Spatial and Size Distribution of Red Drum Caught and Released in Tampa Bay, Florida, and Factors Associated with Post-Release Hooking Mortality

Kerry E. Flaherty
Florida Fish and Wildlife Conservation Commission

Brent L. Winner
Florida Fish and Wildlife Conservation Commission

Julie L. Vecchio
Florida Fish and Wildlife Conservation Commission

Theodore S. Switzer
Florida Fish and Wildlife Conservation Commission

SPATIAL AND SIZE DISTRIBUTION OF RED DRUM CAUGHT AND RELEASED IN TAMPA BAY, FLORIDA, AND FACTORS ASSOCIATED WITH POST—RELEASE HOOKING MORTALITY

Kerry E. Flaherty*, Brent L. Winner, Julie L. Vecchio[1], and Theodore S. Switzer
Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue Southeast, St. Petersburg, FL 33701 USA; [1]Current address: 444 51st Avenue South, St. Petersburg, FL 33705 USA; *Corresponding author, email: kerry.flaherty@myfwc.com

ABSTRACT: The recreational fishery for red drum (*Sciaenops ocellatus*) in Florida is unusual in that most red drum targeted are immature and caught within estuarine waters. Current state regulations rely exclusively on bag and size limits, resulting in the release of a large proportion of captured individuals. This study employed hook—and—line sampling conducted monthly in Tampa Bay, Florida and catch—and—release mortality experiments to determine the spatial and size distribution of red drum and the mortality rate of released fish, respectively. Of the 1,405 red drum collected, more than 70% were smaller than the minimum legal size (457 mm standard length (SL)). Size structure of red drum varied spatially and reflected ontogenetic patterns of habitat use. Data collected during catch—and—release mortality experiments were analyzed to identify factors associated with mortality. A total of 251 red drum (203–618 mm SL) were caught and held for 48 h during 9 experiments, with an overall mortality rate of 5.6%. Higher water temperature and anatomical hook position were significantly correlated with mortality; lip—hooked fish had the lowest mortality rate, while throat—hooked fish had the highest. Although hook type was not correlated with mortality, it did influence whether a fish was deep—hooked. Fish caught by J—hooks were more likely to be deep—hooked than those caught by circle hooks. Catch—and—release fishing is an effective management tool for reducing take but may contribute to short—term mortality, especially in warm, subtropical estuaries.

KEY WORDS: catch—and—release, *Sciaenops ocellatus*, J—hooks, circle hooks

INTRODUCTION

The red drum (*Sciaenops ocellatus*) fishery is one of the most popular recreational estuarine fisheries in the southeastern United States and is unusual in that most harvested red drum are immature (Murphy and Crabtree 2001, Switzer et al. 2009). Anglers target red drum throughout the year in estuaries along the south Atlantic and Gulf of Mexico (GOM) coasts (Murphy and Munyandorero 2008). In Florida, the harvest of red drum is managed with restrictive size and bag limits to ensure that adequate numbers of fish survive to maturity and recruit to nearshore spawning populations. Current state regulations include a daily bag limit of one fish per person in southern waters and 2 fish per person along the northwest and northeast coasts, a slot limit of 457–686 mm (18–27 inches) total length (TL), and prohibition of commercial harvest. Red drum ontogeny, especially their estuarine life history stages, combined with restrictive bag and size limits, results in a fishery characterized as predominantly catch—and—release.

Red drum spawn from mid—August through November near bay mouths and inlets and in nearshore continental shelf waters (Yokel 1966, Mercer 1984, Murphy and Taylor 1990). Recruitment of juveniles into nursery areas begins in September and continues through February, with peak recruitment in October and November (Peters and McMichael 1987, Daniel 1988). Oligohaline backwater areas (e.g., tidal creeks and rivers) have been documented as primary nursery habitats for juvenile red drum in Tampa Bay and other estuaries (Peters and McMichael 1987, Wenner 1992, Bacheler et al. 2008). Newly settled red drum in seagrass and salt marsh habitat in other GOM estuaries also demonstrated significantly higher growth rates and abundance than in non—vegetated or oyster substrates (Baltz et al. 1998, Stunz et al. 2002a, b). Red drum grow quickly during their first year, reaching about 342 mm TL (Murphy and Taylor 1990). Peters and McMichael (1987) observed that as young red drum increase in size and age, they gradually move from oligohaline habitats into areas of higher salinity. Between ages 1 and 4, red drum use a wide variety of estuarine habitats, including oyster bars, flooded salt marsh, seagrass flats, and mangrove shorelines (Peters and McMichael 1987, Wenner 1992). By age 5 (~780 mm standard length (SL)), most GOM red drum mature, leave their natal estuary, and move into nearshore coastal waters (Murphy and Taylor 1990, Murphy and Crabtree 2001).

The frequency of catch—and—release fishing for saltwater species, including red drum, has increased substantially in recent decades. By the early 1990s the estimated number of released red drum in Florida had reached levels 4 to 5 times the harvest (Murphy and Munyandorero 2008). According to the National Oceanographic and Atmospheric Administration's (NOAA) Marine Recreational Fisheries Statistics Survey (MRFSS), an estimated 2.3 – 4.5 million red drum were caught each year in Florida waters from 2005 to 2009 (NOAA 2008). Of these, only 12–16% were harvested; the remaining 2 – 4.2 million were released. The size of red drum

being caught by anglers, as well as the survival of released individuals, has significant bearing on the inshore population and a strong influence on the level of escapement into nearshore adult populations.

Several factors may influence post–release mortality of red drum, including variations in environmental characteristics and fishing techniques. Reviews of catch–and–release publications showed that environmental characteristics (e.g. temperature, depth, dissolved oxygen (DO); Muoneke and Childress 1994), anatomical site of hooking (Aguilar et al. 2002, Aalbers et al. 2004), amount of bleeding (Fabrizio et al. 2008), hook size (Cooke et al. 2005), and whether the hook was removed (Muoneke and Childress 1994) all may influence short–term (48–72 h) mortality. Several studies have shown that deep–hooking (i.e., hooking in the fish esophagus or stomach) is more common with J–hooks than with circle hooks (Aalbers et al. 2004, Beckwith and Rand 2005, Vecchio and Wenner 2007) and J–hooks are also more highly correlated with greater short–term mortality than was the use of circle hooks (Taylor et al. 2001, Bartholomew and Bohnsack 2005, Vecchio and Wenner 2007). Removing deeply–embedded hooks may also affect survival by increasing handling time and causing additional tissue damage and bleeding (Taylor et al. 2001, Vecchio 2006).

Although the relationship between catch–and–release fishing for red drum and mortality has been studied in other parts of their range (Aguilar et al. 2002, Matlock et al. 1993, Vecchio and Wenner 2007), no studies have been published from experiments conducted in waters as far south as Florida. The Tampa Bay watershed is one of the most accessible and heavily urbanized estuaries in the state, is home to more than 2 million people, and is visited by millions more each year (United States Geological Survey 2008). Therefore, the potential for high recreational fishing pressure on red drum makes it a relevant study area. Accordingly, the current study aims to (1) determine the size and spatial distribution of red drum available to the recreational fishery within the Tampa Bay estuary, (2) identify factors contributing to short–term post–release hooking mortality, and (3) relate these results to long–term tag return data for red drum released alive.

