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P. J. RUDERSHAUSEN & J. A. BUCKEL

Department of Zoology, Center for Marine Sciences and Technology, North Carolina State University, Morehead City, NC, USA

E. H. WILLIAMS

NOAA, Center for Coastal Fisheries and Habitat Research, Beaufort, NC, USA

Abstract Minimum size limits may be ineffective for reef fishes because they often sustain barotrauma when caught from deep (> 20 m) waters. A study was undertaken in conjunction with hook-and-line commercial fishermen to calculate discard percentages and evaluate potential release mortality of eight economically important species: black sea bass, *Centropristis striata* (Linnaeus), red grouper, *Epinephelus morio* (Valenciennes), snowy grouper, *Epinephelus niveatus* (Valenciennes), gag, *Mycteroperca microlepis* (Goode and Bean), scamp, *Mycteroperca phenax* (Jordan and Swain), vermilion snapper, *Rhomboplites aurorubens* (Cuvier), white grunt, *Haemulon plumieri* (Lacepède) and red porgy, *Pagrus pagrus* (Linnaeus). Fishing with baited hook and line occurred in 2004 and 2005 in Onslow Bay, NC, in waters 19–150 m deep. Sub-legal discard rates were 15% for vermilion snapper, 25% for red porgy, 7% for red grouper, 33% for gag, 35% for scamp and 12% for black sea bass. Although mortality based on post-release behaviour was relatively low, higher mortalities estimated from models incorporating hooking location and depth of capture suggest that minimum size limits may not provide the population benefits intended by management in the North Carolina reef fishery.

KEYWORDS: barotrauma, commercial fishing, discard mortality, gut hooking.

Introduction

Continental shelf waters off North Carolina, USA represent the northernmost range of populations of fishes in the snapper family (Lutjanidae) and grouper subfamily (Epinephelinaeidae). Species within these groups inhabit deep waters along the continental shelf of the South Atlantic Bight. Members of the Sparidae (porgy) and Haemulidae (grunt) families are also caught in these commercial and recreational reef fisheries.

Stocks of many reef species are overexploited in the South Atlantic Bight (Coleman, Koenig, Huntsman, Musick, Eklund, McGovern, Chapman, Sedberry & Grimes 2000). Economically important species that are over-fished or at risk of being over-fished include vermilion snapper, *Rhomboplites aurorubens* (Cuvier) (SEDAR 2003), red porgy, *Pagrus pagrus* (Linnaeus) (Huntsman, Vaughan & Potts 1994; Harris & McGovern 1997; Vaughan & Prager 2002), red grouper, *Epinephelus morio* (Valenciennes) (Schirripa, Legault & Ortiz 1999), gag, *Mycteroperca microlepis* (Goode and Bean), (McGovern, Wyanski, Pashuk, Manooch & Sedberry 1998), snowy grouper, *Epinephelus niveatus* (Valenciennes) (SEDAR 2004a), and black sea bass, *Centropristis striata* (Linnaeus) (SEDAR 2005). Some species of snappers and groupers possess traits that make them particularly susceptible to overharvest (Coleman *et al.* 2000), including slow growth and late maturity (Musick 1999), as well as high site fidelity, seasonal concentrations and hermaphroditism (Coleman, Koenig, Eklund & Grimes 1999). Stock declines of target species are often associated with increased fishing effort in deeper waters where release mortality among sub-legal fishes makes species protection less successful (Coleman

Correspondence: Paul J. Rudershausen, Department of Zoology, Center for Marine Sciences and Technology, North Carolina State University, 303 College Circle, Morehead City, NC 28557, USA (e-mail: pjruders@unity.ncsu.edu)

et al. 2000). Restrictions in the southeastern US and Gulf of Mexico snapper–grouper fisheries often fail because species targeted for protection still experience fishing mortality from effort targeting other species (Coleman *et al.* 2000).

Post-release survival of reef fishes is negatively related to depth of capture (Gitschlag & Renaud 1994; Wilson & Burns 1996). Barotrauma sustained by fishes rapidly retrieved from deep water include ruptured swim bladders, emboli, bloating and protrusions of stomachs, intestines and eyes (Schirripa *et al.* 1999; Burns & Restrepo 2002). Release mortality of reef fishes can be either immediate (occurring after fish are released at the surface) or delayed (occurring minutes, hours, or days after release as fish attempt to return to the bottom and recover from barotrauma). While specimens may be alive when released, rates of delayed mortality may be high (Schirripa *et al.* 1999). Fishermen often question the use of minimum size limits in reef fisheries when they observe released fish dying or floating away as a result of barotrauma caused by capture from deepwater.

Information on commercial landings and effort targeting reef fish stocks in the South Atlantic Bight is collected using a logbook program that records landings (pounds), areas fished and gear used (SEDAR 2004b). The logbook program began recording discard percentages in 2005; however, neither the logbook nor the Southeast Trip Interview Program documents the fate of released fish. Data accurately documenting rates of release mortality are difficult to obtain.

For minimum size limits to be effective, a high percentage of sub-legal or non-target discards must either escape capture or survive catch and release over the range of depths a species is captured (Burns & Restrepo 2002). Adoption of minimum size rules for deepwater snapper and grouper fisheries assumes that sub-legal fishes will experience only natural mortality and minimal release mortality until they reach legally harvestable sizes (Wilson & Burns 1996). If release mortality is higher and unaccounted for, total mortality is underestimated. On the other hand, if release mortality is low, minimum size limits may be of value in managing stocks of species at risk of being overfished.

The mortality rates of discarded vermilion snapper, red grouper, scamp, *Mycteroperca phenax* (Jordan and Swain), and red porgy have been recently estimated from a caging experiment to be 30%, 33%, 40%, and 43%, respectively (Guccione 2005). Using cages to evaluate the delayed fate of released fishes, however, introduces problems with repeated ascent and descent of caged fish, stress or mortality associated with confinement, high costs of monitoring and low sample sizes of fish. Determining post-release condition using a scoring system has been used in lieu of cages to monitor release mortality in some fisheries (Patterson, Ingram, Shipp & Cowan 2000). Documenting release condition can help refine estimates of fishing mortality. Certain conditions, including gastric distention and bleeding, may be proxies for delayed mortality.

