Short-Term Discard Mortality Estimates for Gray Snapper in a West-Central Florida Estuary and Adjacent Nearshore Gulf of Mexico Waters

Kerry E. Flaherty-Walia, Brent L. Winner, Amanda J. Tyler-Jedlund & John P. Davis

SEDAR51-RD-01

June 2016

North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

Short-Term Discard Mortality Estimates for Gray Snapper in a West-Central Florida Estuary and Adjacent Nearshore Gulf of Mexico Waters

Kerry E. Flaherty-Walia, Brent L. Winner, Amanda J. Tyler-Jedlund & John P. Davis

To cite this article: Kerry E. Flaherty-Walia, Brent L. Winner, Amanda J. Tyler-Jedlund & John P. Davis (2016) Short-Term Discard Mortality Estimates for Gray Snapper in a West-Central Florida Estuary and Adjacent Nearshore Gulf of Mexico Waters, North American Journal of Fisheries Management, 36:2, 329-340, DOI: 10.1080/02755947.2015.1129003

To link to this article: http://dx.doi.org/10.1080/02755947.2015.1129003

Published online: 30 Mar 2016.

North American Journal of Fisheries Management 36:329–340, 2016

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2015.1129003

ARTICLE

Short-Term Discard Mortality Estimates for Gray Snapper in a West-Central Florida Estuary and Adjacent Nearshore Gulf of Mexico Waters

Kerry E. Flaherty-Walia,* Brent L. Winner, Amanda J. Tyler-Jedlund, and John P. Davis
Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue Southeast, St. Petersburg, Florida 33701, USA

Abstract
Gray Snapper *Lutjanus griseus* are fished extensively by recreational anglers in inshore estuarine habitats and in coastal and nearshore reef habitats along Florida's Gulf of Mexico coast. Although a detailed fishery assessment of Gray Snapper has never been conducted, there is a need for discard mortality estimates due to the large number of individuals captured by the recreational fishery. Our objective was to characterize discard mortality for the Gray Snapper recreational fishery in a study area that was representative of the regions in which most of the recreational fishing for this species takes place. In total, 247 Gray Snapper were caught during short-term (48-h) discard mortality experiments; 17 of the fish died, resulting in an overall mortality rate of 6.9%. Discard mortality was lower for fish caught from inshore waters (2/143 fish; 1.4%) than for those captured from the nearshore zone (15/104 fish; 14.4%). The water depth at the capture site and the anatomical hook location significantly influenced the probability of mortality. Individuals that were caught in shallower water and that were hooked in the lip were most likely to survive catch and release, whereas fish that were hooked in the esophagus were least likely to survive.

The Gray Snapper *Lutjanus griseus* is a reef fish that occurs in the Gulf of Mexico (hereafter, Gulf); Gray Snapper depend on estuaries during their early life history (Starck and Schroeder 1971; Allman and Grimes 2002) and are most often found in coastal and offshore waters near structure (i.e., natural and artificial reefs) as adults. Gray Snapper larvae settle out of their planktonic stage into structurally complex estuarine habitats, such as seagrass beds (Allman and Grimes 2002; Tzeng et al. 2003; Denit and Sponaugle 2004). Juveniles and subadults are found in estuarine nursery areas like seagrass beds and mangrove shorelines; subadults later move into deeper seagrass beds and channels, eventually migrating offshore to reef habitats (Nagelkerken et al. 2000; Cocheret de la Morinière et al. 2002; Whaley et al. 2007; Faunce and Serafy 2008; Flaherty et al. 2014; Flaherty-Walia et al. 2015). Because Gray Snapper tend to remain in estuarine habitats longer than other reef-associated fishes, they may be vulnerable to inshore fishing pressure over a greater portion of their life history. Adults (maturing between 175–198 mm SL; ages 2–3) are most often found in deeper channels and farther offshore and are associated with hard bottom and rocky reefs (Starck and Schroeder 1971; Manooch and Matheson 1984; Domeier et al. 1996).

Many exploited reef fishes (specifically those of the snapper–grouper complex; Ault et al. 2006) along the southeastern U.S. coast are being overfished, due in part to increased recreational fishing in recent decades (Ault et al. 1998, 2005a; Coleman et al. 2004; Hanson and Sauls 2011). Traditional management practices include size limits and bag limits, but these harvest-restricting strategies may be less effective in fisheries with a high probability of discard mortality (Bartholomew and Bohnsack 2005). In Florida, the bulk (84%) of Gray Snapper landings occurs along the Gulf coast, and 85% of those landings are from the recreational fishery

*Corresponding author: kerry.flaherty-walia@myfwc.com
Received July 31, 2015; accepted December 2, 2015

(Ault et al. 2005b; FWRI 2010). In addition to directed angling pressure on adult Gray Snapper in coastal habitats, recreational anglers that target other popular sport fishes (e.g., Red Drum *Sciaenops ocellatus* and Common Snook *Centropomus undecimalis*) may incidentally catch undersized Gray Snapper. Fishing pressure on Gray Snapper has been addressed by the use of minimum size restrictions and bag limits to lower fishing mortality. At present, minimum size limits on the Gray Snapper recreational fishery are 254 mm TL (10 in TL) in Florida waters and 305 mm TL (12 in TL) in federal waters, and there is a daily bag limit of five Gray Snapper per person as part of a 10-snapper total bag limit. The management strategy that sets underlying size and bag limits assumes that discard mortality is minimal, yet species-specific discard mortality rates for Gray Snapper have not been estimated.

Full evaluation of these management strategies for Gray Snapper requires the estimation of discard mortality rates across the fishery—especially among undersized individuals, for which discard mortality may exceed (or at least be comparable to) the rate of natural mortality. The discard mortality rate influences the number of individuals that are ultimately available to the fishery or to the spawning population. Individual fish may also be caught and released more than once before recruiting to harvestable size (Taylor et al. 2001; Coggins et al. 2007; Pollock and Pine 2007). In terms of its effect on the population, discard mortality may partly account for potential recruitment failure, since most of the discards are juveniles or subadults that have not yet joined the adult population (Diamond et al. 1999). Spawning stock biomass and yield are typically overestimated in stock assessments that exclude discard mortality (Breen and Cook 2002), and this can lead to an overestimation of a species' allowable catch. Waters and Huntsman (1986) estimated that in reef fishes, discard mortality must be less than 50% if length limits can be expected to increase fishery yields, but discard mortality rates vary significantly across species, fisheries, and habitats (Bartholomew and Bohnsack 2005; Coggins et al. 2007).

Discard mortality rates for other reef fish species have been estimated from tag return data (McGovern et al. 2005; Burns et al. 2008; Sumpton et al. 2008; Rudershausen et al. 2014; Sauls 2014), submergence categories (Patterson et al. 2000; Rudershausen et al. 2007), models (Ault et al. 2005b; Rummer 2007), and cage experiments (Gitschlag and Renaud 1994; Overton et al. 2008; Diamond and Campbell 2009). Short-term (24–72-h) mortality is generally measured through containment studies, whereas long-term mortality is estimated through tag return or telemetry methods (Pollock and Pine 2007). Cage studies conducted with Red Snapper *Lutjanus campechanus* caught in waters of 10–100-m depth have reported a wide range of mortality rates (3–80%; Gitschlag and Renaud 1994; Diamond and Campbell 2009; Campbell et al. 2014). Another cage study using several species from the snapper–grouper complex documented mortality rates of 13–43% (Overton et al. 2008). These short-term mortality studies ascertained factors that influenced mortality, such as depth, temperature changes, and the anatomical location of the hook. Because the mortality rate varies among species and because a number of factors influence mortality, single-species experiments are necessary to obtain accurate mortality estimates that will be useful in stock assessments and management decisions.

Discard mortality for Gray Snapper in the Gulf could be significant given that recreational anglers caught approximately 23 million individuals in Florida Gulf waters from 2010 to 2014, of which approximately 82% were released alive (NOAA 2015). With even a modest rate of postrelease mortality, overall fish mortality estimates could be large. Accordingly, the Florida Fish and Wildlife Conservation Commission (Florida FWC) conducted experiments to estimate the short-term (<48 h) discard mortality rates for Gray Snapper captured with recreational fishing gear in a Gulf estuary and adjacent coastal waters.

