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Does hook type influence the catch rate, size, and injury of grouper in a North Carolina commercial fishery?

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Abstract

Members of the Epinephelinae subfamily of serranids ("grouper") are heavily exploited by both recreational and commercial hook-and-line fishermen on the continental shelf of the southeastern United States. However, aspects of groupers' biology and ecology render them extremely vulnerable to overexploitation, including slow growth, late reproduction, large size, and long life span. In addition to direct fishing mortality, hook and release mortalities likely occur when grouper are caught and released, due to injuries sustained from hooking as well as those associated with retrieval from deep waters. Here, we evaluated four hook sizes and styles (5/0 "J", 7/0 "J", 9/0 "J", and 12/0 circle hooks) during the summer of 2003 by their ability to reduce catches of sublegal grouper and non-target species in Onslow Bay, North Carolina, USA. A total of 1249 fish representing 33 species were landed during 20 days of commercial fishing activities. The most common grouper landed were red grouper *Epinephelus morio* ($n = 459$), gag grouper *Mycteroperca microlepis* ($n = 55$), and scamp grouper *Mycteroperca phenax* ($n = 50$). Overall, 6.8% of grouper landed were below the minimum size limit, and the proportion of sublegal grouper caught per day decreased with depth. Catch rates for small grouper (i.e., <50.8 cm fork length), non-target individuals, and sharks varied across hook treatments, while catch rates for large grouper (i.e., ≥50.8 cm fork length) did not. Circle hooks significantly reduced gut hooking in all groupers as well as non-target species. The proportion of grouper and non-target fish that bled varied across hooking locations, with more fish bleeding from gut and gill hooking than jaw hooking. Finally, the proportion of red and gag grouper with distended stomachs was positively related to the water depth in which the fish were caught. These results suggest a tradeoff between fishing in shallow water to reduce depth-related injuries to grouper and fishing in deeper water to minimize the catch of sublegal grouper.

Keywords: Serranidae; Grouper; Circle hook; Stomach distention

1. Introduction

Sea basses (Serranidae) are among the most important families of commercially harvested tropical marine fishes worldwide. Most members of the Epinephelinae

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subfamily (hereafter referred to as 'grouper'), in particular, are heavily exploited and bring high market prices (Beets and Hixon, 1994; Morris et al., 2000). In the southeastern United States, groupers are an extremely important commercial and recreational species. In this area, grouper occur over continental shelf waters near shallow reef tracts as well as shelf break areas in depths of only a few meters to near 150 m (Johnson et al., 1997). Hook-and-line fishing gear is the most common fishing method used to target grouper; hooks are baited with cut or live bait and fished from an anchored or drifting boat.

Aspects of groupers' biology and ecology render them extremely vulnerable to overexploitation. They exhibit life history characteristics typical of a K-selected species: slow growth, late reproduction, large size, and long life spans (Parrish, 1987). All groupers except Nassau grouper *Epinephelus striatus* are protogynous hermaphrodites, rendering them more vulnerable to overfishing than those species that do not change sex because size-selective harvest may strongly bias the sex-ratio of a stock (Coleman et al., 1996). Moreover, many groupers also form large spawning aggregations, and most are territorial with small home ranges (Domeier and Colin, 1997; Morris et al., 2000). Consequently, approximately half of 101 grouper species in a recent preliminary review were considered Vulnerable or Endangered (Morris et al., 2000).

In addition to direct fishing mortality, hook and release mortalities likely occur when sublegal (i.e., below the minimum size limit) or legal (when more fish are caught than can be retained legally) grouper are caught and released after being hooked. The effect of the hooking location (e.g., gut hooking) on grouper survival has not been evaluated, but has been found to be a significant predictor of the survival of many fish species including striped bass *Morone saxatilis* (Diodati and Richards, 1996), Atlantic bluefin tuna *Thunnus thynnus* (Skomal et al., 2002), yellowfin tuna *Thunnus albacares* (Falterman and Graves, 2002), and summer flounder *Paralichthys dentatus* (Malchoff et al., 2002). Because hook type influences the hooking location in many fish species (Grover et al., 2002; Prince et al., 2002; Skomal et al., 2002), the regulation of hook types used in a fishery may be one of the most effective management strategies to prevent unnecessary losses of sublegal grouper.