Four of the most valuable grouper species in North Carolina's commercial fishery are snowy grouper, gag, red grouper, and scamp (North Carolina Division of Marine Fisheries, unpublished data). Snowy grouper occur near the continental shelf edge in waters 100–200 m deep and have no minimum size limit. Gag have a minimum size limit of 609 mm total length (TL) and are found in shallow waters, generally less than 35 m deep. Red grouper (508 mm TL minimum limit) occur in waters from 30 to 50 m deep. Scamp (508 mm TL minimum limit) occur in a wide range of depths from 30 to 100 m. The most important snapper species by weight landed in North Carolina is the vermilion snapper (330 mm TL minimum limit), which is found at depths from 30 to 60 m. The commercially most important porgy species by weight landed in North Carolina is the red porgy (356 mm TL minimum length limit), which commonly occurs in waters from 30 to 60 m deep. The most important grunt by weight among reef species is the white grunt, *Haemulon plumieri* (Lacepède), which occurs at depths from 20 to 40 m. White grunt have no minimum size limit. Thus, these major species in the North Carolina reef fishery are caught at depths where barotrauma may cause mortality after release.

The objectives of this study were to: (1) measure discard rates (the percentage of undersized fish) for important size-regulated species; (2) record immediate post-release behaviour of target species; (3) compare release indices among legal and sub-legal conspecifics; (4) relate release condition to water depth, hooking location, and barotrauma; and (5) model probabilities of delayed mortality for red porgy, vermilion snapper, white grunt, red grouper, snowy grouper, gag, and black sea bass using observations of proxies for mortality. These results were then used to evaluate the usefulness of minimum length limits for regulating harvest.

Materials and methods

Data were collected on 50 fishing trips from 13 May 2004 to 30 March 2005. A total of 35 of these trips were made aboard two 9-m commercial fishing vessels to areas commonly fished by commercial reef fishermen in Onslow Bay, North Carolina. Data presented herein on discard (sub-legal) percentages and depths of capture for each species are from these 35 trips when fishermen chose where to fish. Fifteen additional trips on the same vessels were made from 9 May to 22 September 2005 and were not commercial fishing trips, so discard percentages were not computed from this sampling. These trips were used only to characterise release condition and collect data for modelling delayed mortality (below).

Terminal tackle consisted of a high–low bottom rig with 59-kg test monofilament line, two three-way swivels, a sinker ranging from 0.5 to 1.0 kg, and two zero-offset J-hooks ranging from 2/0 to 12/0 in size. This J-hook rig is typical in the North Carolina reef fishery. Natural baits, including herring (*Alosa* spp.) and squid (*Ilex* spp.), were used. Between three and four rods were fished simultaneously by an equal number of fishermen. The species in this study were captured with electric reels and braided line that are commonly used by the commercial fishing sector. These reels typically retrieve fish at rates between 1.5 and 2 m s^{-1} (P.J. Rudershausen, personal observation). Fishing took place between sunrise and sunset in waters 19–150 m deep and 32–97 km offshore.

Commercial fishermen were asked to record information on discards during 17 trips. These trips are referred to as unobserved. Observed (33) trips constituted the remainder and involved a research scientist recording discard information.

The following information was recorded for each fish caught: species, fish TL (mm), water depth, hook size, hooking location (jaw, gut, gills, eyes or body), presence of bleeding and presence of gastric (stomach or intestine) distention. Gastric distention was used to indicate barotrauma. Upon release, fish were observed from the surface to roughly 6 m below the surface (depending on water clarity and sea conditions) to assign them a post-release condition. The release index scored fish as: (1) alive, oriented themselves towards the bottom, and swam down vigorously; (2) alive, oriented themselves towards the bottom, and swam down slowly or erratically; (3) alive but floated at the surface; or (4) dead or unresponsive (see Patterson *et al.* 2000 for a description of these indices). While the eventual fate of fish scored as 1 or 2 was unknown, fish scored as 3 or 4 were assumed to eventually die. Fish scored as 3 or 4 will be referred to as immediate mortality. As red porgy and vermilion snapper have been the focus of recent size-based regulation changes by the South Atlantic Fishery Management Council and they were the two most abundant species captured, the decision whether to combine post-release data from observed and unobserved trips was based on a chi-square contingency test ($\alpha = 0.05$) of the post-release indices for these two species. Post-release data were not taken for snowy grouper. Some legal-sized fish were also released to evaluate how release of larger fish (due to proposed increases in minimum sizes) would affect mortality rates.

For species with data collected from each group, a chi-square test on a two-by-two contingency table was used to compare the frequency of indices 3 and 4 to indices of 1 and 2 among fish that were: legal and sub-legal, with and without gastric distention, bleeding and not bleeding and jaw- and gut-hooked. Logistic regression was used to predict the influences of water depth on gastric distention, fish TL on gastric distention and hook size on gut hooking. These tests were performed to evaluate what factors might influence gastric distention or traumatic hooking, which were assumed to result in varying degrees of mortality in the delayed mortality models (see below).

The inference of mortality from the simple scoring system of Patterson *et al.* (2000) assumes that the fate of a fish can be determined from a simple examination at release. This type of observation only identifies overt signs of trauma and may overlook other stresses and trauma that can result in delayed mortality. For example, a fish that has been hooked in the stomach may appear vigorous at the time of release; however, lethal trauma to vital organs may have occurred. For this reason, another method was chosen to infer post-release mortality rates for the species in this study.

A Monte Carlo simulation model was used to compute probability density functions of delayed mortality for each species. Depth (barotrauma) and hooking location were assumed to be the two factors chiefly and independently influencing potential mortality. Other factors, such as handling time, may prove important but remain largely unstudied at this point. However, the method proposed here is easily expanded to include other causes of mortality. Bleeding was not considered a separate factor because hooking location was associated with bleeding (i.e. gut- and gill-hooked fish bled more often than jaw-hooked fish). Depth and hooking location were used in the model,

$$r = 1 - (1 - d)(1 - h)$$

where r is the proportion of fish that die, d is the proportion of fish that die from barotrauma, and h is the proportion of fish that die from hooking location. For each species, the proportion of fish that die due to depth was based on the logistic regression of gastric distention on depth. These data were from both legal and sub-legal fish. Visually determined gastric distention (if the stomach was visible in the mouth) was assumed to result in mortality. Hooking location was divided into three categories: jaw, gill/gut/throat and eyes/body. The proportion of fish that die from various hooking locations was determined from published estimates of release mortality of various species (Table 1). From these data, uniform distributions of potential mortality were applied and ranged from 0–20% for jaw hooking, 25–100% for gill/gut/throat hooking, and 0–60% for eye/body hooking. Using uniform distributions assured equal probability of values within these ranges. Broad ranges of values and uniform distributions were used to capture the full range of uncertainty in the estimates.

