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Catch-and-Release Mortality in Subadult and Adult Red Drum Captured with Popular Fishing Hook Types

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Abstract.—Saltwater anglers along the entire coast of the southeastern United States target red drum *Sciaenops ocellatus* more frequently than any other recreational fish species. The frequency of catch-and-release angling has increased dramatically for this species in the past two decades, but little is known about the survival of released fish. This study demonstrates that catch-and-release mortality rates for subadult and adult red drum differed significantly among the most popular types of fish hooks in each fishery. To investigate the effect of hook type on anatomical hooking location and short-term (48-h) mortality, we captured subadults (339–825 mm total length [TL]) by use of 2/0 J-hooks ($n = 57$ fish), 4/0 nonoffset circle hooks ($n = 58$ fish), and 4/0 offset circle hooks ($n = 57$ fish). Nonoffset circle hooks penetrated shallow regions of the body (jaw, tongue, or inside of mouth) significantly more frequently (90%) than did J-hooks (60%) or offset circle hooks (80%). Nonoffset circle hooks also resulted in the lowest rate of subadult mortality (2%). Adults (660–1,138 mm TL) were captured on bottom longline gear with 7/0 J-hooks ($n = 60$) and 9/0 nonoffset circle hooks ($n = 107$). The frequency of deep hooking in adults was significantly higher for J-hooks (30%) than nonoffset circle hooks (3%). Only deep hooked fish were monitored for 48-h survival. Adult mortality after 48 h was lower for nonoffset circle hooks (1.9%) than for J-hooks (3.3%). These mortality rates should be considered in future red drum stock assessments.

The practice of catch-and-release fishing has become an integral part of the fishery targeting red drum *Sciaenops ocellatus* in South Carolina and along the entire coast of the southeastern United States. According to the Marine Recreational Fisheries Statistical Survey (MRFSS), 17% (on average) of the South Carolina red drum recreational catch in the 1980s was released. This rate increased to 58% in the 1990s and remained approximately 75% from 2000 to 2005 (National Marine Fisheries Service, Fisheries Statistics Division, personal communication).

Anglers often assume that all fish returned to the water alive will survive to grow and spawn. This may not always be the case. Although Arendt and Lucy (2002) indicated that tautogs *Tautoga onitis* may live more than 6 months after capture, Thompson et al. (2002) indicated that striped bass *Morone saxatilis* exhibited increased levels of both metabolic and respiratory acidosis after catch-and-release events. This

respiratory distress was thought to contribute to postrelease mortality in some individuals. The retention of hooks embedded in the peritoneal cavity of the fish could also contribute to postrelease mortality (Lawson and Sampson 1996).

A circle hook is defined as a nonoffset hook with the point turned perpendicularly back to the shank (Atlantic States Marine Fisheries Commission 2003). Circle-shaped hooks have been employed in tropical areas of the Pacific for centuries (Johannes 1981) but are relatively new to western fisheries. The use of circle hooks has been shown to increase catch per unit effort (CPUE) in longline fisheries (Woll et al. 2001) and survival in the catch-and-release recreational fishery (Bartholomew and Bohnsack 2005) when compared with the more common J-hooks. This results from the tendency of circle hooks to become embedded in the corner of the mouth rather than in vital areas, such as the gills or gut (Cooke and Suski 2004). When anglers use live or natural baits, the effectiveness of circle hooks is maximized because the bait is frequently swallowed whole. When a J-hook is swallowed, it often penetrates deeply into the tissue. However, the shape of a circle hook often allows it to be pulled from the gut and to catch in the anterior region of the mouth (Atlantic States Marine Fisheries Commission 2003).

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In a study of adult red drum, Aguilar et al. (2002) found that 45.6% of fish caught with J-hooks and 95.8% of fish caught with circle hooks were caught in the jaw. Cooke and Suski (2004) warned that many factors may be involved in the effectiveness of circle hooks, including hook size, fishing style, fish feeding mode, and mouth morphology. They encouraged the promotion of circle hooks in instances where scientific research has shown an improvement in survival and a comparable CPUE.