METHODS

Field methods.—Four discard mortality experiments were conducted in the lower Tampa Bay estuary (inshore zone) and five experiments were conducted in adjacent Gulf waters (nearshore zone; Figure 1) during December 2009–July 2011 (Table 1). Fishing sites were selected in each zone based on the presence of preferred habitat and the availability of Gray Snapper, as determined by reconnaissance in these areas and knowledge offered by professional fishing guides. During each experiment, Gray Snapper were collected by Florida FWC scientists using recreational hook-and-line gear on one or two vessels during a single day (daytime or nighttime fishing). To represent the larger recreational fishing community during two of the inshore experiments and two of the nearshore experiments, as many as 10 volunteers (including recreational anglers and professional fishing guides and their vessels) were recruited from local fishing clubs to assist Florida FWC biologists. A Florida FWC biologist was on board each vessel to record data and to ensure that standardized sampling protocols were followed.

Discard mortality rates can be affected by anglers' expertise (Stunz and McKee 2006). Accordingly, participating anglers were classified as beginners (angling fewer than 5 times/year), intermediate anglers (angling > 5 times/year but usually not more than once per month), or experts (angling many times per month) based upon a survey that was designed by Florida FWC biologists and administered before each fishing trip. Upon joining scientists on a fishing trip, each angler was observed while using fishing gear and handling fish, and his or her expertise classification was adjusted as needed. Variability among anglers was accounted for by including these levels of expertise and appropriate covariates in subsequent analyses (Switzer and Lehnert 2006).

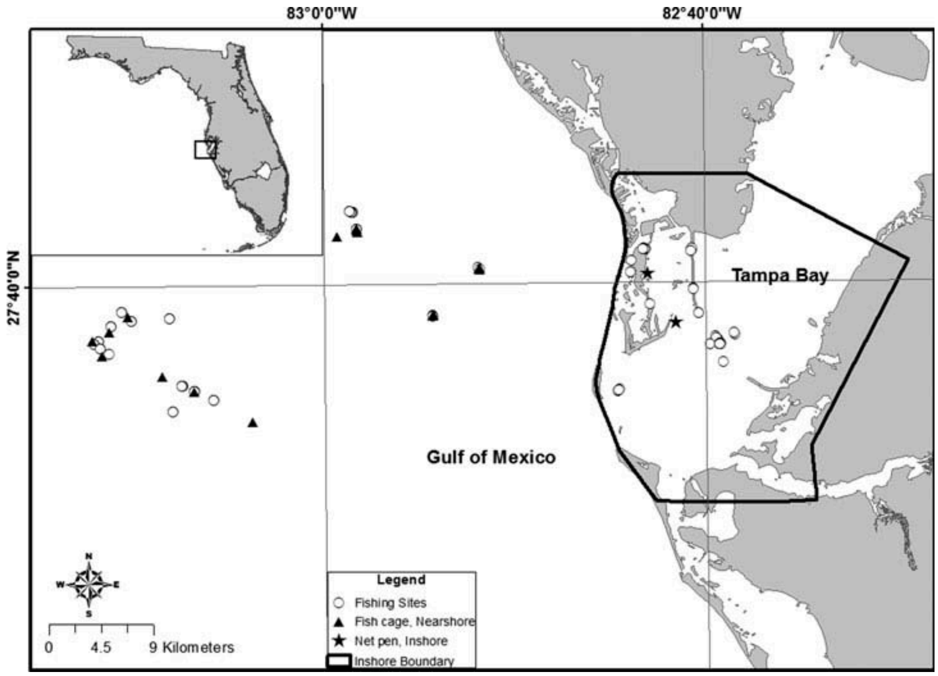

FIGURE 1. Map indicating the spatial extent of the Florida inshore (lower Tampa Bay) and nearshore (Gulf of Mexico) sampling zones and the locations of hook-and-line stations (white circles), net-pens (black stars), and cage drops (black triangles) used in discard mortality experiments with Gray Snapper, 2009–2011.

TABLE 1. Summary of discard mortality experiments with Gray Snapper, conducted in the lower Tampa Bay estuary (inshore zone) and neighboring Gulf of Mexico waters (nearshore zone) of Florida, 2009–2011.

	SL (mm)					
Experiment month and year	Mean ± SE	Min	Max	Total number	Number that died	Percent mortality[a]
Inshore zone						
Dec 2009	174.9 ± 2.3	150	234	53	0	0.0
Jul 2010	236.8 ± 6.1	196	302	24	2	8.3
Mar 2011	212.1 ± 3.6	168	293	56	0	0.0
Apr 2011	212.8 ± 13.2	163	312	10	0	0.0
Combined	202.5 ± 2.9	150	312	143	2	1.4
Nearshore zone						
Jun 2010	281.5 ± 5.4	208	330	22	2	9.1
Aug 2010	264	264	264	1	0	–
Nov 2010	325.6 ± 9.9	272	396	14	1	7.1
Jun 2011	321.8 ± 9.0	296	336	4	1	–
Jul 2011	314.5 ± 4.4	234	410	63	11	17.5
Combined	308.6 ± 3.6	208	410	104	15	14.4
Both zones						
All experiments	247.0 ± 4.0	150	410	247	17	6.9

[a]Percent mortality was not calculated (–) for individual experiments in which fewer than 10 individuals were collected.

Fishing tackle and field protocols were standardized on all vessels to appropriately represent those of the recreational fishery while minimizing variability so that factors influencing mortality could be detected. Light to medium tackle and non-offset circle hooks were used exclusively. Use of non-offset circle hooks for targeting reef fishes in Florida waters is mandated by state law (Wilson and Diaz 2012) and has been reported to significantly reduce the incidence of potentially lethal injuries in reef fishes (Sauls and Ayala 2012). Spinning reels (used in all experiments) were outfitted with 13.6-kg-test braided line, and bait-casting reels (used only in nearshore experiments) were outfitted with 13.6-kg-test monofilament line. Leader length was constrained to less than 60 cm inshore and to 60–120 cm nearshore to be representative of the lengths used in recreational fishing. We used hooks of different sizes depending on the zone fished or the size of fish targeted. For inshore experiments, anglers used a Mustad 2/0 circle hook and a 9.1-kg-test fluorocarbon leader; for nearshore experiments, anglers were randomly assigned either a Mustad 2/0 or 5/0 circle hook that was fished with an 18.1-kg-test fluorocarbon leader. For the four experiments that involved additional sampling effort by anglers and guides, standardized leaders and hooks were provided, but line and reel types varied and were recorded and accounted for in analyses. Bait type was recorded during all fishing; live and dead bait was used in inshore experiments, whereas only dead bait was used in nearshore experiments.

We recorded the time of day, date, location, water depth, and time fished (for each angler) at each fishing site. Standard length (mm) and associated catch-specific data (angler experience, bait type, hook size, hook location, and hook removal) were recorded for all of the collected Gray Snapper. For each fish, anglers also recorded fight time (the interval between hooking a fish and landing it on the boat) and handling time (the interval between landing a fish and releasing it into the surface holding tank). Anglers were limited to one fishing rod at a time to eliminate the confounding effects of an unattended, improperly recorded fish capture. Barotrauma, which is typically associated with a rapid ascent from depth, was recorded in nearshore experiments. A fish was considered to have suffered barotrauma if any of the following symptoms were present: abdominal bloating (due to a distended swim bladder), stomach eversion, exophthalmia, cloacal prolapse, or gas infusion into vital organs (Davis 2002; Rummer and Bennett 2005; Rummer 2007; Wilde 2009; Campbell et al. 2014). Venting (i.e., the use of a tool to release gases that accumulate in the swim bladder) is a common practice used by anglers to facilitate the successful release of fish that exhibit symptoms of barotrauma. However, variation in angler venting ability may affect fish survival (Wilde 2009); thus, to control for this, fish were not vented during the experiments. To permit individual fish to be identified during each experiment, a Florida FWC scientist tagged each fish in the anterior dorsal musculature with a uniquely numbered plastic dart tag (Hallprint type PDA) that was 70 or 100 mm long depending on fish size. To serve as random controls for estimating any tag-related effects on fish survival, the first fish collected in each predetermined 20-mm length-class was not dart tagged. Once processed, fish were temporarily (<1 h) placed into an onboard, flow-through surface holding tank or into a cage floating at the water's surface. The duration of temporary holding before each fish was transferred to the experimental containment enclosure was recorded since mortality rates have been found to decrease as transportation time from the location of capture decreases (Matlock et al. 1993).