For each simulation, 10 000 values of d and h were sampled to generate an overall probability density of mortality for each species. A random value for d was determined by sampling from a normal distribution with the mean and standard deviation from either the logistic regression (if significant) or binomial proportion of gastric distention from fish caught in this study (in those cases where the logistic regression was not significant). Depth was randomly sampled (with replacement) from the depth values observed in this study.

Random values for h were computed in two stages. First, the hooking location frequencies were randomly sampled using a multinomial distribution with the observed sample size. Based on this random hooking frequency distribution, a single hooking location was determined with a random number draw. Second, a mortality value was assigned to the hooking location by sampling from the literature-derived hooking location mortality ranges discussed above. Median results are reported due to the skewed and potentially bimodal probability distributions that may arise.

Results

There were substantial differences in discard percentages among the six species that are size-regulated (Table 2; Fig. 1). Three species (red porgy, gag and scamp) had discard percentages of 25% or more. The generally high percentages of sub-legal specimens (> 10%) demonstrates the importance of evaluating the fate of individuals that are released. Even small (~25 mm) increases in minimum size limits would, at least initially, dramatically increase the number of sub-legal discarded vermilion snapper, red porgy, and black sea bass.

Table 2. Discard percentages (% sub-legal), total lengths and capture depths for eight commercially important reef species collected on 35 fishing trips in 2004 and 2005. There are no minimum length limits for snowy grouper and white grunt

Species	*n* (% sub-legal)	Fish total length (mm)		Capture depth (m)	
		Mean	Range	Mean	Range
Vermilion snapper	577 (14.6)	375	203–584	41.8	31.2–56.7
Red porgy	447 (25.3)	377	229–533	45.7	30.3–100.0
Red grouper	371 (6.7)	704	254–991	40.0	28.2–61.2
Gag	167 (33.5)	654	368–1067	29.0	18.8–85.2
Scamp	37 (35.1)	584	305–838	46.8	28.2–100.0
Black sea bass	199 (11.6)	332	178–482	28.5	19.1–71.2
Snowy grouper	24	482	203–711	137.6	78.8–143.3
White grunt	110	321	203–483	36.6	19.1–42.7

Table 1. Hooking mortality percentages used as input data of mortality models of North Carolina reef fishes

Source	Hook location	Species	Mortality %
Willis & Millar (2001)	Gut	Hauraki Gulf snapper	98
Diodati & Richards (1996)	Gill/gut	Striped bass	24
	Jaw	Striped bass	5.7
Murphy, Heagey, Neugebauer, Gordon & Hintz (1995)	Gut	Spotted seatrout	26.4
	Eye	Spotted seatrout	0
	Jaw	Spotted seatrout	1.4
Muoneke & Childress (1994)	Gill/gut	Numerous	24–100
	Jaw	Numerous	0–22
	Eye/body	Numerous	0–76
Vincent-Lang, Alexandersdottir & McBride (1993)	Gill/gut	Coho salmon	33–45
	Jaw	Coho salmon	22
Bugley & Shepherd (1991)	Gut	Black sea sass	50–66
	Jaw	Black sea bass	0
Wertheimer (1988)	Gill	Chinook salmon	85
	Eye	Chinook salmon	58.5
	Jaw	Chinook salmon	10.6

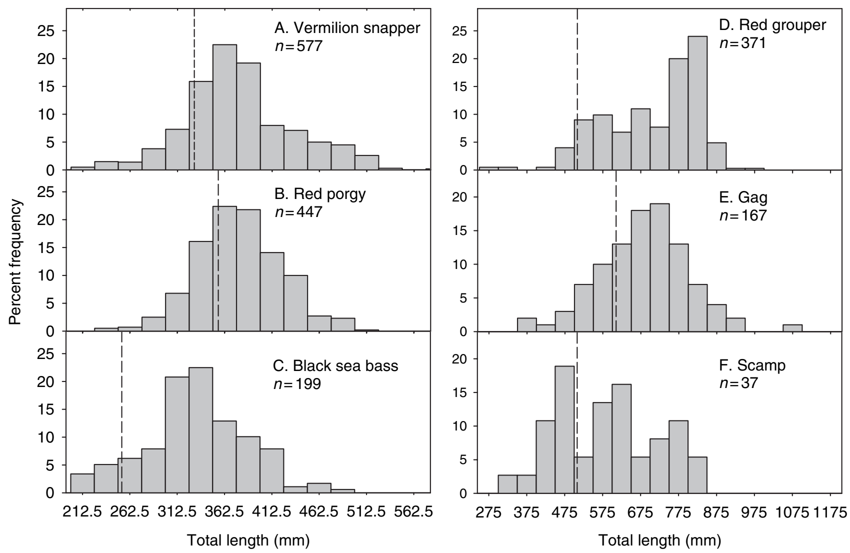

Figure 1. Length–frequency histograms for six commercially important, size-regulated reef species caught from 35 commercial reef fishing trips in 2004 and 2005. Vertical dashed lines on each panel represent commercial minimum total length limits.

Owing to the small area of productive reef habitat, commercial fishermen in this study fished small, discrete areas. For that reason, each of the species was caught from a relatively narrow depth range (Table 2; Fig. 2) where barotrauma may be an issue.

Immediate post-release indices (1–4) were not significantly different among observed ($n = 138$) and unobserved ($n = 88$) released vermilion snapper ($\chi^2 = 6.90$, $P = 0.075$) or for observed ($n = 137$) and unobserved ($n = 58$) released red porgy ($\chi^2 = 6.26$, $P = 0.099$). Because the post-release indices did not differ between observed and unobserved trips for vermilion snapper and red porgy, release data from observed and unobserved trips were combined (Table 3).