MATERIALS AND METHODS

Monthly hook–and–line sampling

Hook–and–line surveys were conducted monthly from April 2005 through December 2007 at 10 stations rang-
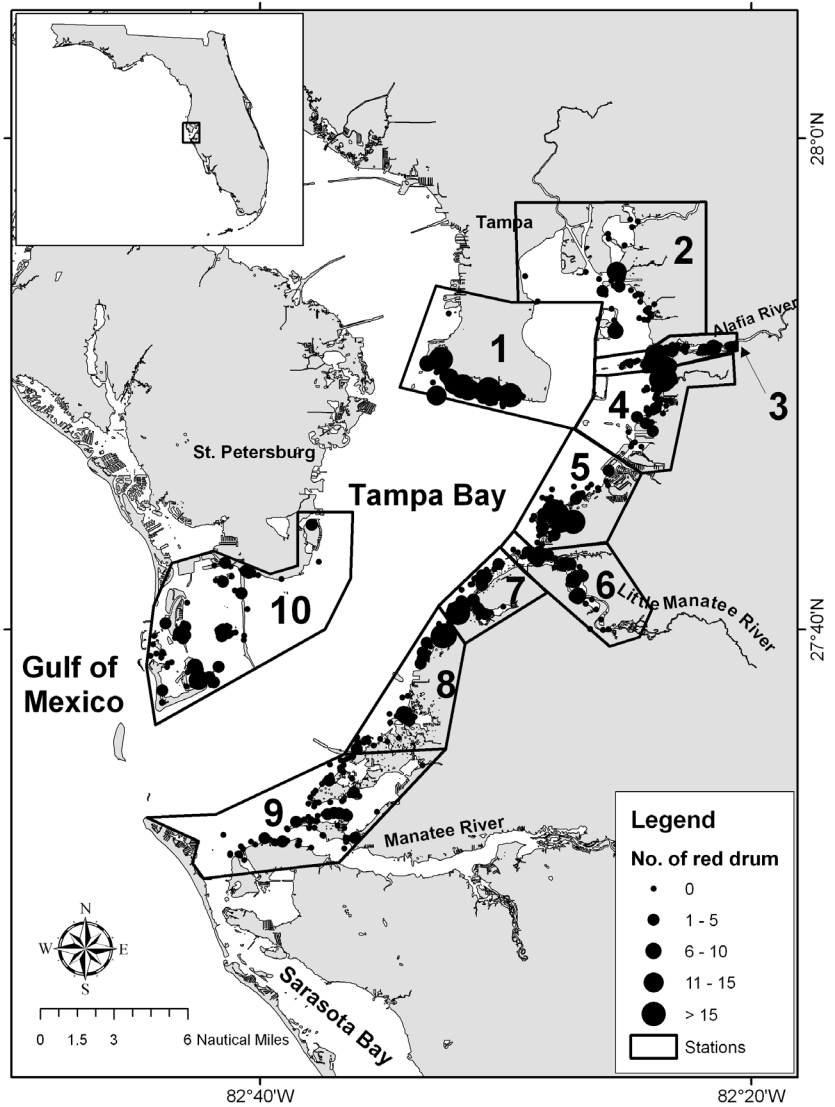
Figure 1. *Distribution of monthly hook-and-line sampling sites and number of red drum captured in Tampa Bay, Florida (black circles, April 2005–December 2007). Multiple sites were fished per sampling trip. Sampling stations selected for monthly hook-and-line sampling are labeled 1–10. Catch-and-release mortality experiments were conducted in stations 1, 3, 4, and 10.*

ing from the interbay peninsula (Station 1) and the eastern shoreline of Tampa Bay to the northern and southern shorelines of lower Tampa Bay (Figure 1). These surveys were used to document spatial differences in abundance and size structure and thus describe the population of red drum accessible to the recreational fishery. One sampling trip per station was conducted each month throughout the study period. Shallow water habitats within the estuary known to be utilized by red drum, such as oyster bars, seagrass beds, vegetated shorelines, and tidal creeks and rivers were targeted for fishing. The particular habitat targeted for fishing was recorded, and a dominant shore type (overhanging vegetation, emergent vegetation, structure, or other), bottom vegetation type (algae, submerged aquatic vegetation (SAV), structure, or other), and substrate (sand, mud, or structure) were assigned to each sampling site. Each habitat category was assigned as

dominant if it characterized > 50% of the fished area at each sampling site.

Sampling crews consisted of 2 to 3 researchers and volunteer anglers with similar fishing expertise who fished for a minimum of 4 h within their assigned station. Anglers used light rods and tackle to best mimic that used in the red drum recreational fishery and fishing intensity on each trip was comparable. Spinning reels were outfitted with 12 lb test monofilament line and a short monofilament leader; however, each angler was allowed to choose between a 1/0 non—offset circle hook and a 1/0 J—hook. Anglers most frequently used circle hooks and live bait (pink shrimp *Farfantepenaeus duorarum*, scaled sardine *Harengula jaguana*, Atlantic thread herring *Opisthonema oglinum*, or pinfish *Lagodon rhomboides*). However, J—hooks were used regularly, and artificial baits were used occasionally, especially at times of the year when live bait was not readily available. Red drum were measured for SL (mm) and TL (mm), tagged externally with a Hallprint® dart tag inserted between the second and third pterygiophores of the first dorsal fin, and released at the sampling site. Catch data were recorded for all fish and included hook type (J—hook or circle hook), hook position, bait used, whether the hook had been removed, and release condition. Hook positions were defined as follows: "lip" indicated being hooked in the lip or corner of the mouth, "inside mouth" indicated being hooked in the buccal cavity, "throat" indicated being hooked just ahead of pharyngeal teeth, "gut" indicated being hooked beyond pharyngeal teeth, and "other" indicated being hooked in any other position. Release condition was considered "good" if the fish swam away immediately, "fair" if it struggled for several seconds before swimming away, "poor" if it struggled for several minutes before swimming away, or "dead" upon release.

Catch—and—release mortality experiments

To collect a wide size range of red drum and evaluate the potential interaction of season and environmental differences on hooking mortality, 9 replicate catch—and—release mortality experiments were conducted in 3 distinct locations within Tampa Bay from November 2005 to March 2008. Experiments were conducted in shallow seagrass beds and tidal creeks near the interbay peninsula in upper Tampa Bay (Station 1; n = 5), in the Alafia River and associated tidal creeks (Stations 3 and 4 combined; n = 3), and in seagrass beds and mangrove shorelines in lower Tampa Bay (Station 10; n = 1; Figure 1). A station was targeted for sampling if the monthly hook—and—line sampling indicated that sufficient numbers (n > 10) of red drum were recently captured to conduct an experiment that would meet assumptions regarding distribution of errors in statistical analyses. For each experiment, at least 2 crews, each consisting of 2 to 4 scientists, volunteer anglers, and local fishing guides, fished in the designated area. Anglers used either a 1/0 J—hook or 1/0 non—offset circle hook and, unlike the monthly hook—and—line sam-

pling trips, exclusively used live bait to control for potential bait—associated differences in mortality (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005). Effort was adjusted during each experiment to ensure that about the same number of individuals were collected with each hook type. Anglers collected red drum using fishing gear identical to that used during the monthly hook—and—line sampling.

Depending on the number of fish collected during each experiment, one (≤ 40 fish) or 2 (> 40 fish) holding pens were deployed in a centralized location within each study area and served as the main containment locations for test fish. The holding pens were cylindrical (5.5 m in diameter by 2.4 m deep), and constructed of 6.4 mm stretch knotless nylon mesh and could have confined many more than 40 fish without overcrowding. Each pen was secured by 8 galvanized poles inserted into rings around the net pen in an area where water depth was at least 1 m at all tidal stages.

