fishery-independent catch data to be of greatest use, they should be accompanied by an understanding of the effects of variable gear settings. Our results demonstrate the utility of vertical longline gear for sampling two of the dominant reef fish species in the northern Gulf of Mexico—the red snapper and gray triggerfish. Performance of the gear was excellent in obtaining a large number of red snapper specimens for analysis of age composition and for eventually establishing long-term

TABLE 4. Descriptive statistics for size and age of red snapper sampled with the remotely operated vehicle (ROV) and vertical longline gear (min = minimum; max = maximum; 11/0 hooks were baited with Atlantic mackerel [M] or squid [S]; the two bait types were combined for all other hook sizes).

	FL (mm)						Age (years)					
Gear	*n*	Min	Max	Range	Median	Mean	*n*	Min	Max	Range	Median	Mean
ROV	89	163	785	622	323	321	89					
3/0 hook	41	253	662	409	378	394	40	1	5	4	3	3.0
8/0 hook	41	184	572	388	371	369	41	1	5	4	3	3.0
9/0 hook	120	240	572	332	365	379	117	2	5	3	3	3.4
11/0 hook M	113	238	624	386	393	402	109	2	5	3	3	3.4
11/0 hook S	85	268	609	341	372	391	83	1	6	5	3	3.4

abundance indices. Coupling the vertical longline survey with a synoptic video survey increases the utility of these data to stock assessors while concurrently providing a large data set of fishery-independent age composition.

The vertical longline is a gear type that is well suited for the capture of red snapper. The fishery-independent gear is similar to commercially used gear and offers several advantages in that it (1) can further our understanding of gear selectivity in the

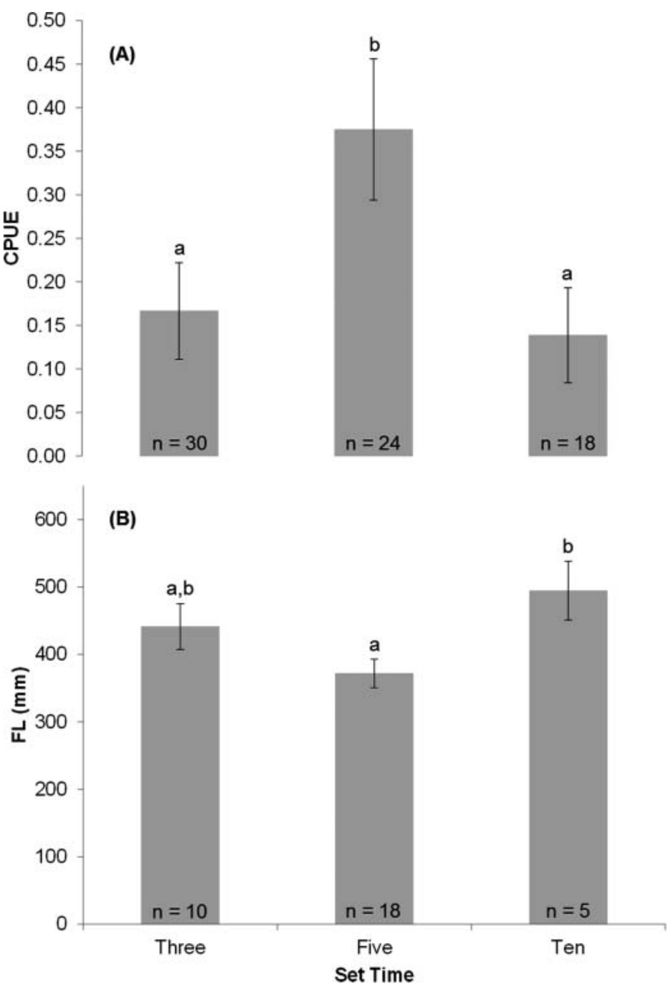

FIGURE 4. (**A**) Mean (±SE) red snapper CPUE (fish/hook) as a function of soak time (3, 5, or 10 min) and (**B**) mean (±SE) red snapper FL as a function of soak time (*n* = number of replicates). Comparisons between soak times were made using a Student–Newman–Keuls post hoc test. Within a given panel, values with different letters are significantly different ($\alpha = 0.05$).