Although most of the large (7/0 and larger) circle hooks manufactured are nonoffset, many smaller ones (6/0 and smaller) on the market have some degree of offset (authors' personal observation). There is little information relating the use of offset circle hooks (those with the point bent to an angle with the shank) to catch-and-release mortality. Some anglers believe that offsetting a circle hook increases its effectiveness. However, in a study of sailfish *Istiophorus platypterus* and blue marlin *Makaira nigricans*, use of severely offset (15°) circle hooks resulted in deep hooking 44% of the time, while circle hooks that were offset by 5° and 0° consistently caught fish in the jaw (Prince et al. 2002). In the fishery targeting summer flounder *Paralichthys dentatus*, angling mortality was similar between J-hooks and circle hooks offset by 15° (Malchoff et al. 2002). In contrast, similar proportions of striped marlin *Tetrapturus audax* died from being caught with nonoffset and 5° offset circle hooks, and both proportions were significantly lower than that of J-hooks (Domeier et al. 2003). Nonoffset and 2° offset circle hooks were also found to result in similar rates of deep hooking in largemouth bass *Micropterus salmoides* (Ostrand et al. 2005).

In South Carolina, red drum spend the first 3–4 years of life in shallow marsh habitat, where they move with the tides between flats of smooth cordgrass *Spartina alterniflora* and reefs of eastern oysters *Crassostrea virginica* (Wenner 1992). At sexual maturity, the fish move into the coastal spawning population and are approximately 800 mm total length (TL; Wenner 1992). The current South Carolina red drum regulations include a daily bag limit of 2 fish/angler and a 380–600-mm slot. Subadult red drum are fished throughout the year, mainly in their shallow (depth < 2 m) marsh habitats. A significant part of the catch is released alive either because of these strict regulatory constraints or angler preference. Adult red drum congregate near entrances to the state's major estuaries between July and September for spawning and are targeted by anglers in deep areas (10–20 m depth) near known spawning aggregation sites. Since the landing of adults (>600 mm TL) is illegal in South Carolina, all adults are theoretically released alive.

Available data indicate that South Carolina red drum anglers overwhelmingly use natural baits (73.9%). They also prefer to use J-hooks (47.5%), circle hooks (34.4%), or offset circle hooks (4.7%; Vecchio 2006). Our objective was to determine catch-and-release mortality rates associated with the most commonly used hook types in the subadult and adult red drum recreational fisheries in South Carolina. Rigorous hook placement and 48-h survival experiments were conducted for subadults and adults caught with natural baits and the most common hook types in each fishery. Subadults and adults were targeted with different sizes of hooks in separate fishing trips. Although 48 h is shorter than the holding periods traditionally described in the literature, several studies have demonstrated that short-term mortality occurs within this time period (Taylor et al. 2001; Cooke et al. 2003a; Aalbers et al. 2004).

Methods

Small-hook study of subadult red drum.—We targeted subadults in shallow water near oyster bars and other structures in the Charleston Harbor estuary, South Carolina. These fish were caught with spinning rods equipped with 5.44-kg-test monofilament line and 9.07-kg-test monofilament leaders (45 cm long) connected by a 13.61-kg-test barrel swivel. Hooks were 2/0 Eagle Claw plain-shank J-hooks (Eagle Claw Fishing Tackle Co., Denver, Colorado; Model 084), 4/0 Eagle Claw nonoffset circle hooks (Model L704), or 4/0 Eagle Claw circle hooks offset by 15° (Figure 1). Hooks were fished with enough weight to keep the terminal tackle on the bottom (7.09–28.35 g). Hooks were baited with live mummichogs *Fundulus heteroclitus* or cut bait (e.g., striped mullet *Mugil cephalus* or spot *Leiostomus xanthurus*). Fishing trips included between one and four individual anglers, each with a single, constantly monitored fishing rod. Surface temperature and salinity were recorded.