As with monthly hook—and—line sampling, catch data (see list earlier) were recorded for all fish. The length of each fish was measured (SL and TL mm) and additional data were recorded during mortality experiments to document handling of individual fish. Anglers recorded fight time (number of seconds from when a fish was hooked to when it was brought into the boat) and handling time (number of seconds a fish was out of the water for measuring and tagging) for each fish. Every fifth red drum collected by each sampling crew was individually identified by external features or markings and left untagged as a control for estimation of tagging—associated mortality; all other fish were tagged for identification. Fish were held in a live well aboard the fishing vessel for no more than 1 hour before being transferred to the larger holding pen. Water temperature (°C), DO (mg/L), and salinity were recorded at each fishing site and periodically at the holding pens (a minimum of every 12 h).

Red drum were held in the holding pen for at least 48 h, a time period that has been shown to be sufficient for documenting short—term mortality (Bugley and Shepherd 1991, Matlock et al. 1993, Murphy et al. 1995, Taylor et al. 2001). The holding pen was thoroughly checked by a snorkeler each day at dawn and dusk. Any dead red drum were removed and the date and time recorded. All dead fish were returned to the laboratory for further examination and evaluated for possible cause of death. After 48 h, the fish used as tagging controls were tagged for identification, condition was noted for all surviving fish, and all fish were released within the sampling area.

Statistical methods

Total effort and catch data were summarized for red drum collected during monthly hook—and—line sampling and catch—and—release experiments conducted within Tampa Bay. Fishing locations were plotted in a geographic information system to examine the spatial coverage of sampling. Habitat types and water quality characteristics were summa-

TABLE 1. Summary of the number of red drum collected during hook-and-line sampling by station (N) including the mean number captured per trip (mean, standard error (se), maximum, frequency of occurrence (% Freq.)) and the ratio of red drum captured using circle vs. J-hooks (C:J).

Station	N	Number of red drum per trip			C:J
		Mean ± se	Maximum	% Freq.	
1	465	6.2 ± 1.1	58	77.3%	3.5
2	76	2.1 ± 0.6	16	45.9%	2.6
3	140	3.7 ± 1.3	34	65.8%	3.7
4	225	6.4 ± 2.5	70	45.7%	2.3
5	159	4.7 ± 2.2	54	41.2%	4.7
6	68	2.0 ± 0.6	18	52.9%	10.3
7	65	1.9 ± 0.8	24	47.1%	4.9
8	131	3.6 ± 1.1	31	51.4%	3.2
9	15	0.5 ± 0.2	4	27.3%	14.0
10	61	1.6 ± 0.5	14	43.2%	5.1
Total	**1,405**	**3.3 ± 1.1**	**70**	**49.8%**	**3.5**

rized and compared by station using Chi–square tests and multiple factor ANOVAs, respectively. Proportions of red drum collected were summarized by station, hook type, and hook position. Length frequency histograms were plotted by station to further explore the spatial distribution of the sizes of red drum captured during hook–and–line sampling and to describe the size structure of red drum that survived or died during catch–and–release experiments. Differences in mean size among hook–and–line stations and size distributions between hook types with which red drum were captured were tested using Kruskal–Wallis and Kolmogorov–Smirnov non–parametric tests, respectively. The proportions of individuals falling within the current regulated slot size were summarized and displayed as length frequency histograms in SL based on SL/TL length regressions calculated from long–term fisheries–independent monitoring data conducted in Tampa Bay (McMichael 2010).

For catch–and–release mortality experiments, logistic regression was used to determine whether a variety of independent variables were significantly related to the probability of mortality. To assess the probability of mortality, categorical variables included whether the fish was an untagged control, the hook type, the hook position, bait type (fish or shrimp), the fish condition, and whether the hook had been removed. Covariates included mean water temperature, salinity, DO, and water depth assessed at the holding pen during each experiment, fight time, handling time, transport time, and fish length. In addition to these main effects, the potentially confounding interaction effects of hook position x hook type and water temperature x dissolved oxygen were also examined. The probability of mortality (M) was determined with the following equation: $P(M) = e^u / (1 + e^u)$; where e = base of the natural logarithm and u = linear function of the independent variables (Sokal and Rohlf 1995). A forward selection method was used to add variables to the model that

were significant at $p \leq 0.05$. Once a significant variable was entered in the model, it was not removed from the model. The process was repeated until none of the remaining variables met the specified level for entry. The probability of deep–hooking (throat– or gut–hooked) was also determined with similar methodology since previous studies have associated a higher incidence of deep–hooking when anglers use J–hooks (Aalbers et al. 2004, Beckwith and Rand 2005, Vecchio and Wenner 2007). To assess the probability of deep–hooking, hook type and bait type were treated as categorical variables, and the covariates included mean water temperature, salinity, DO, and depth, as well as fight time and fish length.

Long–term survival was estimated from tag returns reported from the beginning of the study period to October 2012 for red drum released after mortality experiments. A relative risk analysis was used to compute relative survival (S) using a technique described by Hueter et al. (2006): $S = R_e / R_u$; where R_e and R_u are the recapture rates for red drum that were either exposed (e) or unexposed (u) to a hook position or hook type that may reduce the possibility of survival. Recapture rates for each exposure group were calculated as the number of red drum released alive after mortality experiments that were recaptured, divided by the number not recaptured. This calculation was based on the assumption that after the initial 48 h holding period lip–hooked fish and those captured by circle hooks had a 100% survival rate and were therefore "unexposed." Mantel–Haenszel 95% confidence intervals for relative survival were calculated (Hueter et al. 2006). All statistics were calculated using SAS version 9.1.3 (SAS Institute Inc. 2006) and were considered significant if $p \leq 0.05$.