Before any field sampling on the morning of the first day of inshore mortality experiments, one or two large containment enclosures (net-pens) were deployed in central locations within the study zone where water circulation and depth were sufficient (at all tides). The circular net-pens were constructed of 1.3-cm, knotless-nylon delta mesh; were 3.7 m in diameter × 2.4 m deep (~25 m^3); and were enclosed with a top panel and a bottom panel. Sponge floats (7.62 cm in diameter × 3.8 cm wide) were spaced every 30.5 cm along the top perimeter of each net-pen, and number-13 leads (36.9 g; 2.5 cm long) were spaced every 30.5 cm along the bottom perimeter. Eight stainless-steel rings (10.16 cm in diameter) were sewn into the top and bottom perimeters, evenly spaced, and vertically aligned. During experiments, each net-pen was secured to the estuarine bottom with eight galvanized poles threaded through each set of stainless-steel rings surrounding the pen. A single access port was sewn into the top of each net-pen to facilitate depositing and removing fish at the water surface. Net-pen configurations similar to this one have been tested in other estuarine hooking mortality studies, and no mortality associated with net-pen containment was observed among the control fish (Taylor et al. 2001).

Fish captured in nearshore experiments were held in 2.0-m^3 rectangular cages (2 m long × 1 m wide × 1 m deep; design based on Overton et al. 2008) made of 3.8-cm, vinyl-clad steel mesh. A door (0.7 × 0.7 m) was installed in the top of each cage for depositing and removing fish. Approximately 3 kg of rebar framed the entire inner perimeter of each cage to provide structural support. In addition, two clay bricks were secured via plastic zip ties to the inside of each cage to help sink the cages to the seafloor and minimize their movement due to currents. A cage was sunk once its carrying capacity (see below) was reached or after 1 h had elapsed since the first fish was placed in the cage.

In both inshore and nearshore experiments, Gray Snapper were held at a maximum density of 10 fish/m^3 (not to exceed 100 fish/net-pen [inshore experiments] or 25 fish/cage [nearshore experiments]; the latter was based on density reported by Overton et al. [2008] for the same cage design) and were held for at least 48 h to estimate short-term discard mortality that was likely related to hooking or handling. We selected 48 h as the minimum holding time in the containment enclosures because most of the discard mortality occurs within this period (Bugley and Shepherd 1991; Matlock et al. 1993; Gitschlag and Renaud 1994; Murphy et al. 1995; Taylor et al. 2001; Overton et al. 2008). Bottom temperature (°C), salinity (psu), and dissolved oxygen concentration (mg/L) were recorded at the containment locations by using a water quality data sonde. For inshore experiments, mortalities during the 48-h holding period were checked daily via remotely operated underwater vehicle, drop camera, or a swimmer. For nearshore experiments, a still camera (GoPro) was mounted on each cage to observe fish behavior and mortality within the first 2 h. At the end of each experiment (>48 h postcapture), all live fish in the containment pens or cages were identified based on their tag numbers (or their lengths in the case of controls), their condition was recorded, and the fish were then released. All dead fish were placed on ice and were taken to the laboratory for necropsy. Necropsies included gross external and internal evaluations, such as examination for ascites fluid, peritoneal thrombi, and traumatic hooking injury to major organs (i.e., heart, gill, stomach, anterior kidney, and liver).

Analytical methods.—Catch data were summarized for Gray Snapper collected during the experiments. Fishing locations and net-pen or cage deployment locations were plotted in a GIS. Length frequency histograms were constructed to display survival and mortality over the size ranges collected. Temperature, dissolved oxygen, and salinity levels measured in containment enclosures were compared among experiments in each zone by using a one-way ANOVA (PROC ANOVA in the Statistical Analysis System [SAS]; SAS Institute 2006).

As outlined above (Field Methods), some categorical variables in the experimental design differed between inshore and nearshore zones. For example, in inshore experiments, bait type was varied (live versus dead); in nearshore experiments, hook size was varied (2/0 versus 5/0 non-offset circle hooks) and barotrauma was recorded. Before a discard mortality model was developed, factors that could confound the results between the inshore and nearshore zones were tested for significance. To determine whether these factors differentially influenced mortality, we conducted two-way chi-square tests (PROC FREQ in SAS) to compare the number of fish that survived versus the number that died. To evaluate the effect of hook size on the sizes of fish captured during nearshore experiments, a Kolmogorov–Smirnov (K–S) test (PROC NPAR1WAY in SAS) was also used to compare the length distributions of individuals that were captured with different hook sizes. Containment enclosures (net-pens versus cages) differed between zones, so mortality rates were calculated for net-pen and cage replicates and then were compared between the two zones (PROC ANOVA in SAS). We also tested for a possible correlation between mortality rates and fish density in nearshore enclosures (PROC CORR in SAS).

Logistic regression (PROC LOGISTIC in SAS) was used to determine which variables significantly affected the probability of Gray Snapper mortality for inshore and nearshore zones combined. Class variables that were tested for inclusion in the model were (1) angler experience, (2) whether the fish was a tagging control, (3) hook position (lip, esophagus, or other), and (4) whether the hook had been removed. Continuous variables included (1) averaged bottom water quality characteristics (temperature, dissolved oxygen, and salinity) measured at the location of each containment pen or cage; and (2) each fish's depth at capture, fight time, handling time, surface holding time, and SL. The probability of mortality ($P[M]$) was estimated as $P(M) = e^u/(1 + e^u)$, where e is the base of natural logarithms and u is the linear function of the independent variables. A forward selection method was used to include significant variables ($P < 0.05$) in the model; once a variable was included in the model at $P < 0.05$, that variable was not removed.

RESULTS

Physical and water quality characteristics varied between the inshore and nearshore zones and among experiments. Capture depth differed by zone: Gray Snapper captures occurred in water depths of 1.5–11.0 m for the inshore zone and in depths of 10–25 m for the nearshore zone. Bottom water quality variables recorded at the net-pen and cage locations varied among the experiments (Figure 2). Water temperature for the mortality experiments ranged from 18.4°C to 32.5°C; six experiments were conducted in relatively warm water (28–32.5°C), whereas three experiments were conducted in cooler water (18.4–23.5°C). Dissolved oxygen concentration averaged 6.9 mg/L and ranged from 4.2 to 12.5 mg/L; nearshore dissolved oxygen levels were more stable than inshore levels, with significant differences observed among experiments. Salinity averaged 34.5 psu and ranged from 31.2 to 36.1 psu. Salinity was generally lower inshore (31.2–34.5 psu) than nearshore (34.2–36.1 psu) and differed among the experiments (Figure 2).

In total, 247 Gray Snapper (SL range = 150–410 mm; Table 1; Figure 3) were caught during the nine experiments; 17 fish died within 48 h, resulting in an overall mortality rate of 6.9% (1.4% for inshore waters; 14.4% for nearshore waters). Mortality rates for Gray Snapper over a 48-h time period in the two types of containment enclosure did not differ significantly within or between zones ($F = 0.81$, df = 1, $P = 0.3794$), demonstrating that the higher mortality rate detected in nearshore experiments was not attributable to the different enclosure type used. Mortality rates were also not correlated with the density of fish in nearshore cages ($P = 0.229$).