After capture, each subadult was tagged with a passive integrated transponder (PIT) tag and measured to the nearest millimeter TL. Hook type and hook placement were recorded, along with evidence of external bleeding and elapsed time between hooking and landing. When a hook penetrated the jaw or anterior region of the mouth, it was removed. If it pierced the digestive tract posterior to the pharyngeal teeth, the leader was cut near the hook, which was left in place. The fish were then placed into an oxygenated, 168-L temporary transport tank and held there for a maximum of 3 h. During this period, tank water was changed frequently. In the field, a red drum was considered to be dead if it lost neutral buoyancy and flared its opercula. At the end of each fishing trip, all
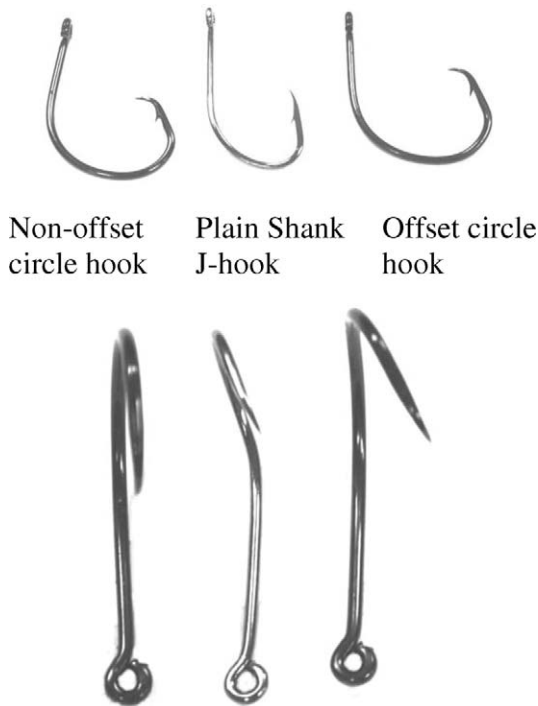
FIGURE 1.—Hook styles used during a study of mortality in subadult red drum angled with small hooks and adult red drum captured on bottom longlines with large hooks in the Charleston Harbor estuary, South Carolina.

surviving subadults were transported to the South Carolina Department of Natural Resources (SCDNR) Marine Resources Research Institute (MRRI) facility on the southern shore of Charleston Harbor for observation. Handling and transport times were recorded.

Subadults were held at MRRI in outdoor fiberglass tanks (approximate volume = 7,500 L; diameter = 4 m; depth = 1 m) for 48 h. Fish were not fed, and ambient seawater from Charleston Harbor was continuously added to the tanks throughout the holding period. The flow rate was sufficient to replace the tank volume 32 times/d. Temperature, salinity, and dissolved oxygen were recorded every 15 min by an automated data logger. Mortality was monitored every 12 h. All fish that survived the 48-h holding period were tagged with internal anchor or stainless-steel dart tags to facilitate identification by recreational anglers and other SCDNR projects. Fish were then released at their original capture locations. A necropsy was performed on all subadult mortalities to determine probable cause of death. The location of hook penetration, occurrence of internal hemorrhaging, and other internal damage were noted, described, and photodocumented.

Large-hook study of adult red drum.—We targeted adults during September and October 2005 with bottom longline gear in coastal waters adjacent to the mouth of the Charleston Harbor estuary. The gear was deployed by hydraulic winch in 9–15 m of water aboard the RV *Silver Crescent.* The fishing gear included (1) 1,829-m-long mainline of 136.08-kg-test monofilament; (2) marker buoys attached to each end of the mainline with 30.5 m of 136.08-kg-test monofilament line; (3) a 12-kg anchor at each end of the mainline; (4) 120 gangions (60 cm long) of 45.36-kg-test monofilament rigged with either a 7/0 plain-shank J-hook (Eagle Claw; Model 084) or a 9/0 nonoffset circle hook (Eagle Claw; Model L2004ELF; Figure 1). Equal numbers of each hook type were alternated on the mainline, and hooks were baited with cut Atlantic mackerel *Scomber scombrus.* Through communication with several local fishing guides, it was determined that offset circle hooks are not commonly used to capture adult red drum; therefore, this hook type was excluded from the adult portion of the study. The longline was soaked for 30 min/set. Red drum caught by the gear were brought aboard the vessel, measured to the nearest millimeter (TL and fork length), and marked with three tag types (nylon dart, stainless-steel dart, and PIT). Hook placement was noted, and a subjective bleeding category was assigned. If the fish was hooked in the jaw or inside the mouth, the hook was removed. However, if hooks were embedded in areas beyond the pharyngeal teeth, the gangion was cut and the hook was left in place.

Due to the numbers and sizes of individuals caught each sampling day, only red drum hooked in the gut or gills were retained aboard the research vessel. All other animals were released immediately after being measured and tagged. Retained fish were held in a 1,000-L transport tank aboard the RV *Silver Crescent.* Water was changed or refreshed every 45 min, and oxygen was continuously added to the tank. Red drum were held in this tank for up to 4 h. At the end of each sampling day, all retained fish were transported to MRRI and placed into 7,500-L tanks (same as used for subadults) for a 48-h observation period. For fish with grossly inflated swim bladders that did not deflate within the transport time, gas was released with an 18-gauge hypodermic needle, a procedure also used by fishing guides and recreational fish taggers. All animals that survived the holding period were released alive at a site adjacent to the SCDNR MRRI facility. Necropsies were performed on all animals that died during the study to determine cause of death and hook injury. Hook placement within the body cavity, hemorrhaging, and other signs of internal damage were examined and photodocumented when appropriate.