RESULTS

Monthly hook–and–line sampling

Three hundred and twenty–four hook–and–line sampling trips were conducted between April 2005 and December 2007 (Figure 1). A total of 1,405 red drum were caught during these trips (Table 1). Red drum were caught on about half of all fishing trips and in all designated fishing stations throughout Tampa Bay (Table 1, Figure 2). Habitat types and water quality characteristics, except temperature (ANOVA, F = 0.86, p = 0.571), were significantly different among stations (X^2 and ANOVA tests p < 0.05). The habitat most targeted for fishing was characterized by overhanging vegetation (predominantly mangroves) that either contained SAV or was unvegetated with substrates of mud or sand (Table 2). By fishing trip, the highest mean number of red drum were caught in Stations 1 and 4 (6.2 and 6.4 red drum per trip, respectively; Table 1). The fewest red drum per trip (0.5)
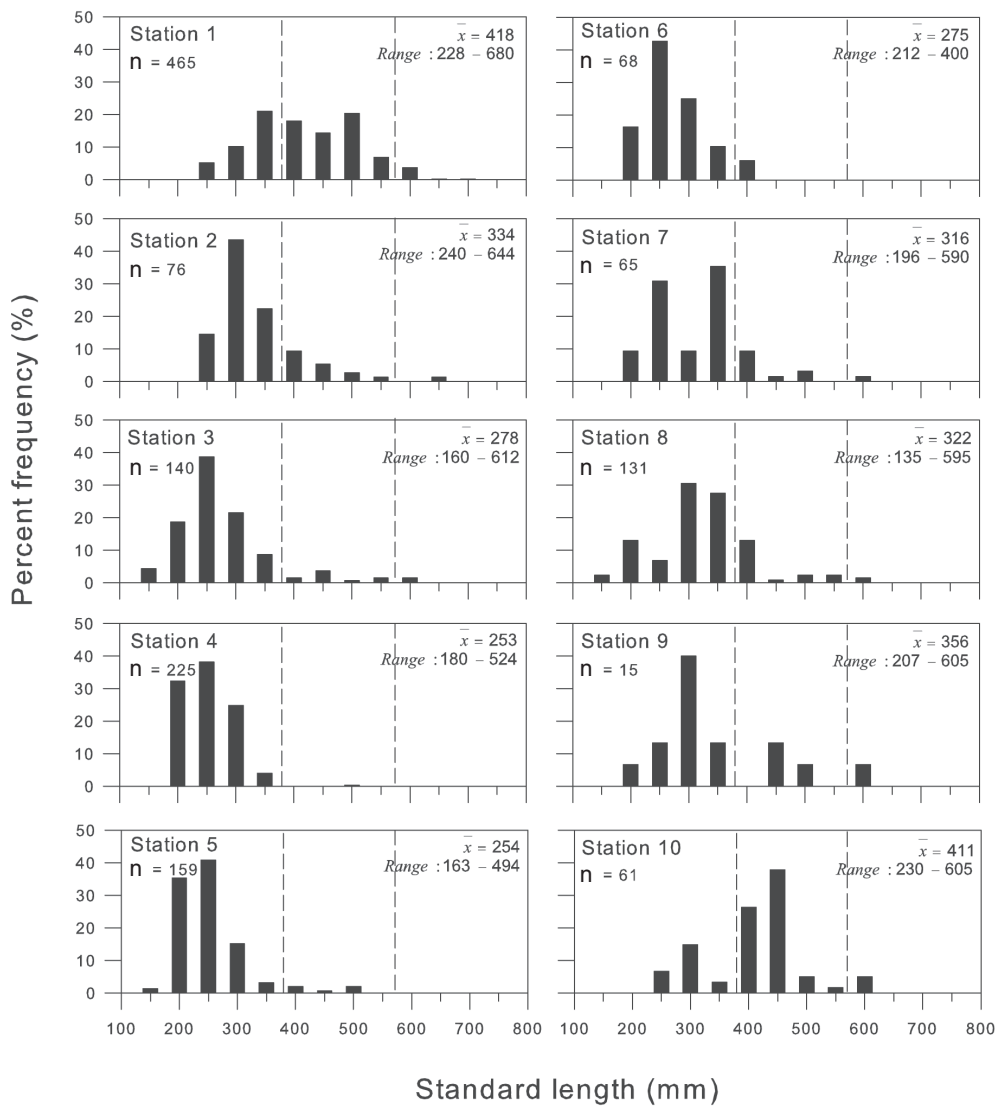
Figure 2. Length frequency (by 50 mm size bins) of red drum caught in Tampa Bay with hook-and-line gear, by sampling station (April 2005 – December 2007; includes fish used for mortality experiments). The Florida legal slot size, estimated from SL/TL length regressions, is indicated by vertical dashed lines on each plot. n = number of red drum collected within that station, $\bar{x}$ = mean SL, range = minimum – maximum SL.

were caught in Station 9 on the southern shore near the mouth of Tampa Bay (Table 1, Figure 1). Red drum were most frequently collected on fishing trips to Stations 1 and 3 (77.3% and 65.8%, respectively; Table 1). In all stations, red drum were more often caught with circle hooks than with J–hooks (Ratio of circle hook to J–hook caught fish ranged from 2.3 – 14.0; Table 1), and the size distribution of red drum captured with J–hooks differed significantly than those caught with circle hooks (K_{sa} = 2.37, p < 0.0001), although mean lengths differed minimally (346.4 and 328.5 mm SL, respectively). Most red drum were captured with natural baits (n = 1,359), primarily live shrimp (n = 800), followed by dead natural bait (n = 360) and live fish (n = 196). The remaining 46 red drum were captured with artificial lures.

Red drum collected in monthly hook–and–line sampling ranged from 135 to 680 mm SL (Figure 2). Catch was dominated by sublegal red drum (< 379 mm SL, n = 994, 70.8%) but also included legal slot–size red drum (379–570 mm SL, n = 377, 26.8%) and a few individuals larger than the legal slot–size (> 570 mm SL, n = 34, 2.4%; Figure 2). Sizes of red drum varied significantly among fishing stations (X^2 = 709.97, p < 0.0001;

TABLE 2. Summary of water quality (mean, standard error (se), range) and dominant habitat characteristics in hook-and-line sampling stations in Tampa Bay, FL (April 2005 – December 2007). Dominant habitat types listed are those that had the highest proportion of sites (in parentheses) in each station in which fishing was targeted towards that habitat type. SAV–submerged aquatic vegetation.

Station	Temperature (°C) Mean ± se	Range	Dissolved oxygen (mg/l) Mean ± se	Range	Salinity Mean ± se	Range	Dominant habitat types (Proportion of sites) Shore type	Bottom Vegetation	Substrate
1	25.4 ± 0.3	14.0 - 34.4	7.5 ± 0.2	0.6 - 14.5	27.2 ± 0.2	13.0 - 33.6	Overhanging (0.54)	SAV (0.62)	Sand (0.69)
2	25.4 ± 0.3	16.1 - 34.2	6.7 ± 0.1	1.8 - 11.8	26.0 ± 0.3	8.6 - 31.6	Overhanging (0.64)	None (0.68)	Sand (0.53)
3	24.6 ± 0.3	14.9 - 32.7	6.5 ± 0.1	0.4 - 13.0	21.6 ± 0.5	0.1 - 34.0	Overhanging (0.83)	None (0.69)	Mud (0.53)
4	25.1 ± 0.3	16.5 - 40.0	6.4 ± 0.1	1.7 - 13.0	24.1 ± 0.4	6.1 - 32.5	Overhanging (0.74)	None (0.65)	Mud (0.54)
5	25.2 ± 0.3	13.8 - 33.3	6.0 ± 0.2	0.6 - 10.6	26.4 ± 0.2	13.7 - 35.0	Overhanging (0.76)	None (0.53)	Mud (0.60)
6	25.0 ± 0.3	15.0 - 31.6	6.2 ± 0.1	2.4 - 11.6	16.7 ± 0.5	0.1 - 30.4	Overhanging (0.80)	None (0.62)	Sand (0.45)
7	24.6 ± 0.3	16.0 - 33.0	5.9 ± 0.2	0.6 - 13.9	28.8 ± 0.2	21.7 - 37.8	Overhanging (0.91)	SAV (0.57)	Sand (0.74)
8	25.1 ± 0.3	13.1 - 32.6	6.7 ± 0.2	1.6 - 13.4	31.2 ± 0.2	23.3 - 36.7	Overhanging (0.75)	SAV (0.70)	Sand (0.68)
9	25.3 ± 0.3	15.8 - 32.1	6.0 ± 0.1	1.0 - 11.4	30.8 ± 0.3	10.0 - 36.0	Overhanging (0.81)	SAV (0.75)	Sand (0.81)
10	25.1 ± 0.4	12.0 - 32.3	6.4 ± 0.1	1.6 - 12.4	33.3 ± 0.1	20.6 - 36.5	Overhanging (0.71)	SAV (0.71)	Sand (0.69)

TABLE 3. Hook positions for red drum captured in Tampa Bay, FL during monthly hook-and-line sampling (April 2005–December 2007) and mortality experiments (November 2005–March 2008). The percentage of the total catch by hook position is given in parentheses for each sampling type.