Immediate release mortality (indices of 3–4) occurred in only 83 of the 862 releases. Low rates of immediate release mortality held true for most species; vermilion snapper, gag, red grouper, black sea bass, and white grunt each had rates less than 10% (Table 3). Across all size classes, red porgy had a moderate mortality rate of 14%. Scamp had the highest rate of mortality (23%).

For size-regulated species with released sub-legal and legal specimens for which a chi-square test statistic could be computed (at least one release value of 3 or 4 per group), the proportions of released fish with indices of 3 or 4 were not significantly different among legal and sub-legal vermilion snapper ($\chi^2 = 0.396$, $P = 0.529$), red porgy ($\chi^2 = 1.23$, $P = 0.267$), red grouper ($\chi^2 = 0.451$, $P = 0.502$) or black sea bass ($\chi^2 = 0.011$, $P = 0.915$) (Table 3). Thus, size does not appear to have an effect on immediate mortality for these species, and an increase in the minimum size limit would not change the percentage of discards that die after release.

The percentage of fish with gastric distention ranged from 16% for red porgy to 91% for snowy grouper (Table 4). The effects of water depth on gastric distention were species specific. Logistic regressions indicated water depth had an unexpected negative association with the percentage of fish with gastric distention for vermilion snapper ($\chi^2 = 6.22$, $P = 0.013$), red porgy ($\chi^2 = 8.53$, $P = 0.003$) and white grunt ($\chi^2 = 9.44$, $P = 0.002$), but a positive association with gastric distention for red grouper ($\chi^2 = 11.54$, $P = 0.007$) and gag ($\chi^2 = 6.46$, $P = 0.011$). The counterintuitive results for vermilion snapper, red porgy and white grunt were due to a few individuals from deepwater with no gastric distention. Water depth was not associated with gastric distention for black sea bass ($\chi^2 = 1.11$, $P = 0.291$) and snowy grouper ($\chi^2 = 1.23$, $P = 0.268$). Fish length had a significant positive relationship with gastric distention only for vermilion snapper ($\chi^2 = 6.98$, $P = 0.008$) and red grouper ($\chi^2 = 13.58$, $P < 0.001$). The incidence of released fish with release indices of 3 or 4 was not significantly different between specimens with and without gastric distention for vermilion snapper ($\chi^2 = 0.004$, $P = 0.953$), red porgy ($\chi^2 = 2.36$, $P = 0.124$), red grouper ($\chi^2 = 0.058$, $P = 0.810$), scamp ($\chi^2 = 0.219$, $P = 0.640$), black sea bass ($\chi^2 = 0.311$, $P = 0.577$) and white grunt ($\chi^2 = 0.358$, $P = 0.549$).

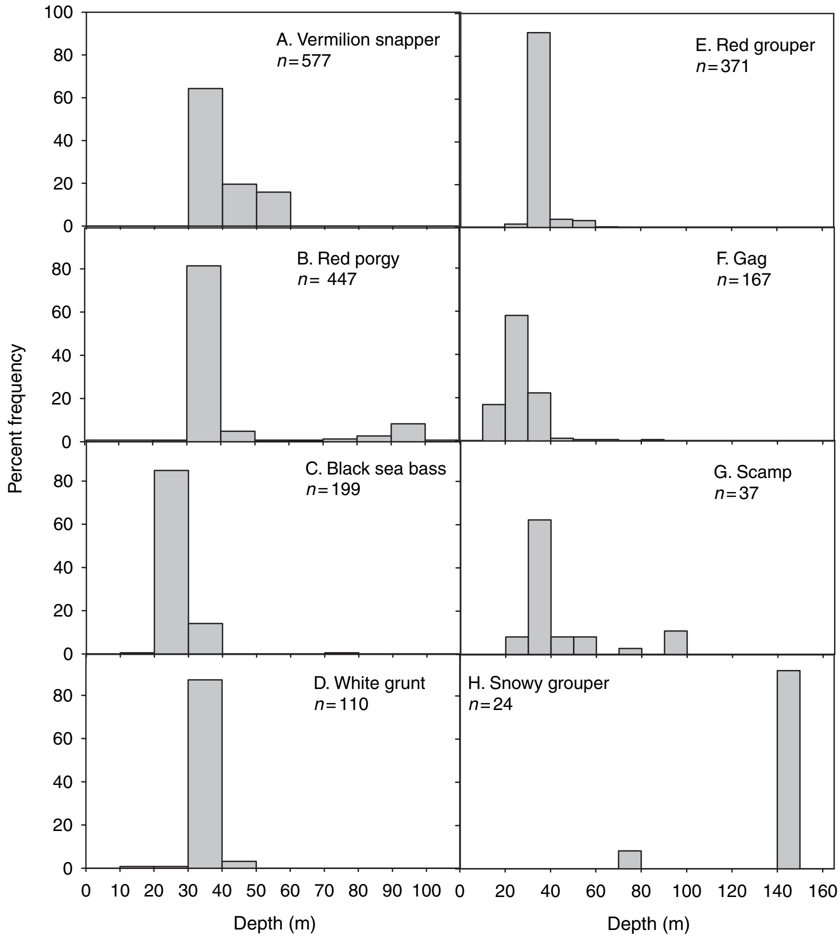

Figure 2. Depth–frequency histograms for eight reef species caught from 35 commercial reef fishing trips in 2004 and 2005.

Bleeding occurred in less than 10% of the cases for vermilion snapper, red porgy, red grouper, scamp and white grunt, but was higher for gag and black sea bass (Table 4). The proportion of released fish with indices of 3 or 4 was significantly different among specimens with and without bleeding only for red porgy ($\chi^2 = 10.60$, $P = 0.001$).

The percentage of jaw hooking was greater than 80% for almost all species and hook sizes combinations (Table 5). Hook size influenced gut hooking only for vermilion snapper ($\chi^2 = 6.96$, $P = 0.008$) and red porgy ($\chi^2 = 6.78$, $P = 0.009$). Due to the low number of gut-hooked gag and scamp and the narrow range of hook sizes that caught snowy grouper, logistic regressions of hook size on gut hooking were not calculated for these species. Hooking reef fishes in areas other than the jaw, such as in the gut, gills or eyes, can also cause delayed mortality.