Both live bait ($n = 132$) and dead bait ($n = 11$) were used during the inshore experiments, but this experimental factor did not significantly influence Gray Snapper survival ($\chi^2 = 0.169$, $P = 0.681$). Similarly, hook size (2/0 [$n = 42$] versus 5/0 [$n = 62$]: $\chi^2 = 0.287$, $P = 0.592$) and observed signs of barotrauma (present [$n = 63$] versus absent [$n = 41$]: $\chi^2 = 1.1944$, $P = 0.275$) did not significantly influence survival during nearshore experiments. In addition, the size distribution of captured Gray Snapper did not vary significantly between the two hook sizes used in nearshore experiments (K–S test: statistic $KS_a = 0.726$, $P = 0.667$). Gray Snapper that were collected during inshore and nearshore experiments were therefore combined for analyses.

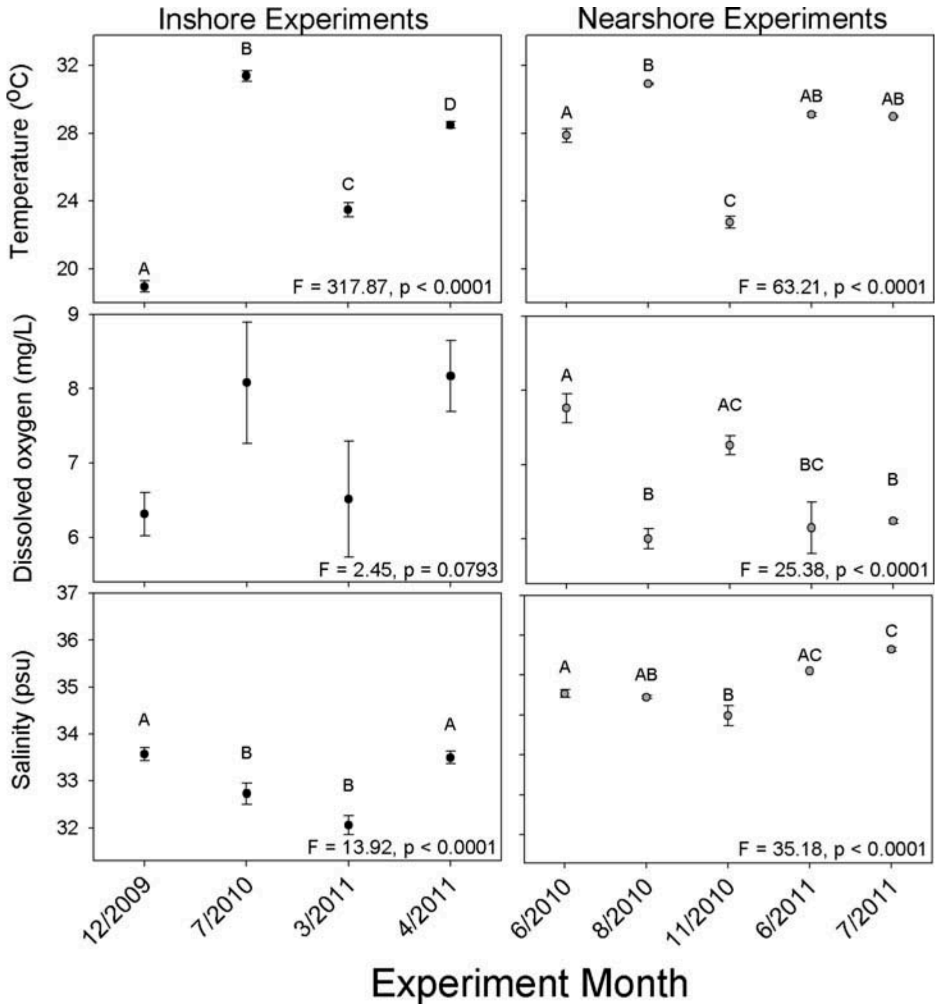

FIGURE 2. Net-pen (inshore) and cage (nearshore) bottom water quality (mean ± SE) measured during each discard mortality experiment with Gray Snapper, 2009–2011. One-way ANOVA results for differences by experiment month within each zone are presented in the bottom-right corner of each panel; points denoted by the same letter do not differ ($P > 0.05$).

Logistic regression analyses indicated that hook position, water depth at the location of capture, and whether the fish was a tagging control significantly influenced the probability of mortality (Table 2). Gray Snapper that were hooked in the lip were most likely to survive the catch-and-release event (100% survival inshore, 93% survival nearshore; Figure 4), whereas fish that were hooked in the esophagus were least likely to survive (0% survival inshore, 20% survival nearshore; Figure 4). The probability of mortality increased with water depth; average depth served as an indirect representation of zone since depths at nearshore sites were more than three times those at inshore sites (Table 3). The significance of whether a fish was a tagging control was misleading since we were controlling for tagging effects, and fish that were not tagged had a coincidentally greater probability of mortality than fish that were tagged; therefore, this effect was more likely attributable to other, confounding, factors (i.e., hook position in control fish). For example, fish that were tagging controls were hooked in the esophagus more often than tagged fish (8.3% versus 4.5%, respectively), likely contributing to the higher mortality among control fish.

Although some variables were nonsignificant in the logistic regression analyses, they exhibited noteworthy patterns related to fish mortality between zones. Average fight time was associated with depth (and, therefore, zone); it took more than twice as long to retrieve a fish in the nearshore zone than in the inshore zone (Table 3). Gray Snapper were significantly larger in the nearshore zone and SL was not significant in the logistic model, but chi-square tests performed on combined data from all Gray Snapper indicated that fish above the legal state size limit (~203 mm SL [10 in TL]; Figure 3) were less likely to survive the catch-and-release event ($\chi^2 = 9.24$, df = 1, $P = 0.0024$).

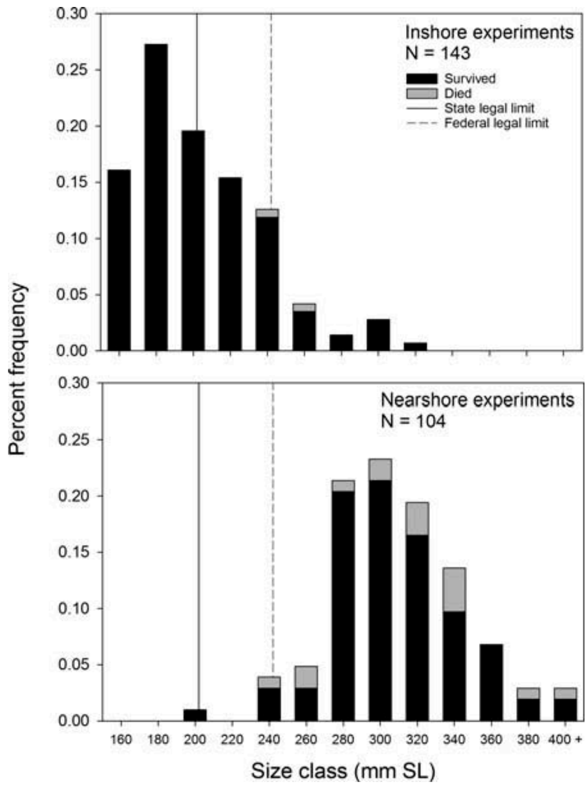

FIGURE 3. Length frequency of Gray Snapper collected during discard mortality experiments in Florida inshore and nearshore zones, 2009–2011. State and federal legal limits are denoted by vertical lines (10 and 12 in TL, estimated as 203 and 241 mm SL, respectively, based on SL–TL relationships from Tampa Bay data; N. Dunham, Florida FWC, personal communication).