The goal of this study was to evaluate various hook size and styles by their ability to reduce capture of sublegal grouper and non-target species in North Carolina, USA. Our specific objectives were: (1) to assess the influences of hook size and style on the catch rates and sizes of grouper and non-target species; (2) to relate hook size and style to hooking location in grouper and non-target species; and (3) to test the influence of hook size and style and water depth on the extent of injury (i.e., bleeding and stomach distention) in grouper and non-target species.

2. Materials and methods

Research trips were conducted on a 9.5 m commercial fishing vessel that fished 20–60 miles offshore in water 12.2–42.1 m deep over the continental shelf in Onslow Bay, North Carolina, USA. Twenty fishing trips took place between 14 May 2003 and 20 August 2003, and actual fishing occurred between 08:00 and 18:00 h during each daily trip.

Four rods, each equipped with a 6/0 Penn reel, a Precision auto electric motor, and 130 lb test braided fishing line, were used during each day of fishing. Each rod was randomly equipped with one of four hook treatments each day: 5/0 straight shank ("J"), 7/0 "J", 9/0 "J" (all Mustad model number 92671), and a 12/0 circle hook (Mustad model number 39960ST) (Fig. 1). Thus, all four hook treatments were fished simultaneously on each day of fishing. These particular hook treatments were selected because they are the most common hook sizes and styles used by commercial and recreational grouper fishermen in North Carolina. The terminal bottom rig used on each rod consisted of a standard two-hook "high–low" bottom rig using a 150 lb test monofilament leader, two three-way swivels, and a 16–20 oz sinker. All hooks were baited with equivalent pieces of cut frozen fish and released to the bottom. When fish were landed, the species, fork length (centimeter), depth, hooking location (e.g., jaw, body, gut, gills, or eye), bleeding (e.g., yes or no), and stomach distention (e.g., yes or no) were noted. Fish were considered to be gut hooked if the hooking location was posterior to the beginning of esophagus. Sharks were released without being brought on board, so length information was not collected on these species.

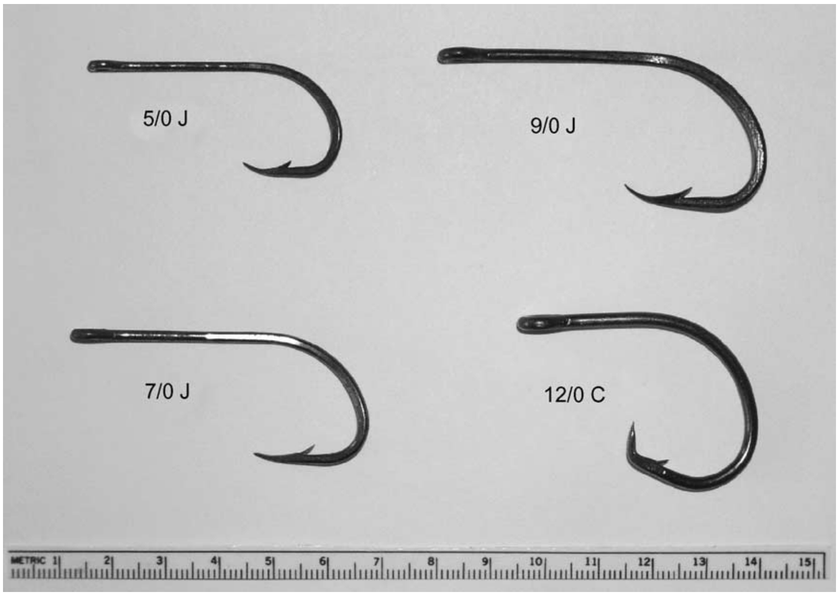

Fig. 1. Four hook treatments used in experimental fishing trips in Onslow Bay, North Carolina, USA.