TABLE 1.—Numbers of red drum in Charleston Harbor estuary, South Carolina, that were shallow or deep hooked on different hook types and their fate at the end of a 48-h holding period used to monitor mortality. Subadults were angled with small (2/0 J, 4/0 nonoffset circle, and 4/0 offset circle) hooks in shallow (<2 m) areas of the estuary. Adults were captured on bottom longline gear with large (7/0 J, 9/0 nonoffset circle) hooks in deep (9–15 m) areas near the harbor's entrance. Shallow hooking involved the jaw, inside of mouth, or tongue; deep hooking involved the gills, esophagus, or stomach.

Hook location	Result	Subadult hook type			Adult hook type	
		2/0 J	4/0 nonoffset circle	4/0 offset circle	7/0 J	9/0 nonoffset circle
Shallow	Survived	34	52	46	43	102
	Died	0	0	0	N/A	N/A
Deep	Survived	19	5	5	15	1
	Died	4	1	6	2	2

Data analysis.—Hook placement data were pooled into shallow (jaw, inside of mouth, tongue) or deep (gill, esophagus, stomach) categories. A *G*-test, similar to a χ^2 test, was used to determine significant differences in deep hooking and survival rates between hook types for each size-class (Sokal and Rohlf 1995). A *G*-test was chosen to compare observed with expected frequencies of deep hooking and mortality using hook types as independent variables. All means are reported with SEs. The SCDNR Inshore Fisheries Group maintained a database describing tagged red drum that were later recaptured by anglers. Using this database, we compared recapture proportions between our study fish and those tagged by the Inshore Fisheries Group in 2005. This procedure was followed to determine whether long-term survival could be inferred.

Results

Small-Hook Study of Subadult Red Drum

We captured 172 subadult red drum by means of small hooks in shallow water. Of these, 58 were caught with nonoffset circle hooks, 57 were caught with offset circle hooks, and 57 were caught with J-hooks (Table 1). Subadults ranged from 339 to 825 mm TL and had an overall mean TL of 443 ± 8 mm.

A *G*-test revealed a significant difference in proportions of fish that were deep hooked among the three hook types ($P < 0.01$; Table 2). The J-hooks accounted for the largest proportion of deep hooked subadults, followed by offset circle hooks. Nonoffset circle hooks resulted in the fewest incidents of deep hooking (Figure 2a). All subadults that died had been deep hooked (i.e., the hook had penetrated tissue posterior to the pharyngeal teeth). No significant difference in mortality of deep-hooked subadults was found among hook types ($P = 0.07$; Table 2); however, differences among hook types were evident (Figure 2a). Although approximately one in six fish that were deep hooked on J-hooks or nonoffset circle hooks died,

over half of the fish that were deep hooked by offset circle hooks died. This resulted in an overall mortality rate of 7% for J-hooks, 2% for nonoffset circle hooks, and 10% for offset circle hooks (not significantly different; Table 2).

Of the 11 subadults that died, 9 fish expired in the transport tank within 3 h of capture and only 2 died between 3 and 35 h postcapture. The mean time from hooking to mortality for these fish was 7.32 ± 3.78 h. All eventual mortalities exhibited severe internal injuries, such as extensive hemorrhaging in the pericardial or peritoneal cavity caused by hooks penetrating vital organs. It was difficult to predict the death of a fish in the field based on hook placement or external bleeding. Most of the fish that were bleeding externally upon capture survived the encounter. More than half of the fish that eventually died showed no external damage. Of the 150 individual subadults that were tagged and released, 20 (13.33%) were recaptured by anglers and reported to SCDNR.

TABLE 2.—Results of *G*-tests examining catch-and-release mortality of red drum captured on different hook types (independent variable) in Charleston Harbor estuary, South Carolina, and held for 48 h. Subadults were angled with small (2/0 J, 4/0 nonoffset circle, and 4/0 offset circle) hooks in shallow (<2 m) areas of the estuary. Adults were captured on bottom longline gear with large (7/0 J, 9/0 nonoffset circle) hooks in deep (9–15 m) areas near the harbor's entrance. Shallow hooking involved the jaw, inside of mouth, or tongue; deep hooking involved the gills, esophagus, or stomach.