	Number caught (%)	
Hook position	Monthly hook-and-line sampling	Mortality experiments
Lip	1,199 (85.3%)	200 (79.7%)
Inside mouth	45 (3.2%)	19 (7.5%)
Throat	60 (4.3%)	16 (6.4%)
Gut	93 (6.6%)	16 (6.4%)
Other	8 (0.6%)	0
Total	**1,405**	**251**

Figure 2). Sublegal red drum were collected in every station, but were more commonly caught in areas of the bay near tidal rivers and creeks. These backwater habitats consisted principally of mangroves (overhanging vegetation), soft substrates, and oyster bars (Stations 2 – 6, Figures 1 and 2, Table 2). On average, the smallest red drum were caught in Stations 4 and 5 (mean SL = 253 and 254 mm, respectively; Figure 2). Fewer slot–size fish (379–570 mm SL) were caught in less saline areas of the bay (Stations 3–6, Table 2). On average, larger red drum were collected predominantly from seagrass flats and sandy substrates near either the interbay peninsula (Station 1) or the mouth of the bay (Stations 9 and 10, Figure 2, Table 2).

Most red drum (n = 1,244) were hooked in shallow anatomical locations such as the lip or inside the mouth (Table 3). Only 153 fish were recorded as either gut–hooked or throat–hooked. Ninety percent of all red drum caught during monthly sampling were released in good condition. Of the 153 fish hooked in deep anatomical locations, 22.9% (n = 35) were released in fair, poor, or dead condition, whereas 0.8% (n = 11) of the 1,244 fish hooked in shallow anatomical locations were released in fair or poor condition, and none were dead upon release.

Catch–and–release mortality experiments

A total of 251 red drum (range: 203–618 mm SL; Table 4, Figure 3) were caught during 9 catch–and–release mortality experiments; 14 of these fish died during the 48–hour holding period. The overall mortality rate for all experiments combined was 5.6% (Table 4). Water temperature and hook position were correlated with the probability of mortality (Table 5), and the logistic model exhibited acceptable goodness–of–fit (Hosmer–Lemeshow test, X^2 = 2.46, p = 0.87). Of environmental variables,

only water temperature was significantly correlated with red drum mortality (Table 5). Eight of the 14 mortalities (57%) occurred in water temperatures > 26°C (Figure 4). Hook position was also significantly associated with red drum mortality (Table 5). Lip–hooked fish had the lowest short–term mortality rate (3.5%), whereas fish hooked in the throat had the highest rate (18.8%; Figure 5). Hook type was not directly associated with mortality; however, significantly more red drum were deep–hooked (in the throat or gut) when J–hooks were used instead of circle hooks (Table 5, Figure 6).

A variety of parameters that we expected to influence mortality were not significant in the logistic regression model. Release condition was not significantly associated with short–term mortality probably due to the fact that 97% of the red drum caught during mortality experiments were released in good condition. Similar to what was found in the monthly fishing experiments, 18.8% (n = 6) of the 32 deep–hooked fish were released in fair or poor condition, whereas only 0.9% (n = 2) of the 219 shallow–hooked fish were released in fair condition. The remainder of the fish were released in good condition. Whether the hook was removed also did not contribute significantly to mortality; however, in our study, hooks were only left in gut–hooked or throat–hooked fish (75% and
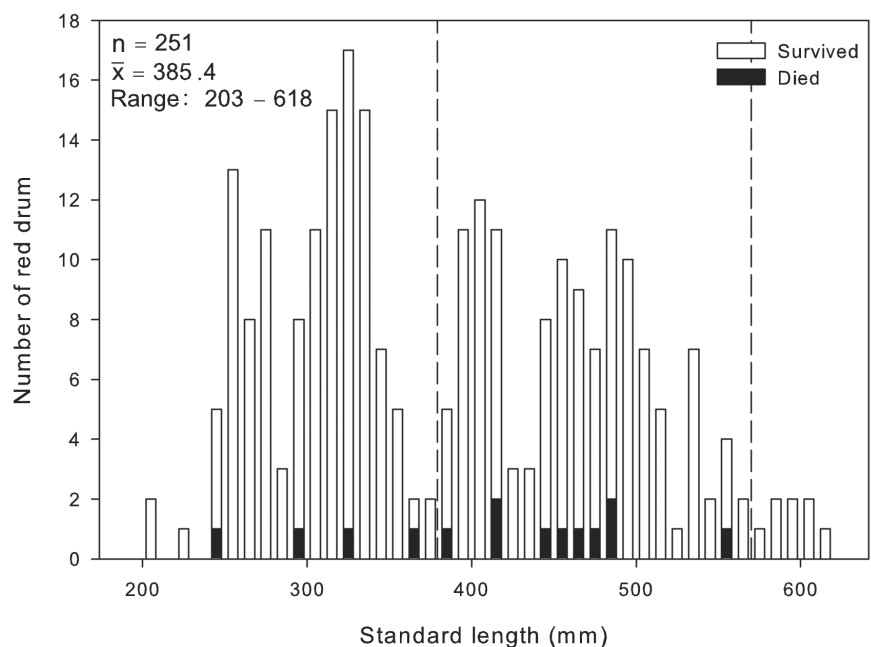
Figure 3. Length frequency of red drum (by 10 mm size bins) collected during catch-and-release mortality experiments in Tampa Bay, November 2005–March 2008. White bars represent fish that survived to be released after the 48 h holding period; black bars represent individuals that died during the experiment. The Florida legal slot size limit, estimated from SL/TL length regressions, is indicated by vertical dashed lines on each plot.

TABLE 4. *Summary of the number and sizes of red drum caught during each catch-and-release mortality experiment conducted in Tampa Bay, FL from 2005–2008, and those that were eventually recaptured from 2005–2012. Percentages were not calculated for experiments in which < 10 red drum were collected.*

Month	Station(s)	SL (mm, mean ± se)	# caught	# died	% died	# recaptured	% recaptured
Nov. 2005	3, 4	275.8 ± 5.4	52	3	5.8	5	10.2
Dec. 2005	3, 4	306.1 ± 5.7	17	0	0.0	2	11.8
Mar. 2006	1	379.0 ± 9.2	68	2	2.9	5	7.6
July 2006	1	476.4 ± 16.2	19	2	10.5	4	23.5
Nov. 2006	3, 4	355.2 ± 26.0	12	0	0.0	1	8.3
May 2007	1	495.7 ± 11.4	26	0	0.0	0	0.0
Aug. 2007	1	515.5 ± 19.7	6	0	–	0	–
Oct. 2007	10	435.5 ± 5.2	34	6	17.6	4	14.3
Mar. 2008[a]	1	431.2 ± 19.4	17	1	5.9	1	6.3
Total		**385.4 ± 6.1**	**251**	**14**	**5.6**	**22**	**9.3**

[a]Additional experiment conducted after monthly hook-and-line sampling ended.

81% of fish captured with each hook position, respectively) including 3 of the fish that died (1 gut—hooked, 2 throat—hooked). Hooks were over 3 times more likely to be removed from fish caught with circle hooks than those caught with J—hooks (5.4% and 18.6% of fish did not have hooks removed, respectively). Tagging did not significantly contribute to red drum mortality. One of the 39 untagged control fish died within the 48 h holding period, resulting in a mortality rate of 2.6%. Other factors such as handling time, fight time, dissolved oxygen, and fish length were not significantly correlated with mortality or significantly different between fish that died and survived (all ANOVAS p > 0.05). Although fish length was not significantly correlated with the probability of mortality, most red drum that died were of legal size (n = 10, Figure 3), whereas only 4 of those smaller than the slot size and none that were larger than the slot size died.