Species were combined into certain groups to allow more robust statistical analyses and to understand general trends in sizes and catches. All Epinephelinae groupers, for instance, were combined due to their ecological and morphological similarities. Small (i.e., <50.8 cm FL) and large (i.e., ≥50.8 cm FL) grouper were analyzed separately to examine differences in catch rates by size. These sizes were chosen to correspond to the current minimum length limit for two of the most common grouper species in North Carolina, red grouper *Epinephelus morio* and scamp *Mycteroperca phenax*. All shark species were also grouped together for analysis. All non-target species (i.e., all species excluding groupers and sharks) were grouped together in the analyses in order to allow a general understanding of the ways that hook size and style influence catch rates of non-target fishes, and because no one non-targeted species, aside from red porgy *Pagrus pagrus*, was caught frequently enough to allow robust statistical analyses.

Catch rates of fish were analyzed using a randomized complete blocking design with analysis of variance (ANOVA), with day as the blocking factor and hook as the main effect. A $\log_{10}(X + 1)$ transformation of catch rates was used to meet assumptions of homogeneity of variance (tested with Bartlett's test) prior to testing with ANOVA. Sizes of fish by hook treatment were pooled across days, and a simple one-way parametric ANOVA was performed with hook treatment as treatment effect to test for differences in mean sizes of fish across hook treatments. In addition, Kolmogorov-Smirnov tests were used to test the hypothesis that independent samples (i.e., fish lengths across hook treatments) come from identical distributions, which is a more sensitive test of the distribution of sizes of fish across hook treatments (Sokal and Rohlf, 1969). Chi-square tests were used to test for differences in hooking location among hook treatments, and also to test for differences in the extent of injury among hook treatments and hooking location.

3. Results

3.1. Catch and trip statistics

A total of 1249 fish representing 33 species were landed (Table 1). Six species of grouper were caught; red grouper alone accounted for 36.7% of the total catch and 77.4% of the grouper catch. Other important grouper included gag *Mycteroperca microlepis* and scamp. Although sublegal red grouper were rarely

Table 1
Summary of all fish species caught between 14 May 2003 and 20 August 2003 in Onslow Bay, North Carolina, USA, in a commercial hook-and-line fishery targeting grouper

Common name	Scientific name	Total	Proportion
Grouper species			
Red Grouper	*Epinephelus morio*	459	0.367
Gag	*Mycteroperca microlepis*	55	0.044
Scamp	*Mycteroperca phenax*	50	0.040
Red Hind	*Epinephelus guttatus*	22	0.018
Rock Hind	*Epinephelus adscensionis*	6	0.005
Coney	*Epinephelus fulvus*	1	0.001
Non-target species			
Red Porgy	*Pagrus pagrus*	260	0.208
Black Sea Bass	*Centropristis striata*	85	0.068
White Grunt	*Haemulon plumieri*	30	0.024
Silk Snapper	*Lutjanus vivanus*	25	0.020
Bank Sea Bass	*Centropristis ocyurus*	13	0.010
Grey Triggerfish	*Balistes capriscus*	11	0.009
Sand Perch	*Diplectrum formosum*	10	0.008
Vermillion Snapper	*Rhomboplites aurorubens*	10	0.008
Snakefish	*Trachinocephalus myops*	9	0.007
Spottail Pinfish	*Diplodus holbrooki*	9	0.007
Spotted Moray	*Gymnothorax moringa*	8	0.006
Greater Amberjack	*Seriola dumerili*	5	0.004
Knobbed Porgy	*Calamus nodosus*	4	0.003
Tomtate	*Haemulon aurolineatum*	4	0.003
Bluespotted Coronetfish	*Fistularia tabacaria*	2	0.002
Oyster Toadfish	*Opsanus tau*	2	0.002
Squirrelfish	*Holocentrus adscensionis*	2	0.002
Conger Eel	*Conger oceanicus*	1	0.001
Dolphin	*Coryphaena hippurus*	1	0.001
Inshore Lizardfish	*Synodus foetens*	1	0.001
King Mackerel	*Scomberomorus cavalla*	1	0.001
Sharksucker	*Echeneis naucrates*	1	0.001
Red Snapper	*Lutjanus campechanus*	1	0.001
Whitebone Porgy	*Calamus leucosteus*	1	0.001
Shark species			
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	154	0.123
Dusky Shark	*Carcharhinus obscurus*	3	0.002
Tiger Shark	*Galeocerdo cuvieri*	3	0.002