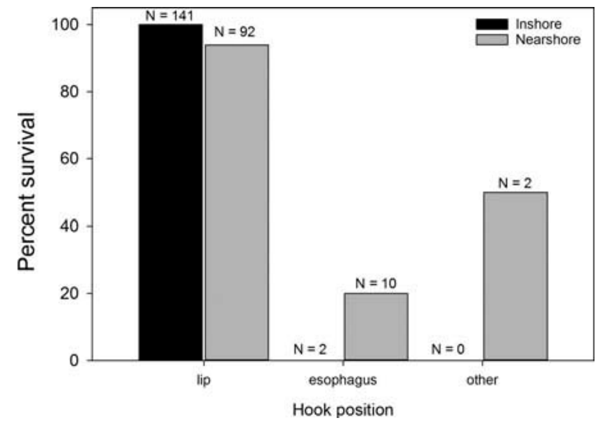

FIGURE 4. Percent survival of Gray Snapper relative to the hook position observed during discard mortality experiments conducted in Florida inshore and nearshore zones, 2009–2011 (N = number of fish collected).

TABLE 2. Factors influencing the probability of mortality for Gray Snapper captured in Florida inshore and nearshore zones (2009–2011), as determined via logistic regression analysis (forward selection; initial $P < 0.05$ required for inclusion in the model).

Factor	df	Wald χ^2	P
Intercept	1	5.127	0.024
Hook position	2	16.638	0.001
Water depth	1	6.741	0.009
Control	1	5.206	0.023

TABLE 3. Means (±SE) for selected continuous variables measured in discard mortality experiments with Gray Snapper in Florida inshore and nearshore zones, 2009–2011.

Variable	Zone	Survived	Died
Water depth (m)	Inshore	6.54 ± 0.17	6.50 ± 0.50
	Nearshore	20.67 ± 0.54	22.00 ± 1.16
Fight time (s)	Inshore	9.91 ± 0.98	10.00 ± 2.00
	Nearshore	26.64 ± 1.44	29.07 ± 4.33
Handling time (s)	Inshore	69.22 ± 2.52	56.00 ± 13.00
	Nearshore	67.32 ± 2.13	70.87 ± 6.12

TABLE 4. Necropsy results by hook position, indicating the types of injuries associated with Gray Snapper mortalities after capture from Florida inshore and nearshore zones, 2009–2011.

	Hook position			
Injury	Lip	Esophagus	Stomach	Total
Inshore zone				
Esophageal trauma		1		1
Other trauma		1		1
Nearshore zone				
Barotrauma	1			1
Gill trauma		2		2
Heart trauma		3		3
Unknown	5	3	1	9
Both zones				
Total	6	10	1	17

Necropsies identified five main classes of injury in Gray Snapper: esophageal trauma, gill trauma, heart trauma, other hooking trauma, and barotrauma (Table 4; Figure 5). Although hook location was originally recorded as the esophagus in two mortalities from inshore experiments and five mortalities from nearshore experiments, necropsies found that the cause of those mortalities was hook trauma to gill, heart, esophageal, or other tissue (Table 4; Figure 5). The cause of mortality could not be determined for nine other individuals that had been hooked in the lip, esophagus, or stomach; most of those fish were too badly decomposed after the 48-h experiment to observe hook trauma that might have contributed to their death. Barotrauma may have caused the death of one fish

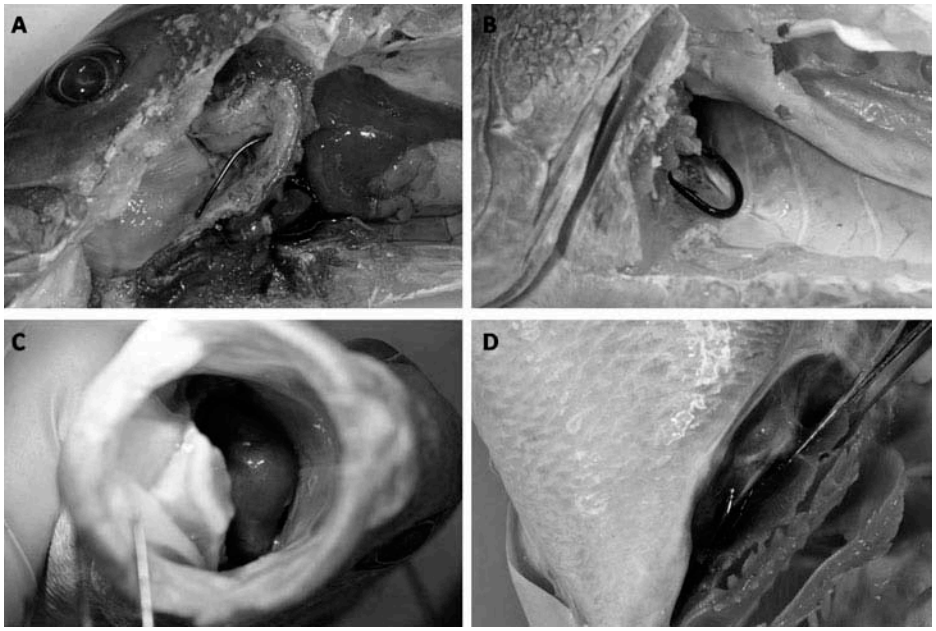

FIGURE 5. Examples of hook trauma observed in Gray Snapper, as determined by necropsy: **(A)** heart trauma, **(B)** esophageal trauma, **(C)** barotrauma, and **(D)** gill trauma (photos courtesy of Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Health program).

whose stomach had intruded into the peritoneum and expanded (Table 4; Figure 5).

Overall, 150 surveys were completed by 20 beginner anglers, 44 intermediate anglers, and 86 expert anglers. In general, the answers provided on the angler survey were appropriate for assigning their experience levels; only two anglers were assigned to a different experience level after being observed while participating in one of the discard mortality experiments. Angler experience did not influence the probability of Gray Snapper mortality based on the logistic regression (Table 2).

Based on tag recaptures through November 2015, 10 (4.3%) of the Gray Snapper that had been tagged and released (n = 230) during the mortality experiments were recaptured after 8–309 d at large; the recaptured individuals were all originally lip-hooked during the mortality experiments. The probability of recapturing a deep-hooked fish would have been very low considering that only three such fish had been released. In spite of the limited data available from tag returns, this recapture information indicates that lip-hooked fish survived much longer than the 48-h holding time.

DISCUSSION

These discard mortality experiments are the first of their kind to be conducted with Gray Snapper, and the estimated discard mortality rates (6.9% overall) were lower than published estimates for other species in the snapper–grouper complex (Collins 1991; Bartholomew and Bohnsack 2005; McGovern et al. 2005; Overton et al. 2008; Campbell et al. 2014; Sauls 2014). Collins (1991) reported an overall estimate of 19% discard mortality among 19 reef fish species. Estimates of discard mortality for Gags *Mycteroperca microlepis* ranged from 13% to 79% (Wilson and Burns 1996; McGovern et al. 2005; Sauls 2014). In a review of Red Snapper discard mortality studies, Campbell et al. (2014) reported that discard mortality ranged from 1% to 79% across a variety of study conditions. Overton et al. (2008) conducted a study using cage methods similar to ours and observed discard mortality rates of 37.5% for Red Porgy *Pagrus pagrus*, 43.8% for Scamps *Mycteroperca phenax*, and 13% for Gags. Variation in discard mortality rates among reef fishes can be substantial; although some of the variation can be attributed to species-specific differences, it is more often correlated with experimental design and environmental conditions (Collins 1991; Bartholomew and Bohnsack 2005; Overton et al. 2008; Campbell et al. 2014). In the present study, the anatomical hook location and the water depth at the capture site significantly influenced the probability of Gray Snapper mortality. These two factors are frequently found to influence discard mortality in reef fishes, but the lower mortality rates we observed may have been due to the exclusive use of circle hooks (i.e., less-frequent deep hooking) and due to the shallower overall depth range.