Due to low sample sizes for other species, the number of release indices 3 or 4 to indices 1 or 2 was compared among jaw-hooked and gut-hooked fish only for vermilion snapper, red porgy and black sea bass. The ratio of released fish with indices of 3 or 4 was significantly greater among specimens with gut hooking than jaw hooking for vermilion snapper ($\chi^2 = 5.66$, $P = 0.017$) and red porgy ($\chi^2 = 4.66$, $P = 0.031$) but not for black sea bass ($\chi^2 = 0.547$, $P = 0.460$) (Table 6).

Delayed mortality estimates were greater than immediate mortality estimates (Table 7). Estimates of delayed mortality varied by species and depth (Fig. 3). Depth had a positive effect on delayed mortality for gag. Depth had a negative effect on delayed mortality for red porgy and vermilion snapper owing to a small number of individuals that were captured from deeper waters with no signs of gastric distention. Red porgy and white grunt had the lowest rates, gag and vermilion snapper moderate rates, red grouper and black sea bass high rates and snowy grouper the highest rate of delayed mortality for the depths observed in this study.

Table 3. Number of fish at each release index for the seven most abundant species captured from 50 reef fishing trips in 2004 and 2005. The release indices are: (1) alive, oriented themselves towards the bottom, and swam down vigorously; (2) alive, oriented themselves towards the bottom, and swam down slowly or erratically; (3) alive but swam at the surface; (4) dead or unresponsive. Vermilion snapper, red porgy, red grouper, gag and black sea bass are separated by legal and sub-legal specimens. Vermilion snapper and red porgy were also separated by observed ($n = 33$) and unobserved trips ($n = 17$). Not enough legal-sized scamp (≥508 mm) were released to separate legal from sub-legal specimens. White grunt do not have a minimum size limit. Mortality is the percent of fish assigned release indices 3 or 4

		Release index				
Species	Total number released	1	2	3	4	Mortality
Vermilion snapper	226	90	114	12	10	9.7
< 330 mm	114	51	50	7	6	11.4
≥330 mm	112	39	64	5	4	8.0
Observed	138	63	60	8	7	10.9
Unobserved	88	27	54	4	3	8.0
Red porgy	195	103	64	13	15	14.4
< 356 mm	139	79	43	6	11	12.2
≥356 mm	56	24	21	7	4	19.6
Observed	137	66	49	12	10	16.1
Unobserved	58	37	15	1	5	10.3
Red grouper	81	65	9	4	3	8.6
< 508 mm	68	57	4	4	3	10.2
≥508 mm	13	8	5	0	0	0
Gag	55	49	6	0	0	0
< 609 mm	46	43	3	0	0	0
≥609 mm	9	6	3	0	0	0
Scamp	13	5	5	2	1	23.0
Black sea bass	83	70	10	1	2	3.6
< 254 mm	39	32	6	1	0	2.6
≥254 mm	44	38	4	0	2	4.5
White grunt	203	137	49	4	13	8.4

Table 5. Percentage hooking location by J-hook hook size for eight reef species from 50 trips in 2004 and 2005. Only hook sizes with $n \geq 10$ are listed

			Hooking location				
Species	Hook size	n	Jaw	Gut	Gill	Eye	Body
Vermilion snapper	1/0	10	90.0	10.0			
	2/0	153	91.0	5.2	0.6	2.6	0.6
	3/0	339	90.1	9.0	0.3	0.3	0.3
	4/0	30	100				
	5/0	33	100				
	6/0	54	96.3			1.9	1.9
Red porgy	2/0	116	94.0	6.0			
	3/0	159	86.2	13.8			
	4/0	22	77.3	22.7			
	5/0	54	92.6	7.4			
	6/0	70	95.7	4.3			
	7/0	21	85.7	14.3			
	8/0	24	100				
	9/0	45	97.8			2.2	
Red grouper	3/0	26	88.5	11.5			
	6/0	64	92.1	6.3	1.6		
	7/0	29	69.0	31.0			
	8/0	89	89.9	10.1			
	9/0	171	91.8	8.2			
Gag	6/0	23	100				
	7/0	39	100				
	8/0	19	100				
	9/0	34	97.1	2.9			
	10/0	60	95	1.7	3.3		
Scamp	8/0	11	100				
Black sea bass	3/0	22	81.8	4.5	13.6		
	4/0	67	68.6	26.9	3.0	1.5	
	5/0	118	78.9	16.1	4.3		
	6/0	83	90.4	6.0	3.6		
	8/0	10	90.0	10.0			
	10/0	12	83.3	16.7			
Snowy grouper	5/0	72	94.4	5.6			
	6/0	96	95.8	3.1			
White grunt	2/0	10	90.0	10.0			
	3/0	117	100				
	5/0	12	91.7				8.3
	6/0	375	98.7	0.3	0.3	0.3	0.5
	9/0	13	86.2	7.1			7.1

Table 4. Percentage of fish with gastric distention and bleeding for eight reef species from 50 trips in 2004 and 2005. Percentage of release indices 3–4 to all fish caught in a category is listed as Mortality

Species	n	Gastric distention	Mortality (gastric distention)	Mortality (no gastric distention)	Bleeding	Mortality (bleeding)	Mortality (no bleeding)
Vermilion snapper	648	36.7	9.3	10.0	4.5	21.4	8.9
Red porgy	555	15.6	27.5	12.0	5.1	50.0	11.7
Red grouper	438	64.6	9.1	5.4	7.3	20.0	7.9
Gag	190	34.2	0	0	14.7	0	0
Scamp	46	45.7	20.0	25.0	2.2	n/a	23.0
Black sea bass	329	60.8	3.7	3.4	17.6	7.7	2.9
White grunt	552	25.4	5.9	9.6	2.1	16.7	8.1
Snowy grouper	180	91.1			4.4		