landed, sublegal scamps and gags were frequently landed (28.0 and 30.9% of their total catch, respectively). Sharks and other non-target species were also caught. Three species of sharks were landed, but 96.3% of all sharks caught were Atlantic sharpnose sharks *Rhizoprionodon terraenovae*. Twenty-four non-target species were also caught. By far the most commonly caught non-target species was red porgy, followed by black sea bass *Centropristis striata* and white grunt *Haemulon plumieri* (Table 1).

3.2. Catch rates and sizes of fish across hook treatments

A total of 549 large (i.e., ≥50.8 cm FL) grouper were caught, representing 92.0% of all groupers caught in this study. Daily catches of large grouper, pooled across hooks, ranged from 2 to 57 fish. The effect of day was highly significant (ANOVA: $F = 6.51$, d.f. = 19, $P < 0.0001$), suggesting large daily variability in catches. Differences in large grouper catch rates across hook

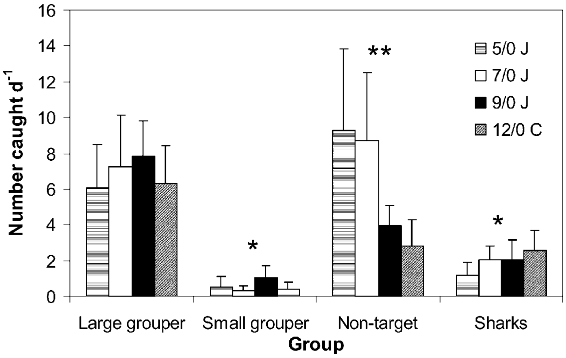

Fig. 2. Daily catch rates of large (≥50.8 cm FL) grouper, small (<50.8 cm FL) grouper, non-target species, and sharks across four hook treatments in Onslow Bay, North Carolina, USA. Asterisks represent significantly different daily catches across hook treatments for that fish group at the $^{*}P < 0.05$ and $^{**}P < 0.01$ levels.

treatment were not significant (ANOVA: $F = 1.57$, d.f. = 3, $P = 0.21$) (Fig. 2).

Forty-seven small (<50.8 cm FL) grouper were caught, which comprised 8.0% of the total grouper catch. Daily catches of small grouper, pooled across hooks, ranged from 0 to 14 fish; small grouper were only caught on 11 of 20 days of fishing. Excluding days when no small grouper were caught, no effect of day was evident (ANOVA: $F = 2.57$, d.f. = 10, $P = 0.072$), suggesting relatively invariant daily catches of small grouper. There was a significant difference in catch rates of small grouper across hook treatments (ANOVA: $F = 2.24$, d.f. = 3, $P = 0.043$).

The number of non-target individuals caught per day ranged from 9 to 72 fish. The effect of day was significant (ANOVA: $F = 1.99$, d.f. = 19, $P = 0.024$), suggesting daily variability in catches of non-target individuals. Mean daily catches of non-target species also varied across hook treatments (ANOVA: $F = 12.82$, d.f. = 3, $P < 0.0001$). Shark catches were variable across days (ANOVA: $F = 3.67$, d.f. = 17, $P < 0.01$) and hook treatments (ANOVA: $F = 3.01$, d.f. = 3, $P = 0.038$).