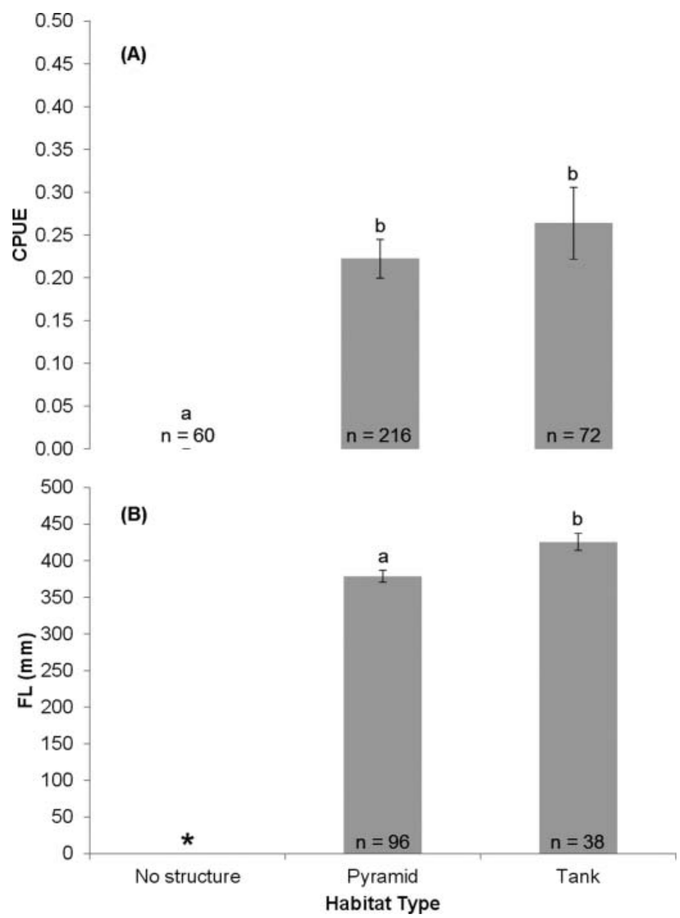

FIGURE 5. (**A**) Mean (±SE) red snapper CPUE (fish·hook^{-1}·5 min^{-1}) as a function of habitat type (reef pyramid, military tank, or no structure) and (**B**) mean (±SE) red snapper FL as a function of habitat type (*n* = number of replicates). Comparisons between habitat types were made using a Student–Newman–Keuls post hoc test. Within a given panel, values with different letters are significantly different ($\alpha = 0.05$). No fish were captured at sites without structure.

absence of fisher behavior, (2) is highly efficient, and (3) is cost effective to implement. The cost effectiveness of the gear results from its availability and the pool of fishers and vessels that can be enlisted to assist in data collection. Referred to as "bandit gear" by commercial fishers, vertical longlines are used by the majority of commercial fishers that target reef fish in the northern Gulf of Mexico. The gear was extremely effective at sampling a broad size range of red snapper and (to a lesser degree) gray triggerfish, both of which are relatively large reef fish species. Not surprisingly, the gear did not adequately sample smaller conspecifics or the smaller reef-associated fishes, such as the tomtate and gray snapper. Although the availability of other large species was limited, the gear appeared equally poor at sampling larger reef fishes. For instance, scamps were seen on 4 of the 15 videos from the ROV but were never sampled on the vertical longline. Between March and November 2010, reef fishes that were similar in size to the sampled red snapper (e.g., scamp, gag, and red grouper) accounted for less than 1% of the total catch. If the gear can be standardized and if its performance can be adequately described and repeated, then the adaptation of a commercial fishing gear for use in fishery-independent surveys represents an excellent avenue for specimen collection and for establishing long-term abundance indices. Our catch data clearly indicate that if red snapper sampling is desired as part of a fishery-independent monitoring program, then the inclusion of standardized vertical longline gear should be considered.