Table 6. Immediate mortality percentage (indices 3–4 compared with total sample size for a group) based on release index by hooking location (jaw and gut) for vermilion snapper, red porgy, and black sea bass from 50 reef fishing trips in 2004 and 2005. Hooking locations other than the jaw occurred in too few cases for the other species to report average release indices

Species	Hooking location	*n*	Mortality
Vermilion snapper	Jaw	208	7.7
	Gut	12	33.3
Red porgy	Jaw	175	12.6
	Gut	14	35.7
Black sea bass	Jaw	72	2.7
	Gut	6	16.7

Table 7. Percent immediate mortality and median delayed mortality for five reef species, by depth strata

Species	Depth strata (m)	Immediate mortality	Delayed mortality
Vermilion snapper	25–50	9.6	44.5
	50–75	14.3	31.3
Red porgy	25–50	13.6	26.0
Gag	19–25	0	33.7
	25–50	0	49.0
Red grouper	25–50	8.6	70.6
White grunt	25–50	8.4	31.5
Snowy grouper	All depths	n/a	92.1
Black sea bass	All depths	3.6	65.7

Discussion

The data collected suggest that sub-legal specimens comprise a substantial percentage of the catch of commercially important groupers, snappers, and porgies caught off North Carolina. Of the six size-regulated target species, only red grouper had a discard rate less than 10%. Catches of vermilion snapper indicate that the discard rate for this species would, at least initially, roughly double by increasing the minimum size limit from 330 to 356 mm TL. Overton & Zabawski (2004) also found that high percentages of catches of several important reef species (gag, scamp and red porgy) in North Carolina are composed of sub-legal specimens. High discard rates necessitate an evaluation of the fate of released individuals.

Without citing specific capture depths, Huntsman & Manooch (1978) reported that most undersized specimens caught in the south Atlantic snapper–grouper–porgy reef fishery will likely die from barotrauma. In contrast, less than 10% of released individuals were scored as immediate mortalities in this study. However, discarded fish in this study may have suffered from delayed effects of being caught (hooking, barotraumas or prolonged handling times) or predation (Burns, Koenig & Coleman 2002; Guccione 2005).

Reef fish may have suffered predation mortality attempting to swim to the bottom after release. Mid-water apex predators in North Carolina waters that are capable of consuming reef fishes include bottlenose dolphins *Tursiops truncates* (Montagu) (Burns, Parnell & Wilson 2004), king mackerel *Scomberomorus cavalla* (Cuvier), greater amberjack, *Seriola dumerili* (Risso) and a variety of sharks. It is reasonable to assume that piscivorous predators accounted for relatively few mortalities of released fishes in this study because they were rarely seen in surface waters, infrequently captured as by-catch, and never preyed on fish that were being reeled up.

The hook styles and sizes used by the commercial fishing cooperators used in this study are also commonly used in the North Carolina commercial reef fishery. In this fishery, larger hooks appear to reduce the rate of gut hooking and, thus, would increase survival of released sub-legal fishes although they may decrease catches of gape-limited species such as snappers and porgies (Bacheler & Buckel 2004).

Gastric distention did not increase the rate of immediate mortality for any species. However, this or other barotrauma may cause delayed mortality (Burns *et al.* 2002; Guccione 2005). The tissue and organ damage caused by rapid depressurisation can be extensive and may be lethal (Huntsman & Manooch 1978; Schirripa *et al.* 1999; Burns & Restrepo 2002). In analysing survival of caged vermilion snapper, Collins, McGovern, Sedberry, Meister & Pardieck (1999) found that survival was 100% down to 35 m, but decreased to 82% at 43–55 m. Burns *et al.* (2002) suggested for a water-column species, like vermilion snapper, predation on released individuals would be high because of their inability to maintain position in the water column. Therefore, even though physoclistous swim bladders can heal (Burns *et al.* 2002), they would be susceptible to epibenthic predators until their bladders healed sufficiently for them to return to their normal habitat a few metres above the bottom. Barotrauma in reef fishes may also lead to delayed mortality because reef fishes cannot meet the energetic demands to regulate their position in the water column by actively swimming if they have damaged swim bladders (Burns *et al.* 2002).

There were substantial differences among grouper species in the percentage of fish with gastric distention. Because they all possess physoclistous swim bladders, the differences in rates of barotrauma among grouper species in this study are likely due to differences in depths of capture. Snowy grouper, which were caught