Necropsies of red drum that died during mortality experiments revealed 3 internal conditions: no noticeable injury, a torn esophagus, or an injury to the heart (Table 6). Red drum caught on circle hooks more frequently had no noticeable injury. Of the 9 individuals with no noticeable injury, 6 had been shallow—hooked and caught in experiments with warm water temperatures (July 2006 and October 2007; Figure 4). Red drum mortalities with injuries to the esophagus or heart had mostly been caught with J—hooks (n = 4; Table 6); only one had been caught with a circle hook. Based on tag recaptures through October 2012, relative long—term survival of red drum released alive (n = 237) was extremely good after accounting for short—term mortality through mortal-

ity experiments (Table 7). An overall recapture rate of 9% indicated high survival of fish that did not suffer short—term mortality, and those fish hooked in deeper anatomical locations had a lower relative survival than those hooked in shallower locations. Relative survival was not markedly lower for red drum captured with J—hooks versus circle hooks and reinforces the short—term catch—and release results that indicated that hook type was not a significant factor in mortality. The confidence intervals were extremely broad for relative survival rates by hook position, reflecting the low sample size and rarity of instances in which fish were not lip—hooked. However, for hook position and type, the results suggest that
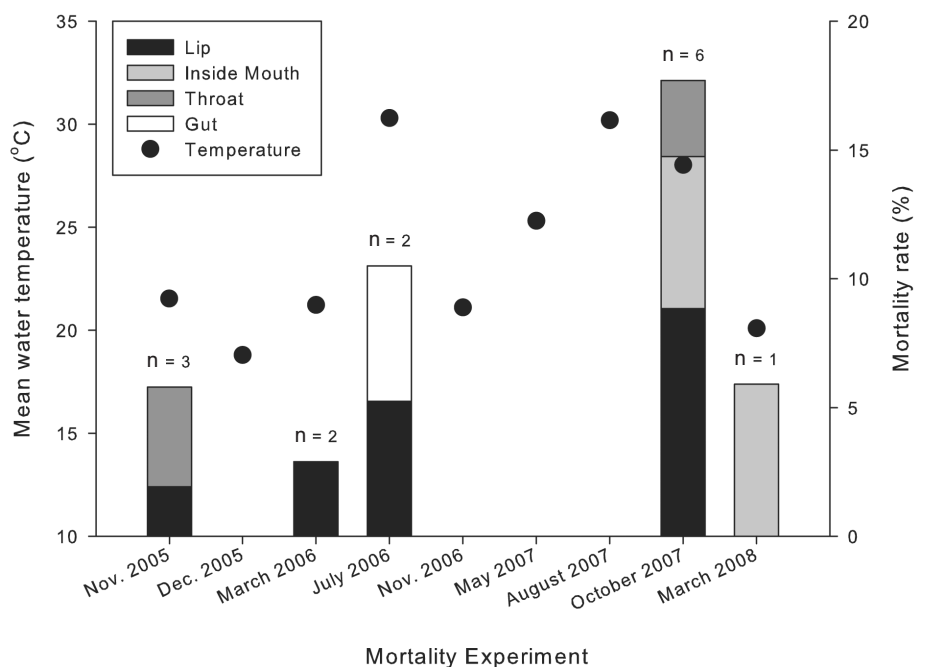
Figure 4. *Mean water temperature recorded at the main holding pen and percent mortality of red drum during catch-and-release mortality experiments, 2005–2008. Black dots represent the mean temperature. Stacked bars represent the percentage of red drum that died during each experiment and the hook position of each fish. n = number of red drum mortalities for a given experiment.*

TABLE 5. *Significant Wald Chi-square statistics (X^2) from 2 different logistic regression models (forward selection at p < 0.05) describing the factors associated with the probability of red drum mortality and deep-hooking, respectively.*

Response	Factor	df	X^2	p value
Mortality	Temperature (ºC)	1	4.9786	0.0257
	Hook position	3	8.6198	0.0348
Deep-hooking	Hook type	1	11.7849	0.0006

the risk ratios are greater than 1, indicating that there is a greater chance of recapture for fish that were lip–hooked or caught by circle hooks. Recapture rates varied over the different mortality experiments and did not indicate a seasonal (or water temperature related) trend (Table 4). Interestingly, the highest long–term recapture rates were associated with the experiments that had the highest mortality rates (July 2006 and October 2007).

DISCUSSION

Spatial differences were evident with respect to the size structure of red drum collected during this study; these differences generally reflected ontogenetic patterns of habitat use by various life–history stages of red drum. Small (sub–legal) red drum were collected primarily from areas near tidal rivers and small tidal creeks. These backwater, less saline habitats contained soft substrates and oyster bars adjacent to mangrove shorelines that represent the preferred habitats of young–of–year and small sub–legal red drum (Peters and McMichael 1987, Stunz et al. 2002a). In contrast, legal–sized red drum were most frequently collected near the interbay peninsula (Station 1; Figures 1 and 2) and to a lesser extent near the mouth of the Tampa Bay estuary (Stations 9 and 10) which are characterized by large expanses of seagrass flats with sandy substrates. The interbay peninsula contains a functional large marine protected area because boaters are not allowed in the security zone surrounding MacDill Air Force Base, which encompasses the southern tip of the interbay peninsula. These restrictions on boaters may offer some protection for legal–sized red drum in this area of the bay. The large red drum caught in the lower portion of Tampa Bay may be individuals that were staging prior to emigration into nearshore GOM waters (Switzer et al. 2009). With the exception of the larger red drum caught around the interbay peninsula, our length–frequency and ancillary tag–recapture data (Switzer et al. 2009) indicate that red drum move from the primary nursery

areas to the mouth of the bay as they grow.

The survival of red drum released after being caught by an angler has significant bearing on the inshore population and ultimately influences the numbers of red drum that emigrate into nearshore GOM waters. Due to recent interest in reopening Federal waters of the GOM for a limited harvest of large adult red drum, the catch–and–release survival of red drum within the estuary and their rate of escapement could be relevant to this discussion. The short–term catch–and–release mortality rate calculated for red drum in this study is similar to that seen in other studies, which reported mortality rates < 10% throughout waters adjacent to the southeastern United States (Matlock et al. 1993, Muoneke and Childress 1994, Aguilar et al. 2002, Vecchio and Wenner 2007). Overall, the catch–and–release mortality rate is low for red drum; however, we have shown that this rate can be significantly elevated with deep–hooking and with higher water temperature. Long–term survival rates estimated from tag return data were also quite high, and although these rates were extremely variable, the results correspond to conclusions regarding differential survival among hook positions.