Soak time is an important factor affecting CPUE and species composition (Løkkeborg and Pina 1997; Ward et al. 2004) and can affect relative population abundance estimates derived from hook-and-line gear. Analysis of pelagic longline data from six different fisheries revealed that soak time had a significant, species-specific effect on longline CPUE, with longer soak times resulting in higher CPUEs for some species but lower CPUEs for other species (Ward et al. 2004). Our data indicated that catches were highest for the 5-min soak time, a slightly shorter duration than is suggested by most fishers. The decrease in catch rates between 5 and 10 min suggest escapement from the gear. While measuring the "saturation effect" in trap gear, Miller (1990) demonstrated that the relationship between catch and soak time followed a normal distribution, and they attributed the decreasing catch on the descending portion of the curve to escapement. Similar catch patterns have been suggested for hook-and-line gear (Steffensen et al. 2011) and underscore the importance of measuring the effect of variable soak times on CPUE. Although studies examining the effect of bait loss and saturation on relative abundance indices from longline surveys suggest that bias is minimal, CPUEs from longline sets with relatively short soak times provide the most reliable distribution and abundance estimates (Haimovici and Avila-da-Silva 2007). Additionally, if decreasing catch with increasing soak time is indicative of escapement from the gear, then testing variable soak times to maximize catch not only provides the greatest number of hard parts (e.g., otoliths) for stock assessment but also allows for increased replication given the constraints of vessel time. Most importantly, if long soak times lead to the escape of fish from the gear, then identifying the ideal soak times could result in CPUE estimates that more accurately reflect true population structure. Future studies examining red snapper escapement from longline gear should consider the use of hook timers or video.

Our use of a standardized bait size allowed us to examine the effect of hook type on catch characteristics. Previous studies have documented little effect of hook size (Ralston 1982, 1990; Løkkeborg and Bjordal 1992; Bacheler and Buckel 2004), yet bait type is considered an important factor in size selectivity and the most important factor in species selectivity (Løkkeborg and Bjordal 1992). Our data for hook type support previous findings and have clear implications for red snapper stock assessment, which currently relies heavily on fishery-dependent data. In a recent synthesis of the commercial vertical longline fishery in the Gulf of Mexico, Scott-Denton et al. (2011) reported that the majority of the fishery is composed of 8/0 and 9/0 circle hooks baited with eels *Ophichthus* spp. In our study, these two hook sizes sampled the smallest red snapper (the lowest mean sizes and the smallest maximum sizes). However, the largest hooks did not sample the largest red snapper. Previous studies have suggested that decreasing hook sizes do not alter the size of the largest fish but rather the minimum size at capture (Otway and Craig 1993). In the current study, analysis of all hook sizes revealed that the smallest hook size caught the largest red snapper and sampled the largest range of sizes. These data suggest that effective sampling across the entire size range of red snapper will require a large range of disparate hook sizes. A commercial fishery will use the gear that captures the most desirable size range of fish, whereas our data for hook type demonstrate a mismatch between the true population and the commercially sampled population; hence, future fishery-independent sampling programs that employ vertical longline gear should incorporate a wide range of disparate hook sizes.

The ROV sampled a length frequency distribution that was distinct from the distributions obtained with hooked gear. The ROV sampled the largest size range of red snapper, capturing length measurements of both the smallest and largest fish. Our results have implications for calculating hook selectivity. Although selectivity curves for gill nets and trawls are well established, those curves are largely inapplicable to hooked gear, particularly when size frequencies are highly overlapped. New techniques, such as the application of artificial neural networks (Czerwinski et al. 2010), appear to offer better fits for hook-and-line data. The combination of catch data from multiple hook sizes with ROV-based length estimates is a powerful means by which to estimate selectivity functions (Patterson et al. 2012) and offers future application for the data presented here.