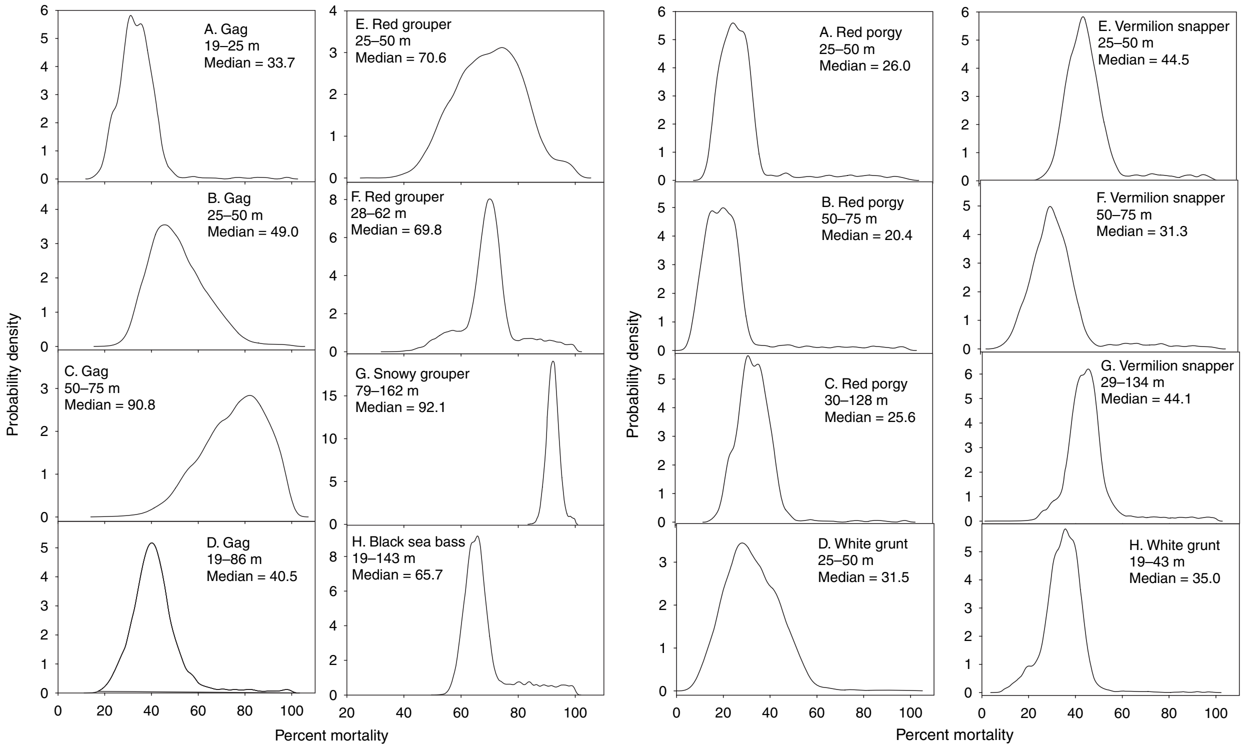

Figure 3. Probability densities of delayed mortality for reef species captured in Onslow Bay, North Carolina. Plots for each species include depth strata commonly observed in the North Carolina commercial fishery and median percent mortality. For panels G and H, as the regressions of gastric distention vs depth were not significant, depth was randomly sampled from the binomial proportion of fish exhibiting gastric distention over all depths of collection in this study.

in the deepest waters, had the greatest rates of gastric distention. Gag, caught from the shallowest waters among the groupers, had the lowest rate of gastric distention. Previous studies have addressed methods to ameliorate gastric distention for groupers captured from deepwater. Rapid depressurisation with a very small diameter, hollow needle inserted into the peritoneal cavity (see Collins *et al.* 1999 for a description of this method) increased short-term (< 1 month) survival of red grouper and gag with ruptured swim bladders that were captured in Florida waters > 21 m deep, tagged, and recaptured by hook and line (Burns & Restrepo 2002). This simple depressurisation technique may hold promise of further increasing post-release survival of sub-legal serranids captured in North Carolina waters if coupled with short onboard de-hooking and handling times achieved by experienced commercial fishermen.

Deck times (when fish are exposed to air and surface atmospheric pressure) for sub-legal individuals in typical commercial fishing operations may vary widely. Commercial fishermen typically elect to stop fishing to cull their catch only after the catch rate has declined below some subjective threshold. Even when held in water at the surface, Burns *et al.* (2002) found that mortality of reef fishes captured from 40 m ranged from 20% when held at the surface for 3 min to 100% when held at the surface for 18 min. In contrast, the authors found no mortality after 18 min in fish captured from 20 m deep. Such depth-related findings may partially explain why survival is thought to be so low for deepwater species (Huntsman & Manooch 1978). Although the effect of handling time was not measured, future research on this fishery should consider examining the effect of deck time on survival of important species over the depths at which they are captured in North Carolina.

One advantage in using the probability model to predict delayed mortality is that it examines the combined effects of two major sources of mortality (viz. hook location and presence of barotrauma) in angling reef fishes. These mortality probabilities by depth strata indicate that rates of delayed mortality are substantially higher than those observed at release. Modelled results for delayed mortality are similar to the logistic regression modelling by Burns *et al.* (2002)

that found a 50% mortality rate could be expected for gag collected from roughly 40 m. The mortality results simulated for gag are also similar to a recently completed tagging study in the South Atlantic Bight (McGovern, Sedberry, Meister, Westendorff, Wyanski & Harris 2005) that modelled gag mortality for this species to be 23.0%, 49.2% and 75.9% at water depths of 25, 45 and 65 m, respectively. The modelling conducted as part of this study assumes that fish with obvious signs of barotraumas died. While it is possible that some fish with obvious barotrauma survive after release, it is also possible that fish without observed barotrauma die after release. The results of this study lack validation, therefore unbiased measurements of mortality rates of pressure-traumatised reef fishes are needed across a wide range of depths to aid in estimating rates of delayed mortality.

Despite mortality of fishes after they are released, minimum size limits will likely be used to manage this deepwater fishery for the foreseeable future. Minimum size limits are easy to apply and enforce in this commercial fishery due to the small number of ports where fish are landed. Such limits may discourage fishing at times and places where sub-legal fish are frequent (Huntsman & Manooch 1978). Commercial fishermen inherently desire to reduce their catches of sub-legal or unmarketable discards, which likely helps the effectiveness of size limits. For these reasons, the utility of size limits for reef fishes cannot be assessed solely in the context of post-release survival rates but must also be considered for their influence on fishing practices. As minimum size limits are increased, commercial reef fishermen will likely modify the species targeted, fishing locations, and hook sizes to try to eliminate catches of sub-legal fishes.

While immediate mortality in released fishes may appear low, but the results of the simulation model suggest that delayed mortality can be substantial. Based on the results above, it was concluded that minimum size limits are moderately effective for vermilion snapper, red porgy, gag and black sea bass caught over the shallower portions of their depth ranges, and nearly ineffective for reef species such as snowy grouper that inhabit deep waters. For each species over the most common depths of capture in North Carolina, managers should determine whether the benefits to a stock of an increased size limit will offset release mortality as the number of sub-legal discards rises. Some alternative management methods (e.g. marine-protected areas) do not use minimum size limits and are now being considered by the South Atlantic Fisheries Management Council.

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References

Bacheler N.M. & Buckel J.A. (2004) Does hook type influence catch rate, size, and injury of grouper in a North Carolina commercial fishery? *Fisheries Research* **69,** 303–311.

Bugley K. & Shepherd G. (1991) Effect of catch-and-release angling on the survival of black sea bass. *North American Journal of Fisheries Management* **11,** 468–471.

Burns K.M. & Restrepo V. (2002) Survival of reef fish after rapid depressurization: field and laboratory studies. *American Fisheries Society Symposium* **30,** 148–151.

Burns K.M., Koenig C.C. & Coleman F.C. (2002) *Evaluation of Multiple Factors Involved in Release Mortality of Undersized Red Grouper, Gag, Red Snapper, and Vermilion Snapper*. Mote Marine Laboratory Technical Report No. 790. 53 pp.