No differences in mean length of grouper across hook treatments were observed (one-way ANOVA: $F = 2.18$, d.f. = 3, $P = 0.09$) nor were there any significant differences in the distribution of sizes of grouper caught across hook treatments (Kolmogorov-Smirnov test: $P > 0.10$ for all hook treatment combinations). Similarly, neither mean length of non-target species differ across hook treatments (one-way ANOVA: $F = 0.58$, d.f. = 3, $P = 0.59$) nor did the length distributions differ across hook treatments (Kolmogorov-Smirnov test: $P > 0.10$ for all hook treatment combinations).

3.3. Hooking locations across hook treatments

Grouper were most commonly hooked in the jaw, but hooking also occurred in the gut, gills, body, and eye (Table 2). Gut hooking was significantly higher with the “J” hooks than with the 12/0 circle hooks ($\chi^2 = 21.78$, d.f. = 3, $P < 0.001$). Gill hooking ($P = 0.082$), body hooking ($P = 0.59$), and eye hooking ($P = 0.50$) did not differ across hook treatments.

Non-target species were most commonly hooked in the jaw, but were also hooked in the gut, body, and gills (Table 2). The smallest hooks were more likely than bigger ones to hook non-target species in the gut ($\chi^2 = 8.99$, d.f. = 3, $P = 0.03$) and gills ($\chi^2 = 12.71$, d.f. = 3, $P < 0.01$), but there was no difference in body hooking across hook treatments ($\chi^2 = 1.01$, d.f. = 3, $P = 0.80$). Sharks were primarily hooked in the jaw (95.0%), and rarely hooked in the gut, body, and gills.

Table 2
Proportions of various hooking locations across hook treatments in grouper and non-target species caught between 14 May 2003 and 20 August 2003 in Onslow Bay, North Carolina, USA

Species	Hook treatment	Jaw	Gut	Gills	Body	Eye
Grouper	5/0 J	0.833	0.167	0	0	0
Grouper	7/0 J	0.829	0.145	0.026	0	0
Grouper	9/0 J	0.818	0.159	0.011	0.006	0.006
Grouper	12/0 C	0.985	0.008	0	0.008	0
Non-target	5/0 J	0.855	0.097	0.005	0.043	0
Non-target	7/0 J	0.925	0.034	0.023	0.017	0
Non-target	9/0 J	0.937	0.013	0	0.051	0
Non-target	12/0 C	0.905	0.018	0	0.018	0

3.4. Injury of fish across hook treatments, hooking locations, and water depths

Overall, 8.2% of all fish landed bled from hooking and hook removal, with more grouper bleeding (10.2%) than non-target species (5.6%). There were no differences in proportion of bleeding across hook treatments in grouper (χ^2 = 4.83, d.f. = 3, P = 0.185), non-target species (χ^2 = 0.75, d.f. = 3, P = 0.86), or sharks (χ^2 = 2.48, d.f. = 3, P = 0.48). However, bleeding was different across different hooking locations in grouper (χ^2 = 101.93, d.f. = 4, P < 0.001) and non-target species (χ^2 = 161.80, d.f. = 3, P < 0.001). Grouper were much more likely to bleed from gill (66.7%) and gut (40.0%) hooking than from jaw hooking (5.0%), while non-target species were more likely to bleed from gut (54.0%), gill (40.0%), and body hooking (33.0%) than jaw hooking (1.0%).