Our examination of the effect of habitat type suggests that differences in catch rates are partially attributable to the type of structure present. This result is not surprising, but the test does illustrate the potential applicability of a standardized vertical longline in quantifying covariates that could be used in the calculation of longer-term abundance indices. Red snapper tend to aggregate around natural and artificial reefs—a fact that is well known to scientists and fishers (Topping and Szedlmayer 2011)—and, thus, higher catch rates in the vicinity of emergent structure are to be expected. Higher catches near military tanks versus prefabricated reef pyramids could be a function of the size, complexity, or age of the structures. Tanks occupied a bottom area that was roughly 6.5 times that of reef pyramids, although both types of structure offered similar relief (2.5–3.2 m). The military tanks are also much older structures, as they were deployed in 1994, whereas deployments of the reef pyramids started in 2004. Interestingly, mean fish size also increased along this continuum.

Based on the data generated during our survey, we offer the following recommendations for those initiating fishery-independent vertical longline surveys. The use of side-scan sonar allowed us to define our sampling universe as sites with suitable structure, which most closely mimicked the sampling patterns of the commercial fishery and maximized the amount of data collected per unit effort. When structure can be identified, further quantification of structure size will allow for the potential detection of catch patterns similar to those described here. This is particularly important for species like red snapper, which appear to be closely tied to structure.

Using camera gear in tandem with vertical longline gear provided an assessment of species selectivity and identified target fish that were not selected by the hooked gear. If our vertical longline survey had not used video, our conclusions concerning gear performance and hook selectivity would have been incomplete. While the use of an ROV may be cost prohibitive, fixed camera arrays outfitted with parallel lasers accomplish the same objective, and even inexpensive underwater video arrays (e.g., GoPro cameras) can provide the species composition of fishes that are not sampled via vertical longline.

Careful consideration should be given to the specific choice of vertical longline hook size and bait type. Following the recommendations of previous studies (Erzini et al. 1998), we recommend the use of at least four hook sizes. For comparison, two of the hooks should represent the sizes most commonly used in the commercial fishery, and at least one smaller hook and one larger hook should also be included (Erzini et al. 1996). Many studies examining the effect of hook size have only tested the hook sizes that are most commonly used in the commercial or recreational fishery and have found highly overlapped size frequencies; such studies have therefore concluded that for size frequency to vary widely, highly dissimilar hook sizes must be used. In our survey, the length frequency distribution of red snapper did not differ between the two smallest hook sizes—an 8/0 hook is only about 140% larger than a 3/0 hook. Conversely, we observed a difference in length frequency distribution between the two smaller hooks and the 11/0 hook (with Atlantic mackerel bait), which is nearly twice the size of an 8/0 hook. Quantification of the effect of hook size necessitates the standardization of bait size; if multiple bait types are used, they should be allocated to hook treatments orthogonally. Once the gear specifics have been decided upon, experimental identification of an optimum soak time is recommended to maximize the amount of data collected by increasing replication given the constraints of vessel time.

ACKNOWLEDGMENTS

We thank the following people for help with our vertical longline sampling program: M. Ajemian, N. Bawden, S. Bosarge, F. Boullieret, A. Brown, S. Chutkan, E. Collins, V. Cruz, L. Dodd, C. Hightower, M. Kenworthy, A. Kroetz, K. Nixon, C. Pabody, L. Showalter, T. Spearman, M. Valentine, and N. Wepking. We are grateful to the Dauphin Island Sea Laboratory's vessel staff, specifically Captains R. Collier, T. Guoba, and R. Wilson. We also thank Captain Skipper Thierry and mates Andy Harden and Blake Bridges for their assistance and use of the vessel *Escape*. The Alabama Department of Conservation and Natural Resources, particularly C. Newton, provided assistance in project design and sampling. The manuscript was greatly improved by constructive comments from the reviewers. Funding for this project was provided by the Southeast Area Monitoring and Assessment Program and the Northern Gulf Institute.

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