Differences in catch–and–release mortality rates related to the anatomical location of the hook have been reported in several studies (Muoneke and Childress 1994, Aguilar et al. 2002, Aalbers et al. 2004, Bartholomew and Bohnsack 2005, Cooke et al. 2005, Vecchio and Wenner 2007). The major-
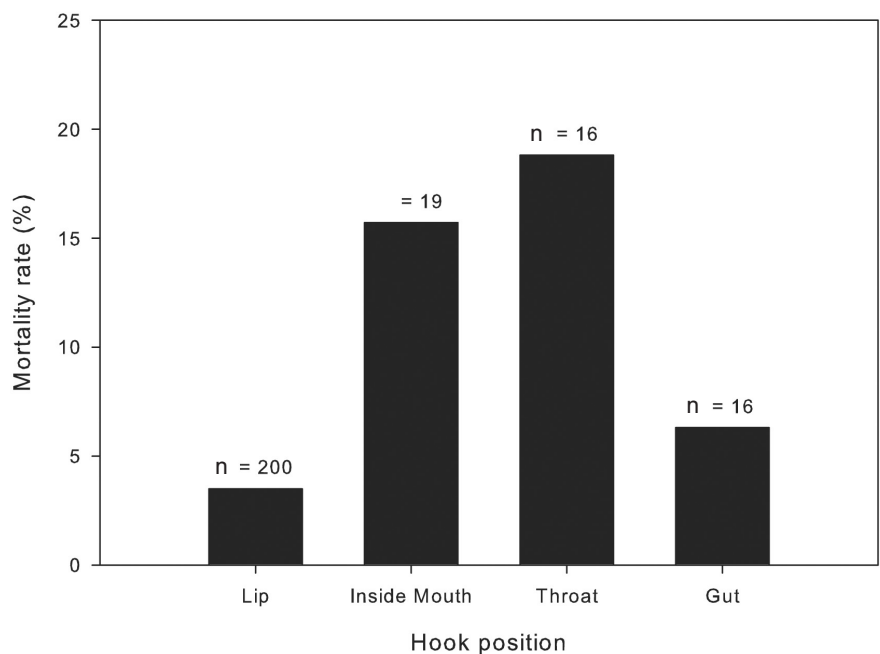
Figure 5. *Percentage of red drum that died during catch-and-release mortality experiments by hook position (lip = corner of mouth; inside mouth = buccal cavity; throat = anterior of pharyngeal teeth; gut = posterior of pharyngeal teeth). n = number of red drum hooked in a given anatomical location.*
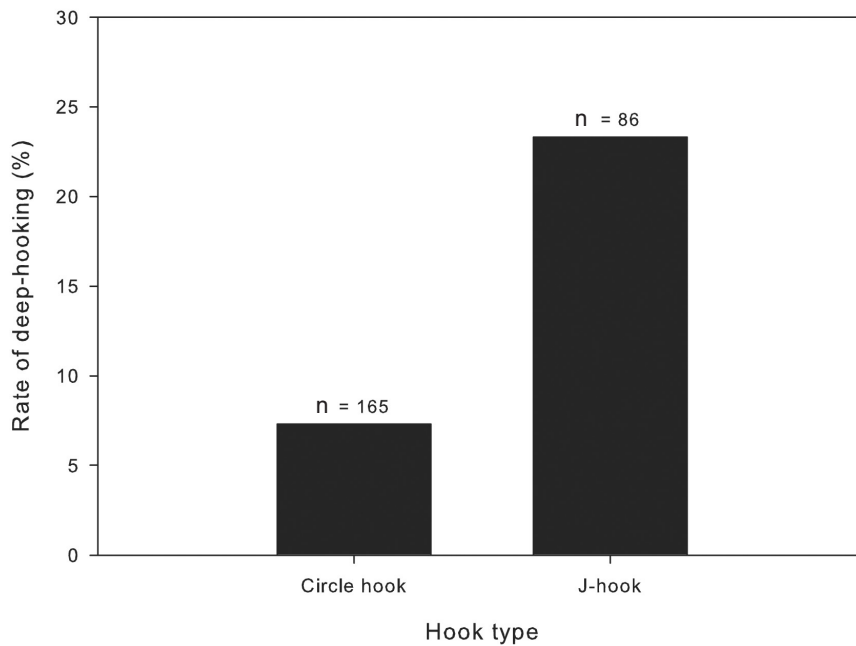
Figure 6. *Percentage of red drum deep-hooked (throat- or gut-hooked), by hook type, during catch-and-release mortality experiments. n = number of red drum captured using each hook type.*

ity of red drum caught in our study were hooked in shallow anatomical locations such as the lip or inside the mouth; hook wounds in these areas usually result in fewer injuries to vital organs, resulting in a lower rate of short—term mortality for the total population (Aalbers et al. 2004, Cooke and Suski 2004, Vecchio and Wenner 2007). Conversely, hook wounds in deep anatomical locations such as the gills, esophagus, or gut have been found to damage vital organs and contribute to higher rates of mortality (Muoneke and Childress 1994). During monthly hook—and—line sampling and mortality experiments, the percentage of deep—hooked red drum released in fair or poor condition was greater than that of shallow—hooked fish. In addition, 3 of the 4 deep—hooked fish that died during mortality experiments had noticeable injuries either to the esophagus or to the heart. Of all deep—hooked fish in our study, fish that were hooked in the throat had the highest mortality rate, and gut—hooked fish had the lowest mortality rate. This lower mortality rate for gut—hooked fish may be a result of the small sample size of these fish in our study (n = 16); however, the percentage of gut—hooked fish (6.4%) is consistent with that seen in our monthly hook—and—line sampling (6.6%), and the sample size is equivalent to that of throat—hooked fish. Fish that are hooked in the throat or gill region often sustain immediate trauma and bleeding, which is reflected in the higher mortality rates observed. In contrast, adverse effects due to gut—hooking may not be apparent in the short—term, especially if the hook is left inside the fish, which is often the case in order to avoid additional trauma. The removal of deeply

ingested hooks can increase handling stress, cause significant trauma, and contribute to short—term mortality (Muoneke and Childress 1994); however, hooks left embedded in the peritoneal cavity or gut may cause damage that can contribute to long—term (> 48 h) post—release mortality (Lawson and Sampson 1996, Aalbers et al. 2004, Vecchio 2006). Of the fish that survive, hooks may dissolve within the fish, be extruded, or show evidence of tissue growth around the wounds (Muoneke and Childress 1994). Although recapture rates of red drum based on long—term tag return data were high and variable for all hook positions, these rates were lowest for gut—hooked fish suggesting long—term survival may be affected.

Release condition was not associated with mortality in this study; however, in other species, the amount of bleeding (Aalbers et al. 2004, Fabrizio et al. 2008, Grixti et al. 2008) and general release condition (Burns et al. 2008; Sumpton et al. 2008) has been associated with mortality or used for tag—recapture mortality estimates, respectively. Similar to our study, Aguilar et al. (2002) observed very few red drum that exhibited external bleeding. The vast majority of the red drum caught during monthly hook—and—line sampling and mortality experiments were released in good condition (90% and 97%, respectively), which indicates that this may not be a good indicator of short—term mortality. Several caveats must be presented with the results of net pen studies of fish survival. Confinement studies generally preclude large scale ecosystem interactions, like predation, and do not assess behavioral movements of fish after the catch—and—release event (Donaldson et al. 2008). Also, confinement in pens may possibly increase stress and mortality. Although a fish may be released in good condition, this assessment is subjective and may not reflect the physiological stress of being captured.

Contrary to other published work (Bartholomew and

TABLE 6. *Number of red drum mortalities by type of injury, hook position, and hook type as determined by necropsy. Three main observations were recorded: no visible injury; injury to the esophagus; and injury to the heart. Hook type with which the individuals were captured is represented by C (circle hook) or J (J-hook).*

Hook position	No injury		Esophagus		Heart		Total
	C	J	C	J	C	J	
Lip	5	2	–	–	–	–	7
Inside mouth	–	1	–	1	–	1	3
Throat	1	–	–	2	–	–	3
Gut	–	–	–	–	1	–	1
Totals	**6**	**3**	**—**	**3**	**1**	**1**	**14**

TABLE 7. *Long-term relative survival rates of red drum released alive after mortality experiments based on tag recaptures from April 2005 – October 2012 by hook position and hook type. Relative survival (S) and 95% confidence interval (CI) calculations for other categories were based on the assumption that fish that were lip-hooked or captured by circle hook had a survival rate of 1.*

	Number of red drum		Recapture rate		
Variable	Released	Recaptured	(%)	S	CI
Hook position					
Lip	193	17	8.81	1.00	–
Inside mouth	16	3	18.75	2.13	0.70–6.50
Throat	13	1	7.69	0.87	0.13–6.06
Gut	15	1	6.67	0.76	0.11–5.30
Total	**237**	**22**	**9.28**	**–**	**–**
Hook type					
Circle	158	15	9.49	1.00	–
J	79	7	8.86	0.93	0.40–2.20
Total	**237**	**22**	**9.28**	**–**	**–**