Anatomical hook position was found to influence the short-term discard mortality of Gray Snapper in this study, and hook-related trauma was evident in several dead fish, especially those that were hooked in the esophagus. The anatomical location of hooking can have a significant effect on the postrelease survival of fish (Muoneke and Childress 1994; Aalbers et al. 2004; Bartholomew and Bohnsack 2005;

Cooke et al. 2005; St. John and Syers 2005; Overton et al. 2008; Sauls and Ayala 2012). Bartholomew and Bohnsack (2005) found that hooking location was the most important factor contributing to fish discard mortality. The majority of fish caught in our study were hooked in the lip; hook wounds in the lip rarely result in injuries to vital organs, and this is typically reflected in a lower rate of short-term discard mortality (Aalbers et al. 2004; Cooke and Suski 2004; Vecchio and Wenner 2007). The high proportion of lip-hooked fish was most likely due to our exclusive use of circle hooks, which are designed to hook fish in the lip area, thus improving discard survival (Bartholomew and Bohnsack 2005). Sauls and Ayala (2012) found that 88.8% of Gray Snapper that were caught with circle hooks were hooked in the lip and that the use of circle hooks reduced potentially lethal injuries by 30%. Overton et al. (2008) reported that lip-hooked fish were 11 times more likely to survive a catch-and-release event than fish that were hooked in other anatomical locations. Conversely, hook wounds in deep anatomical locations (e.g., gills, esophagus, or gut) damage vital organs and contribute to higher rates of mortality (Muoneke and Childress 1994). The presence of bleeding due to hook wounds was associated with an increased probability of mortality (Fabrizio et al. 2008), so this would be a helpful variable to include in future studies. Removal of deeply ingested hooks can increase handling stress and mortality (Muoneke and Childress 1994), but if the hooks are left embedded in the peritoneal cavity or gut, they may eventually cause damage and contribute to long-term (>48 h) postrelease mortality (Lawson and Sampson 1996; Aalbers et al. 2004). Hooks can dissolve within a fish or can be extruded; tissue growth can also occur around the hooking wound (Muoneke and Childress 1994). Leaving the hook in deep-tissue areas may be less invasive initially but can have a negative effect on the long-term survival of a fish. Our results and those of other studies suggest that deeply hooked fish are less likely to survive once discarded (Lawson and Sampson 1996; Aalbers et al. 2004; Overton et al. 2008).

Numerous studies (including the present study) involving a variety of reef fish species have documented a positive correlation between the depth at capture and discard mortality, which is typically associated with barotrauma (Wilson and Burns 1996; Bartholomew and Bohnsack 2005; McGovern et al. 2005; Morrissey et al. 2005; St. John and Syers 2005; Overton et al. 2008; Sauls 2014). We observed a significant increase in Gray Snapper discard mortality with increasing depth at the capture site, but the observed barotrauma was not significantly correlated with mortality, although it may have contributed in some form to this observation. All of our nearshore field experiments were conducted in waters with depths less than 30 m, and such depths rarely produce lethal injuries from barotrauma (Rummer and Bennett 2005). It is possible that at such moderate depths, internal barotrauma effects were simply not noticeable upon external observation. For example, among the six lip-hooked fish for which we could not determine a cause of death, only one individual exhibited signs of barotrauma when landed. Other studies of various fish species have also found reduced discard mortality and barotrauma effects at shallower depths (McGovern et al. 2005; Jarvis and Lowe 2008; Sauls 2014). Sauls (2014) reported that more than 90% of fish collected at depths less than 20 m showed no external signs of barotrauma and that 70% of fish collected at depths greater than 30 m did show signs of barotrauma. Sauls (2014) also determined that discard mortality was only 15% for fish captured at depths less than 30 m but was 36% for fish captured at greater depths (>70 m). Campbell et al. (2014) likewise reported reduced mortality rates (7–13%) for recreationally caught Red Snapper at depths less than 30 m. Future studies of barotrauma's effects on Gray Snapper discard mortality across an increased depth range (>30 m) would help to define this relationship and would provide a better metric for estimating overall discard mortality in this species.

Cages or pens have been used to hold fish in discard mortality studies with a variety of species (Render and Wilson 1994; Taylor et al. 2001; Overton et al. 2008; Diamond and Campbell 2009; Flaherty et al. 2013; Campbell et al. 2014), but several caveats must be considered when interpreting the results of net-pen or cage studies for estimating fish mortality. In this study, fish were protected from predation during experiments, which could lead to underestimation of discard mortality in nature, as angled fish are typically released immediately back into the water and are then subject to predation. In addition, reef fish that are suffering from barotrauma and are released by fishers may die floating at the surface (if not properly vented) or may be preyed upon before they have time to submerge and recompress. In this study and other studies that have used cages, any fish that are affected by barotrauma are not only protected from predators but are also effectively recompressed as the cage is submerged, possibly reducing discard mortality estimates: studies have shown that a quick release back to depth can reduce mortality associated with barotrauma (Render and Wilson 1994; Parker et al. 2006). Campbell et al. (2014) reported a 10–20% reduction in discard mortality for fish that were caged but not vented. In the same meta-analysis, mortality was lower for fish that were vented and released immediately into the water (i.e., not caged) than for fish that were released immediately without being vented. However, evidence that venting fish with signs of barotrauma increases survival is still inconclusive, and the benefits can be depth dependent (Wilde 2009). Venting can also cause injuries to internal organs, and although venting may reduce some symptoms, it will not necessarily remedy all of the injuries associated with barotrauma (Morrissey et al. 2005; St. John and Syers 2005; Parker et al. 2006; Jarvis and Lowe 2008; Wilde 2009). In the present study, we chose to avoid venting the fish so as to eliminate venting-related internal injuries; we knew that at our experimental depths, barotrauma would usually be minimal. The use of pens or cages could also contribute to fish mortality via starvation, stress, or infection associated with containment (Diamond and Campbell 2009). However, holding times in the present study were so short that such factors were minimal or absent.

Stress associated with fight time, handling time, and surface holding time can affect discard mortality in fishes. For example, a study of Rainbow Trout *Oncorhynchus mykiss* demonstrated an increase in the probability of mortality with increased fight time and handling time out of the water (Schisler and Bergersen 1996). However, in a study of Chinook Salmon *O. tshawytscha*, increased handling stress was not associated with higher mortality rates (Wertheimer et al. 1989). Short-term survival of rockfishes *Sebastes* spp. was found to increase with decreasing surface holding time, indicating that a rapid return to depth could decrease the rate of discard mortality (Parker et al. 2006; Jarvis and Lowe 2008). In this study, we practiced responsible fighting and handling techniques, such as limiting play while fighting the fish, supporting the fish with both hands while handling, and processing the fish as quickly as possible. Fight time (<1 min) and handling time (<2 min) in our study were minimized and did not cause the critical stress levels that likely would have contributed to mortality risk. Although fight times for Gray Snapper collected nearshore were more than twice those for fish collected inshore, this was more a function of fishing at greater depths and landing larger fish. Handling times for nearshore-collected Gray Snapper that died were slightly longer than handling times for fish that survived, albeit not significantly so. Although surface holding and handling times did not significantly influence mortality in our experiments, it is still a good practice to minimize handling time, especially when fishing in deeper habitats. Fighting and handling times may also vary with angler expertise, and angling by inexperienced anglers has been shown to decrease fish survival (Stunz and McKee 2006). In our study, angler experience did not influence the probability of discard mortality; this result is likely attributable to the standard practices we established for handling the fish once they were removed from the water. The education of fishers—both recreational and commercial—on the negative effects of excessively handling the fish can increase fish survival and the effectiveness of management strategies that mandate discards.

Recent management strategies (i.e., size limits, bag limits, quotas, and seasonal closures) have generated increases in the number of discarded marine fishes, thereby increasing the need for valid, species-specific estimates of discard mortality (Bartholomew and Bohnsack 2005). Ninety-six percent of all Gray Snapper releases by recreational anglers in the Gulf are made in the inshore and nearshore areas along the Florida coast (inshore of the Exclusive Economic Zone; NOAA 2015). Information obtained from this study could be used in future stock assessments for Gray Snapper and in recommendations for management. Short-term mortality rates calculated during our study are relatively low compared with those for similar species, but the rates may increase depending on the capture depth and the hook position in the fish. Future studies on Gray Snapper should expand experimentation to a greater range of depths than represented in this study and should explore the effectiveness of various methods of fish recompression. Although catch-and-release fishing is an effective management tool for reducing take, it can contribute to mortality, and these impacts should not be overlooked when evaluating the overall health of fish populations and the value of management strategies.