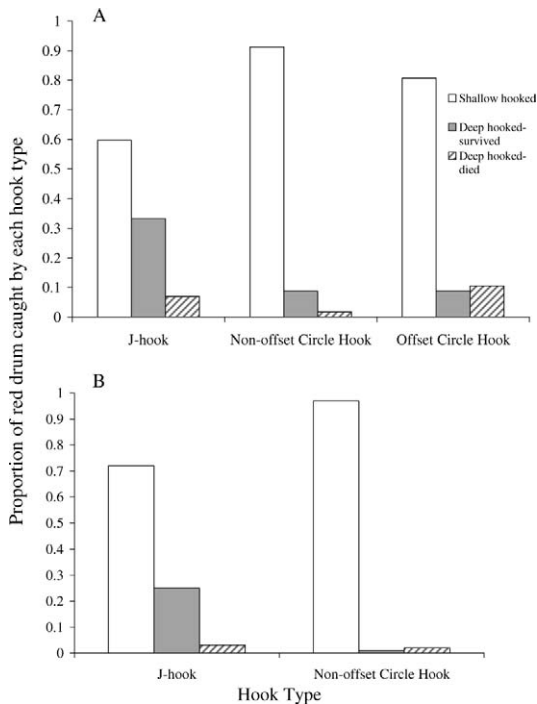| Fish age and result	df	*G*	*P*
Subadults			
Deeply hooked	2	15.18	<0.01
Deeply hooked and died	2	5.23	0.07
Overall mortality	2	4.34	0.11
Adults			
CPUE	1	13.41	<0.01
Deeply hooked	1	23.10	<0.01
Deeply hooked and died	1	3.88	0.05
Overall mortality	1	0.32	0.85

FIGURE 2.—Proportions of red drum in Charleston Harbor estuary, South Carolina, that were shallow hooked (white bars), deep hooked and survived (gray bars), or deep hooked and died (black bars): **(A)** subadults angled with small (2/0 J, 4/0 nonoffset circle, and 4/0 offset circle) hooks in shallow (<2 m) areas of the estuary and **(B)** adults captured on bottom longline gear with large (7/0 J, 9/0 circle) hooks in deep (9–15 m) areas near the harbor's entrance. Shallow hooking involved the jaw, inside of mouth, or tongue; deep hooking involved the gills, esophagus, or stomach. Survival was monitored in holding tanks for 48 h.

Large-Hook Study of Adult Red Drum

We captured 167 adults by use of bottom longline gear near the entrance to Charleston Harbor. Of these, 60 were landed on J-hooks and 107 were landed on nonoffset circle hooks (Table 1). A G-test revealed a significant difference in CPUE between the two hook types ($P < 0.01$; Table 2); circle hooks were significantly more successful than J-hooks. Fish ranged in TL from 660 to 1,138 mm and had an overall mean TL of 932 ± 7 mm. Two fish were excluded from the remainder of statistical analyses because we were unable to attribute the cause of death to injuries sustained when hooked on the longline.

A significantly higher proportion of adults was deep hooked on J-hooks than on nonoffset circle hooks ($P < 0.01$; Figure 2b). However, a significantly higher proportion of deep-hooked fish died when caught on nonoffset circle hooks than on J-hooks ($P = 0.05$;

Figure 2b). The resultant mortality rate was 3.3% for J-hooks and 1.9% for nonoffset circle hooks (Table 2). In all necropsied adults, the hook pierced the liver and the fish hemorrhaged and died in less than 36 h. The mean time to mortality was 12.5 ± 8.25 h for all adults that died. The presence of external bleeding was not correlated with deep hooking or mortality. None of the fish that were observed bleeding externally were deep hooked. None of the fish that died as a result of hook injuries exhibited external bleeding.