Bohnsack 2005, Beckwith and Rand 2005, Jones 2005, Vecchio and Wenner 2007), hook type was not directly associated with mortality in this study. Similar to other studies, however, a higher proportion of red drum were captured and deep–hooking was less frequent with circle hooks as opposed to J–hooks (McEachron et al. 1985, Vecchio and Wenner 2007). Deep–hooking is more common with J–hooks (Bartholomew and Bohnsack 2005, Beckwith and Rand 2005, Jones 2005, Vecchio and Wenner 2007) because their design allows them to catch on tissue in the gut or throat, whereas the shape of a circle hook makes it more likely to hook the lip after bypassing the esophageal tissues without penetrating them. Hook trauma was noticeable in several mortalities involving J–hooks; 4 of the 5 fish that died and had injuries to the esophagus or heart were caught on J–hooks. Because of the tendency of J–hooks to become deeply embedded in tissue, it is possible that some red drum may have broken free with embedded J–hooks before being landed, therefore decreasing observed catch and making their survival unknown (Vecchio and Wenner 2007). In addition to hook type, hook size has been associated with mortality rates (Muoneke and Childress 1994) and is related to minimum capture size in some species (Otway and Craig 1993, Cooke et al. 2005). A study of red drum, however, showed no relationship between hook size and size of fish caught (Aguilar et al. 2002). Because we used small J–hooks and circle hooks of the same gauge (1/0) in this study, future research could focus on the differences related to hook size in deep–hooking, mortality, or catch rates of different sized fish.

Although water temperature was significantly correlated with mortality in this study, in other studies in GOM estuaries this association was variable. A study of spotted seatrout, *Cynoscion nebulosus*, in Florida detected no significant correlation between catch–and–release mortality and water

temperature (Murphy et al. 1995), but the reverse was true for spotted seatrout in Texas (James et al. 2007). The catch–and–release mortality of common snook, *Centropomus undecimalis*, was not significantly related to temperature (Taylor et al. 2001), which may be explained by the ability of this tropical species to tolerate and spawn in temperatures warmer than 30°C. Studies of red drum and other species in various locations have shown positive correlations between water temperature and mortality (Muoneke and Childress 1994, Schisler and Bergersen 1996, Latour et al. 2001, Bartholomew and Bohnsack 2005). Latour et al. (2001) observed a relatively high mortality rate (19.1%) for large red drum (>550 mm SL) in water temperatures above 25°C, while Aguilar et al. (2002) found no correlation of red drum mortality with temperature. In our experiments, several red drum without noticeable injury died in water warmer than 26°C, suggesting that thermal stress may be a contributing factor to mortality. Catch–and–release mortality rates calculated in this study represent the most southerly such estimates for red drum and represent a broader range of water temperatures than found in most other studies (Matlock et al. 1993, Muoneke and Childress 1994). Red drum have been observed in waters at temperatures from 2 to 33°C (Mercer 1984), but movement from warm, shallow waters to cooler, deeper waters is commonly observed. The inability of red drum to escape into waters deeper (and cooler) than the holding pens may have added to thermal stress and contributed to mortality rates during experiments in warmer waters. The upper limits of thermal tolerance for juvenile red drum (71–155 mm SL) from hatcheries in Texas and South Carolina ranged from 28.8 to 35.7°C, depending on acclimation temperature (Procarione and King 1993). In our study, the greatest mortality rate was observed during an experiment in October 2007, when mean water temperature was 28.0°C, although a large proportion of these fish survived long–term as suggested by the high recapture rate. Contrary to expectations, all 6 fish caught during an experiment in August 2007, when the mean water temperature was 30.2°C, survived. These fish may have experienced less stress, since only 6 fish were in the holding pen and all had been shallow–hooked with circle hooks. None of these fish were recaptured, but this is not surprising considering the small sample size. Although the level of DO was not correlated with mortality in our study, low DO levels in high–temperature waters may contribute to mortality because of increased respiratory demands. Injuries sustained during catch–and–release fishing may also be more prone to infection in warmer waters (Muoneke 1992).

Stress associated with increasing fight and handling times did not affect the mortality of red drum in this study. Re-

sults from prior studies examining these angling—related factors have been equivocal. For example, a rainbow trout, *Oncorhynchus mykiss*, study showed an increase in probability of mortality with increased fight time and handling time out of the water (Schisler and Bergersen 1996). However, a study on chinook salmon, *Oncorhynchus tshawytscha*, did not have higher mortality rates associated with increased stress (Wertheimer et al. 1989). Responsible fighting and handling techniques were practiced during our study, including fishing actively, limiting play in the line while fighting the fish, supporting the fish with both hands, processing the fish as quickly as possible, and leaving the hook in deeply hooked fish (Bartholomew and Bohnsack 2005). On average, our fight times (< 1 minute) and handling times (< 3 minutes) were in a conservative range and probably did not cause critical stress levels that would be expected to increase mortality. Thus, our catch—and—release mortality estimates are conservative with regard to these factors.

Previous studies have found no relationship between fish size and catch—and—release mortality (Muoneke and Childress 1994, Aguilar et al. 2002, Stunz and McKee 2006). Although fish length was not a significant factor in this study, a slightly larger percentage of legal—sized red drum died than sublegal or supralegal red drum. This potential difference in mortality rates of legal—sized red drum should be investigated further and may have implications for management. The size range of fish captured during our catch—and—release mortality experiments was similar to that observed in our monthly hook—and—line trips, which represented a relatively broad size range of red drum available to the recreational fishery throughout Tampa Bay. Because we caught relatively few supralegal fish, however, future research efforts should focus on either large subadult or young adult red drum, which often school in the lower estuary in the fall. Schools of these sizes of red drum are common in shallow estuarine waters during the warmest months, when DO levels are lowest. These trophy—size red drum are heavily targeted by fishing guides and recreational anglers and may be subject to longer fight and handling times because of their size. This heavy fishing pressure was potentially reflected by the high mortality coupled with a high recapture rate of fish from the October 2007 experiment conducted in this area. In addition, all but one of our mortality experiments were conducted in the upper bay and may not be representative of the population in the lower bay. Although in our study no fish larger than legal size died within the 48 h holding period, these factors could very well contribute to some short—term catch—and—release mortality.

The results of this study can be used in stock assessments and outreach programs aimed at recreational anglers. In addition to calculating catch—and—release mortality estimates for the southerly Tampa Bay estuary, this study incorporates data collected from year—round hook—and—line sampling for red drum to estimate sizes available to the recreational fishery. The most recent Florida Fish and Wildlife Conservation Commission (FWC) red drum stock assessment (Murphy and Munyandorero 2008) assumed 5% post—release mortality, which is closely in line with our estimate. Depending on water temperature and hook position, however, the probability of mortality may be substantially higher. The FWC stock assessment also concluded that a 30% escapement goal was barely being met as of 2007 (Murphy and Munyandorero 2008). If the number of anglers continues to increase, as it has for the past several decades, this goal will no longer be met under current regulations coupled with the 5% post—release mortality assumption (Murphy and Munyandorero 2008). One option would be to support outreach efforts that educate anglers on the advantages of using circle hooks. Our study found that anglers using circle hooks deep—hooked fish about one—third as often as those using J—hooks, which corresponded to a lower incidence of hook trauma. Catch—and—release fishing is an effective management tool for reducing take in the red drum fishery and should be encouraged as a management strategy; however, the practice can contribute to cryptic mortality, especially with heavy fishing pressures, and these impacts should not be overlooked when evaluating the overall health of fish populations.

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