ACKNOWLEDGMENTS

We are grateful to the Fish and Wildlife Research Institute (FWRI; Florida FWC) staff who put in countless hours of collecting and entering data; catching, measuring, and tagging fish; and ensuring that all components of this project were completed smoothly. Charter captains Bill Fehl, Matt McDuffee, Steve Papen, Jim Lemke, John Fabian, Harry Conner, Tony Frankland, Doug Hall, and Steve Betz provided their vessels and fishing expertise during nearshore hook-and-line sampling and inshore discard mortality experiments; Hubbard's Marina partnered with FWRI staff to conduct two 24-h nearshore discard mortality experiments. More than 40 volunteer recreational anglers participated in this project, contributing over 600 h, and 150 anglers responded to our Gray Snapper survey. Fellow FWRI scientists T. Cody, A. Richardson, C. Gray, M. Tabuchi, and M. Bakenhaster conducted the necropsies and related health assessments. Scientific oversight and grant administration were provided by P. Hood and D. Ruiz (National Oceanic and Atmospheric Administration, National Marine Fisheries Service [NMFS], Southeast Regional Office), respectively. The manuscript was improved by insightful reviews from D. Topping, S. Martin, D. Tremain, C. Purtlebaugh, B. Sauls, A. Collins, B. Crowder, and two anonymous reviewers. This project was supported in part by proceeds from State of Florida saltwater recreational fishing licenses and by funding from the U.S. Fish and Wildlife Service (Federal Aid in Sportfish Restoration Project FL-F-F14AF00328) and NMFS (Cooperative Research Program Grant NA09NMF4540136). The statements, findings, views, conclusions, and recommendations contained in this document are those of the authors and do not necessarily reflect the views of the U.S. Department of the Interior or the U.S. Department of Commerce and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

REFERENCES

Aalbers, S. A., G. M. Stutzer, and M. A. Drawbridge. 2004. The effects of catch-and-release angling on the growth and survival of juvenile White Seabass captured on offset circle and J-type hooks. North American Journal of Fisheries Management 24:793–800.

Allman, R. J., and C. Grimes. 2002. Temporal and spatial dynamics of spawning, settlement, and growth of Gray Snapper (*Lutjanus griseus*) from the west Florida shelf as determined from otolith microstructures. U.S. National Marine Fisheries Service Fishery Bulletin 100:391–403.

Ault, J. S., J. A. Bohnsack, and G. A. Meester. 1998. A retrospective (1979–1996) multispecies assessment of coral reef fish stocks in the Florida Keys. U.S. National Marine Fisheries Service Fishery Bulletin 96:395–414.

Ault, J. S., J. A. Bohnsack, S. G. Smith, and J. Luo. 2005a. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bulletin of Marine Science 76:595–622.

Ault, J. S., S. G. Smith, and J. A. Bohnsack. 2005b. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. ICES Journal of Marine Science 62:417–423.

Ault, J. S., S. G. Smith, J. A. Bohnsack, J. Luo, D. E. Harper, and D. B. McClellan. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: positive signs in the Dry Tortugas. Bulletin of Marine Science 78:633–654.

Bartholomew, A., and J. A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129–154.

Breen, M., and R. Cook. 2002. Inclusion of discard and escape mortality estimates in stock assessment models and its likely impact on fisheries management. International Council for the Exploration of the Sea, Cooperative Research Report CM-002.

Bugley, K., and G. Shepherd. 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., N. J. Brown-Peterson, R. M. Overstreet, J. Gannon, P. Simmons, J. Sprinkle, and C. Weaver. 2008. Evaluation of the efficacy of the current minimum size regulations for selected reef fish based on release mortality and fish physiology. Mote Marine Laboratory, Technical Report 1176, Sarasota, Florida.

Campbell, M. D., W. B. Driggers, B. Sauls, and J. F. Walter. 2014. Release mortality in the Red Snapper (*Lutjanus campechanus*) fishery: a meta-analysis of three decades of research. U.S. National Marine Fisheries Service Fishery Bulletin 112:283–296.

Cocheret de la Morinière, E., B. J. Pollux, I. Nagelkerken, and G. van der Velde. 2002. Post-settlement life cycle migration patterns and habitat preference of coral reef fish that use seagrass and mangrove habitats as nurseries. Estuarine, Coastal, and Shelf Science 55:309–321.

Coggins, L. G. Jr., M. J. Catalano, M. S. Allen, W. E. Pine III, and C. J. Walters. 2007. Effects of cryptic mortality and the hidden costs of using length limits in fishery management. Fish and Fisheries 8:196–210.

Coleman F., W. Figueira, J. Ueland, and L. Crowder. 2004. The impact of United States recreational fisheries on marine fish populations. Science 305:1958–1960.

Collins, M. R. 1991. Survival estimates for demersal reef fishes released by anglers. Proceedings of the Gulf and Caribbean Fisheries Institute 44:470–482.

Cooke, S. J., B. L. Barthel, C. D. Suski, M. J. Siepker, and D. P. Philipp. 2005. Influence of circle hook size on hooking efficiency, injury, and size selectivity of Bluegill with comments on circle hook conservation benefits in recreational fisheries. North American Journal of Fisheries Management 25:211–219.

Cooke, S. J., and C. D. Suski. 2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Aquatic Conservation Marine and Freshwater Ecosystems 14:299–326.

Davis, M. W. 2002. Key principles for understanding fish bycatch discard mortality. Canadian Journal of Fish and Aquatic Sciences 59:1834–1843.

Denit, K., and S. Sponaugle. 2004. Growth of early stage Gray Snapper, *Lutjanus griseus*, across a latitudinal gradient. Proceedings of the Gulf and Caribbean Fisheries Institute 55:839–843.

Diamond, S. L., and M. D. Campbell. 2009. Linking "sink or swim" indicators to delayed mortality in Red Snapper by using a condition index. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science [online serial] 1:107–120.

Diamond, S. L., L. B. Crowder, and L. G. Cowell. 1999. Catch and bycatch: the qualitative effects of fisheries on population vital rates of Atlantic Croaker. Transactions of the American Fisheries Society 128:1085–1105.

Domeier, M. L., C. Koenig, and F. Coleman. 1996. Reproductive biology of the Gray Snapper (*Lutjanus griseus)*, with notes on spawning for other western Atlantic snappers (Lutjanidae). Pages 189–201 *in* F. Arreguín-Sánchez, J. L. Munro, M. C. Blagos, and D. Pauly, editors. Biology and culture of tropical groupers and snappers. International Center for Living Aquatic Resources Management, Conference Proceedings 48, Manila, Philippines.

Fabrizio, M. C., F. S. Scharf, G. R. Shepherd, and J. E. Rosendale. 2008. Factors affecting catch-and-release mortality of Bluefish. North American Journal of Fisheries Management 25:533–536.

Faunce, C. H., and J. E. Serafy. 2008. Selective use of mangrove shorelines by snappers, grunts, and Great Barracuda. Marine Ecology Progress Series 356:153–162.

Flaherty, K. E., T. S. Switzer, B. L. Winner, and S. F. Keenan. 2014. Regional correspondence in habitat occupancy by Gray Snapper (*Lutjanus griseus*) within estuaries of the southeastern United States. Estuaries and Coasts 37:206–228.

Flaherty, K. E., B. L. Winner, J. L. Vecchio, and T. S. Switzer. 2013. Spatial and size distribution of Red Drum caught and released in Tampa Bay, Florida, and factors associated with post-release hooking mortality. Gulf and Caribbean Research 25:29–41.

Flaherty-Walia, K. E., T. S. Switzer, B. L. Winner, A. J. Tyler-Jedlund, and S. F. Keenan. 2015. Improved ability to characterize recruitment of Gray Snapper in three Florida estuaries along the Gulf of Mexico through targeted sampling of polyhaline seagrass beds. Transactions of the American Fisheries Society 144:911–926.