The proportion of grouper with distended stomachs was high (69.3%), but low in non-target species (5.3%). Across all depths, stomach distention was most common in red grouper (80.5%) and gag (70.9%). The percentage of distended stomachs for red grouper was different across depth categories (χ^2 = 7.25, d.f. = 2, P = 0.03); 75% of red grouper had distended stomachs when caught in water shallower than 38 m, but this percentage increased to 95% in water deeper than 41 m. The percentage of stomach distention in gag was similarly positively related to depth (χ^2 = 17.65, d.f. = 3, P < 0.01). No gag had a distended stomach when caught in water shallower than 24.0 m, but over 60% had distended stomachs in water than 36 m.

4. Discussion

4.1. Catch and trip statistics

Sublegal grouper accounted for only a small percentage of the overall grouper catch in this study (6.8%). This result is inconsistent with previous findings in the Gulf of Mexico, where 35.7% of gag and red grouper caught from the commercial hook-and-line fishery were below the 50.8 cm TL minimum size limit (Johnson et al., 1997). An important difference to note between these studies, however, is the depth of the water in which fishing took place. During only three trips did fishing take place in water less than 40 m in depth in the present study, whereas a large proportion of the catch from Johnson et al. (1997) came from water less than 40 m deep. Mean grouper length in our study was positively correlated with mean daily water depth (ANOVA: F = 8.08, d.f. = 1, P = 0.01), and this phenomenon has been documented elsewhere (Johnson et al., 1997). That most of our fishing occurred in deep waters likely minimized sublegal grouper catch rates.

4.2. Catch rates and sizes of fish across hook treatments

There were no differences in catch rates of large grouper among four hook treatments we used in this study, but significant differences were observed for small grouper (Table 3). However, it wasn't the smallest hooks that caught the greatest number of small grouper, but rather the largest (9/0) "J" hook. This non-intuitive result was likely due to low catch rates of small grouper (i.e., 2.3 fish caught per day across all hook treatments). Thus, this result is likely not statistically robust and should be interpreted with caution. Regardless, it was obvious that even the smallest grouper caught in this study (i.e., 28.0 cm FL) was clearly not gape limited and could easily engulf the largest hooks used in this study. Sizes of grouper caught in North Carolina are appear unaffected by moderate changes in hook types and sizes. Ralston (1982) found catch rates and sizes of Hawaiian bottom fish invariant across four sizes of circle hooks; only the number of opakapaka (*Pristipomoides filamentosus*), a snapper (Lutjanidae), varied significantly across hook sizes. Our findings are also

Table 3
Summary of all analyses performed on size and number of fish catch across four hook treatments and 20 days fished (fish were caught between 14 May 2003 and 20 August 2003, in Onslow Bay, North Carolina, USA)

Analysis	Hook treatment (P-value)	Day (P-value)
Number of large grouper	0.208	<0.001
Number of small grouper	0.043	0.072
Size of grouper	0.09	*
Number of non-targets	<0.001	0.024
Size of non-target	0.59	*
Number of sharks	0.038	<0.001

* The effect of day could not be tested on the sizes of fish because size data were pooled across all days.

consistent with the review of Løkkeborg and Bjordal (1992), who concluded that daily variability in catches or sizes of fish may mask any small effects of moderate differences in hook size. Thus, it appears that changes made to hook sizes or type within the ranges used here will have very little noticeable effect on the catch and size of grouper.

Catch rates of non-target species were much higher for the small "J" style hooks than for the large "J" hook or the circle hook. These results suggest gape size limitations exist for small, non-target bottom fishes such as red porgy (Sparidae) and white grunt (Haemulidae). Likewise, Erzini et al. (1998) found the smallest "J" style hooks (size 15) caught more sea breams (Sparidae) than larger hooks (size 13 and 11) in a longline fishery in Portugal. Thus, if the goal of North Carolina fishermen is to maximize the catch of grouper while simultaneously minimizing the number of non-target species caught, then circle hooks or large "J" hooks may be the most appropriate hook to use.