Burns K.M., Parnell, N.F. & Wilson R.R. (2004) *Partitioning Release Mortality in the Undersized Red Snapper Bycatch: Comparison of Depth vs. Hooking Effects*. Mote Marine Laboratory Technical Report No. 932. 36 pp.

Coleman F.C., Koenig C.C., Eklund A.M. & Grimes C.B. (1999) Management and conservation of temperate reef fishes in the grouper–snapper complex of the southeastern United States. *American Fisheries Society Symposium* **23,** 233–242.

Coleman F.C., Koenig C.C., Huntsman G.R., Musick J.A., Eklund A.M., McGovern J.C., Chapman R.W., Sedberry G.R. & Grimes C.B. (2000) Long lived reef fishes: the grouper-snapper complex. *Fisheries* **25**(3), 14–21.

Collins M.R., McGovern J.C., Sedberry G.R., Meister H.S. & Pardieck R. (1999) Swim bladder deflation in the black sea bass and vermilion snapper: potential for increasing postrelease survival. *North American Journal of Fisheries Management* **19,** 828–832.

Diodati P.J. & R.A. Richards (1996) Mortality of striped bass hooked and released in salt water. *Transactions of the American Fisheries Society* **125,** 300–307.

Gitschlag G.R. & Renaud M.L. (1994) Field experiments on survival rates of caged and released red snapper. *North American Journal of Fisheries Management* **14,** 131–136.

Guccione D.V. (2005) *Hooking Mortality of Reef Fishes in the Snapper–Grouper Commercial Fishery of the Southeast United States*. MSc Thesis, Wilmington, USA: University of North Carolina, 42 pp.

Harris P.J. & McGovern J.C. (1997) Changes in the life history of red porgy, *Pagrus pagrus*, from the southeastern United States, 1972–1994. *Fishery Bulletin* **95,** 732–747.

Huntsman G.S. & Manooch C.S. III (1978) Minimum size limits for reef fishes. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* **32,** 509–513.

Huntsman G.R., Vaughan D.S. & Potts J. (1994) *Trends in Populations Studies of the Porgy*, Pagrus pagrus, *in the Atlantic Ocean off North Carolina and South Carolina*, USA, 1972–1992. Beaufort, USA: National Marine Fisheries Service, 27 pp.

McGovern J.C., Wyanski D.M., Pashuk O., Manooch C.S. III & Sedberry G.R. (1998) Changes in the sex ratio and size at maturity of gag, *Mycteroperca microlepis*, from the Atlantic coast of the southeastern United States during 1976–1995. *Fishery Bulletin* **96,** 797–807.

McGovern J.C., Sedberry G.R., Meister H.S., Westendorff T.M., Wyanski D.M. & Harris P.J. (2005) A tag and recapture study of gag, *Mycteroperca microlepis*, off the southeastern U.S. *Bulletin of Marine Science* **76,** 47–59.

Muoneke M.I. & Childress W.M. (1994) Hooking mortality: a review for recreational fisheries. *Reviews in Fisheries Science* **2,** 123–156.

Murphy M.D., Heagey R.F., Neugebauer V.H., Gordon M.D. & Hintz J.L. (1995) Mortality of spotted seatrout released from gill-net or hook-and-line gear in Florida. *North American Journal of Fisheries Management* **15,** 748–753.

Musick J.A. (1999) Ecology and conservation of long-lived marine animals. *American Fisheries Society Symposium* **23,** 1–10.

Overton A.S. & Zabawski J. (2004) *Release Mortality of Undersized Fish from the Snapper/Grouper Complex off the North Carolina Coast*. Raleigh, USA: North Carolina Sea Grant, Raleigh, 26 pp.

Patterson W.F. III, Ingram G.W. Jr, Shipp R.L. & Cowan J.H. Jr (2000) Indirect estimation of red snapper (*Lutjanus campechanus*) and gray triggerfish (*Balistes capriscus*) release mortality. *Proceedings of the Annual Gulf and Caribbean Fisheries Institute* **53,** 26–536.

Schirripa M.J., Legault C.M. & Ortiz, M. (1999) *The Red Grouper Fishery of the Gulf of Mexico. Assessment 3.0*. Miami, USA: National Marine Fisheries Service, 57 pp.

SEDAR (2003) *Report of the Vermilion Snapper Assessment Workshop. Second SEDAR Process*. Charleston, USA: South Atlantic Fishery Management Council, 40 pp.

SEDAR (2004a) *Southeast Data Assessment and Review. SEDAR 4 Stock Assessment Report. Section IIIA. Assessment of Snowy Grouper (Epinephelus niveatus*) in the South Atlantic. Charleston, USA: South Atlantic Fishery Management Council, 134 pp.

SEDAR (2004b) *Southeast Data Assessment and Review 4, Report 1. Stock Assessment of the Deepwater Snapper–Grouper Complex in the South Atlantic*. Charleston, USA: South Atlantic Fishery Management Council, 513 pp.

SEDAR (2005) *Report of Stock Assessment: Black Sea Bass. SEDAR Update Process #1*. Charleston, USA: South Atlantic Fishery Management Council, 40 pp.

Vaughan D.S. & Prager M. (2002) Severe decline in abundance of the red porgy (*Pagrus pagrus*) population off the southeastern United States. *Fishery Bulletin* **100,** 351–375.

Vincent-Lang D., Alexandersdottir M. & McBride D. (1993) Mortality of coho salmon caught and released using sport tackle in the Little Susitna River, Alaska. *Fisheries Research* **15,** 339–356.

Wertheimer A. (1988) Hooking mortality of chinook salmon released by commercial trollers. *North American Journal of Fisheries Management* **8,** 346–355.

Willis T.J. & Millar R.B. (2001) Modified hooks reduce incidental mortality of snapper (*Pagrus auratus*: Sparidae) in the New Zealand commercial longline fishery. *ICES Journal of Marine Science* **58,** 830–841.

Wilson R.R. & Burns K.M. (1996) Potential survival of released groupers caught deeper than 40 m based on shipboard and in-situ observations, and tag-recapture data. *Bulletin of Marine Science* **58,** 234–247.