FWRI (Fish and Wildlife Research Institute). 2010. Status and trends of Florida nearshore and inshore fishes: species account, Gray Snapper. Florida Fish and Wildlife Conservation Commission, FWRI, Tallahassee.

Gitschlag, G. R., and M. L. Renaud. 1994. Field experiments on survival rates of caged and released Red Snapper. North American Journal of Fisheries Management 14:131–136.

Hanson, C., and B. Sauls. 2011. Status of recreational saltwater fishing in Florida: characterization of license sales, participation and fishing effort. Pages 355–365 *in* T. D. Beard Jr., R. Arlinghaus, and S. G. Sutton, editors. The angler in the environment: social, economic, biological, and ethical dimensions. Proceedings of the 5th world recreational fishing conference. American Fisheries Society, Symposium 75, Bethesda, Maryland.

Jarvis, E. T., and C. G. Lowe. 2008. The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (Scorpaenidae, *Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Sciences 65:1286–1296.

Lawson, P. W., and D. B. Sampson. 1996. Gear-related mortality in selective fisheries for ocean salmon. North American Journal of Fisheries Management 16:512–520.

Manooch C. S. III, and R. H. Matheson III. 1984. Age, growth and mortality of Gray Snapper collected from Florida waters. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 35 (1981):331–344.

Matlock, G. C., L. W. McEachron, J. A. Dailey, P. A. Unger, and P. Chai. 1993. Short-term hooking mortalities of Red Drums and Spotted Seatrout caught on single barb and treble hooks. North American Journal of Fisheries Management 13:186–189.

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

Morrissey, M. B., C. D. Suski, K. R. Esseltine, and B. L. Tufts. 2005. Incidence and physiological consequences of decompression in Smallmouth Bass after live-release angling tournaments. Transactions of the American Fisheries Society 134:1038–1047.

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

Murphy, M. D., R. F. Heagey, V. H. Neugebauer, M. D. Godon, and J. L. Hintz. 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

Nagelkerken, I., G. van der Velde, M. W. Gorissen, G. J. Meijer, T. Van't Hof, and C. den Hartog. 2000. Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. Estuarine, Coastal, and Shelf Science 51:31–44.

NOAA (National Oceanic and Atmospheric Administration). 2015. Recreational fisheries statistics queries. Available: www.st.nmfs.noaa.gov/st1/recreational/queries/index.html. (March 2015).

Overton, A. S., J. Zabawski, and K. L. Riley. 2008. Release mortality of undersized fish from the snapper–grouper complex off the North Carolina coast. North American Journal of Fisheries Management 28:733–739.

Parker, S. J., H. I. McElderry, P. S. Rankin, and R. W. Hannah. 2006. Buoyancy regulation and barotraumas in two species of nearshore rockfish. Transaction of the American Fisheries Society 135:1213–1223.

Patterson, W. F., G. W. Ingram, R. L. Shipp Jr., and J. H. Cowen. 2000. Indirect estimation of Red Snapper (*Lutjanus campechanus*) and Gray Triggerfish (*Balistes capriscus*) release mortality. Proceedings of the Annual Gulf and Caribbean Fisheries Institute 53:526–536.

Pollock, K. H., and W. E. Pine. 2007. The design and analysis of field studies to estimate catch-and-release mortality. Fisheries Management and Ecology 14:1–8.

Render, J. H., and C. A. Wilson. 1994. Hook-and-line mortality of caught and released Red Snapper around oil and gas platform structural habitat. Bulletin of Marine Science 55:1106–1111.

Rudershausen, P. J., J. A. Buckel, and J. E. Hightower. 2014. Estimating reef fish discard mortality using surface and bottom tagging: effects of hook injury and barotrauma. Canadian Journal of Fisheries and Aquatic Sciences 71:514–520.

Rudershausen, P. J., J. A. Buckel, and E. H. Williams. 2007. Discard composition and release fate in the snapper and grouper commercial hook-and-line fishery in North Carolina, USA. Fisheries Management and Ecology 14:103–113.

Rummer, J. L. 2007. Factors affecting catch and release (CAR) mortality in fish: insight into CAR mortality in Red Snapper and the influence of catastrophic decompression. Pages 123–144 *in* W. F. Patterson III, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Rummer, J. L., and W. A. Bennett. 2005. Physiological effects of swim bladder overexpansion and catastrophic decompression on Red Snapper. Transactions of the American Fisheries Society 134:1457–1470.

SAS Institute. 2006. Base SAS 9.1.3 procedures guide, 2nd edition, volumes 1–4. SAS Institute, Cary, North Carolina.

Sauls, B. 2014. Relative survival of Gags *Mycteroperca microlepis* released within a recreational hook-and-line fishery: application of the Cox regression model to control for heterogeneity in a large-scale mark–recapture study. Fisheries Research 150:18–27.

Sauls, B., and O. Ayala. 2012. Circle hook requirements in the Gulf of Mexico: application in recreational fisheries and effectiveness for conservation of reef fishes. Bulletin of Marine Science 88:667–979.

Schisler, G. J., and E. P. Bergersen. 1996. Postrelease hooking mortality of Rainbow Trout caught on scented artificial baits. North American Journal of Fisheries Management 16:570–578.

St. John, J., and C. J. Syers. 2005. Mortality of the demersal West Australian Dhufish, *Glaucosoma hebraicum* (Richardson 1845) following catch and release: the influence of capture depth, venting and hook type. Fisheries Research 76:106–116.

Starck, W. A. II, and R. E. Schroeder, editors. 1971. Investigations on the Gray Snapper, *Lutjanus griseus*. University of Miami Press, Studies in Tropical Oceanography 10, Coral Gables, Florida.

Stunz, G. W., and D. A. McKee. 2006. Catch-and-release mortality of Spotted Seatrout in Texas. North American Journal of Fisheries Management 26:843–848.

Sumpton, W., D. Mayer, I. Brown, B. Sawynok, M. McLennan, A. Butcher, and J. Kirkwood. 2008. Investigation of movement and factors influencing post-release survival of line-caught coral reef fish using recreational tag–recapture data. Fisheries Research 92:189–195.

Switzer, T. S., and R. L. Lehnert. 2006. Comparison of a de facto marine protected area to similar nearby habitat: do small estuarine reserves impact local fisheries dynamics? National Marine Fisheries Service, Cooperative Research Program, Final Report, Grant NA04NMF4540211, St. Petersburg, Florida.

Taylor, R. G., J. A. Whittington, and D. E. Haymans. 2001. Catch-and-release mortality rates of Common Snook in Florida. North American Journal of Fisheries Management 21:70–75.

Tzeng, M. W., J. A. Hare, and D. G. Lindquist. 2003. Ingress of transformation stage Gray Snapper, *Lutjanus griseus* (Pisces: Lutjanidae) through Beaufort Inlet, North Carolina. Bulletin of Marine Science 72:891–908.

Vecchio, J. L., and C. A. Wenner. 2007. Catch-and-release mortality in subadult and adult Red Drum captured with popular fishing hook types. North American Journal of Fisheries Management 27:891–899.

Waters, J. R., and G. R. Huntsman. 1986. Incorporating mortality from catch and release into yield-per-recruit analyses of minimum-size limits. North American Journal of Fisheries Management 6:463–471.

Wertheimer, A., A. Celewycz., H. Jaenicke, D. Mortensen, and J. Orsi. 1989. Size-related hooking mortality of incidentally caught Chinook Salmon, *Oncorhynchus tshawytscha*. Marine Fisheries Review 51:28–35

Whaley, S. D., J. J. Burd Jr., and B. A. Robertson. 2007. Using estuarine landscape structure to model distribution patterns in nekton communities and in juveniles of fishery species. Marine Ecology Progress Series 330:83–99.

Wilde, G. R. 2009. Does venting promote survival of released fish? Fisheries 34:20–28.

Wilson, J. A., and G. A. Diaz. 2012. An overview of circle hook use and management measures in United States marine fisheries. Bulletin of Marine Science 88:771–788.

Wilson, R. R., and K. M. Burns. 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.