4.3. Hooking locations across hook treatments

There were large differences in hooking locations of fish across hooking treatments. In grouper, circle hooks had drastically fewer gut hookings (e.g., 0.8%) compared to "J" hooks (e.g., approximately 15%), while gill, body, and eye hookings were rarely observed for either circle or "J" hooks. Although circle hooks have been found to reduce gut hooking in bluegill *Lepomis macrochirus* (Cooke et al., 2003), rainbow trout *Oncorhynchus mykiss* (Jenkins, 2003), and striped marlin *Tetrapturus audax* (Domeier et al., 2003), this is to the best of our knowledge the first study to evaluate the use of circle and "J" hooks simultaneously in a grouper fishery.

Gut hooking in non-target species was observed much less frequently (5.2%) than in grouper. As in grouper, gut hooking in non-target species was less common in circle hooks than in "J" hooks. It is also important to note that, in non-target species, the large "J" hooks greatly reduced gut hooking as compared to the smallest "J" hook. If fishermen want to either avoid catching non-target species or to reduce injuries in non-target species, then the largest "J" hook or the circle hook should be the most preferable hook choice.

4.4. Injury of fish across hook treatments, hooking locations, and water depths

Bleeding associated with hooking has been found to be a significant predictor of post-release mortality in many fish species (Diodati and Richards, 1996; Malchoff et al., 2002). Thus, in lieu of conducting a time-consuming and expensive holding tank study to quantify grouper survival, we used the presence or absence of bleeding as a proxy of grouper survival. Although there were no differences in bleeding rates across hooking treatments for grouper or non-target species, bleeding rates did vary by the location of hooking for both grouper and non-target species. For both groups, bleeding was much more likely to occur when the fish was gut or gill hooked. Hence, even though the hook treatment did not directly appear to influence the bleeding rate, it did so indirectly because the hook treatment influenced hooking location, which in turn greatly influenced bleeding rates. Most importantly, circle hooks were more likely to hook fish in the jaw, and jaw hooked fish were much less likely to bleed.

Bottom fish brought rapidly to the surface from a substantial depth often experience a rapid expansion of swim bladder gasses, which can lead to ruptured swim bladders, bloating, stomach distention, protruding eyes, and emboli (Burns and Restrepo, 2002). These injuries are often lethal if fish are not returned quickly to depth with human aid, such as puncturing the swim bladder before release (Wilson and Burns, 1996). The presence of grouper stomach distention, an obvious and easily documented phenomenon, was used as an indicator of potential mortality due to retrieval from depth. The proportion of stomach distensions in red and gag grouper was positively related to water depth, a result that is consistent with previous research (Gilschlag and Renaud, 1994; Wilson and Burns, 1996; Guccione, 1998). Using shipboard pressurized chambers and in situ observations, Wilson and Burns (1996) estimated low rates of potential survival (<33%) for scamp and red grouper when retrieved from water 44 m or deeper, but potential survival was much higher (86–100%) when fish were caught in water shallower than 44 m. This has potentially negative consequences for both sublegal groupers, which are required by law to be returned to the water by both commercial and recreational fishermen, and legal groupers, which may be caught and released if fishing continues after the maximum daily limit of fish (i.e., bag limit) has been reached by recreational fishermen.

4.5. Management implications

These results suggest a potential tradeoff that fishermen face between fishing in shallow water to reduce depth-related injuries to grouper, such as stomach distention, and fishing in deeper water to minimize the catch of sublegal grouper. The presence of such a tradeoff implies an optimum depth that can be fished where fishermen could simultaneously reduce injuries to grouper and minimize the sublegal catch. Thus, managing the grouper fishery with the use of spatially dependent methods such as no-take zones, as well as the regulation of hook type, may prevent more unnecessary losses of grouper than traditional management actions such as size limits, bag limits, and closed seasons. Although managing the grouper fishery with spatially explicit methods or hook regulations may be the most influential biologically based upon the work presented here, it is unfortunate that the enforcement of hook use and no-take zones will also likely be the most difficult to regulate.

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