The deaths of the two red drum that were excluded from analyses were not attributed to injuries resulting from interaction with the longline gear. Both fish were caught by circle hooks and appeared to be hooked in the corner of the jaw. One fish died before it came aboard the vessel. A necropsy revealed coagulated blood and a small J-hook that seemed to have been in the peritoneal cavity for several weeks (similar to those examined in Aalbers et al. 2004). The other fish was retained because of a possible hook interaction with gill tissue. Upon necropsy, a large tear was found in the stomach wall. The liver was necrotic, and a thick layer of vascularized adipose tissue lined the inner wall of the peritoneal cavity near the injury site. A wildlife veterinarian determined that this damage would have taken several days to occur (A. Segars, SCDNR, personal communication). These results suggest possible long-term effects of deep hooking on adult red drum.

Discussion

Nonoffset circle hooks were shown to deep hook the fewest red drum in this study as well as in several recent studies of other recreationally important species (Aalbers et al. 2004; Cooke et al. 2005; Horodysky and Graves 2005). The shape of a nonoffset circle hook prevents the point of the hook from lodging in deep tissues. This results in the hook remaining in the corner of the mouth. It has been hypothesized that once a circle hook is bent out of line (offset), the point becomes more exposed, which facilitates its penetration into deep tissue (Atlantic States Marine Fisheries Commission 2003).

Although nonoffset circle hooks have been shown to increase jaw hook insertion and decrease the incidence of deep hooking in a variety of studies (Lucacovic and Uphoff 2002; Bartholomew and Bohnsack 2005; Jones 2005), anglers may be resistant to using them. Circle hooks must be fished differently than J-hooks. Instead of jerking up on the rod tip to set the hook, the angler must apply slow and steady pressure to the line to keep the hook from being pulled from the mouth of the fish. This subtle change in fishing method may render circle hook fishing unattractive to many anglers. However, if

results of these studies are distributed to the public, many anglers may decide that the benefits to the resource are worth the change in habits.

For subadult red drum, the highest deep-hooking rate occurred with the use of plain-shank J-hooks. This result was similar to those of studies investigating catch-and-release mortality in a variety of other marine species (Lucacovic and Uphoff 2002; Bartholomew and Bohnsack 2005; Horodysky and Graves 2005). Despite the fact that the frequency of deep hooking by offset circle hooks was only half that of J-hooks, the overall mortality rate associated with offset circle hooks was the highest of the three hook types tested. Studies of other species have indicated that fish taken on severely (15°) offset circle hooks died at rates higher than those associated with nonoffset circle hooks (Prince et al. 2002) and similar to those associated with plain-shank J-hooks (Malchoff et al. 2002).

All 11 subadult red drum that died had swallowed hooks into the esophagus or stomach. In three cases, the hook penetrated the esophagus and lodged in the heart. In the remaining eight subadults, the hook penetrated the wall of the stomach and pierced the liver, as has been described in other hooking studies (Aguilar et al. 2002; Aalbers et al. 2004). All subadults died well within the 48-h holding period, and most died within 3 h—even more quickly than observations in many of the studies reviewed by Bartholomew and Bohnsack (2005) but consistent with the results of Cooke et al. (2003a). Casual observation of hook placement or bleeding could not predict survival. Most deep-hooked red drum and those with external evidence of bleeding survived in the short term.

We found that the proportion of tagged subadults that were recaptured by anglers was similar to that for fish released from trammel nets during 2005. During a similar period in 2005, the SCDNR Inshore Fisheries Group tagged and released 6,238 red drum in a similar size range (<800 mm TL) during monthly trammel-net surveys. Of these, 610 (9.78%) were recaptured by anglers and reported to SCDNR. The trammel-net survey and tag return rewards have been in place for over a decade. Anglers were not able to distinguish between fish from our study and the SCDNR study. A similar rate of angler recapture for the two data sets suggests that fish in our study did not experience a higher rate of delayed mortality than fish captured by trammel net. Previous studies have shown no mortality for red drum tagged and released from trammel nets during winter, spring, or fall (Latour et al. 2001).

Similar to results published for the North Carolina commercial fishery for groupers (subfamily Epinephelinae; Bacheler and Buckel 2004) and the Greenland commercial fishery for halibut *Reinhardtius hippo-*

glossoides (Woll et al. 2001), a significantly larger number of adult red drum were landed with nonoffset circle hooks than J-hooks. For adults, nonoffset circle hooks produced a significantly lower frequency of deep hooking than did J-hooks when fished on a bottom longline. Aguilar et al. (2002) found similar results for adult red drum angled in North Carolina waters. Other studies have also shown that circle hooks increase CPUE while decreasing deep hooking in a longline setting (Trumble et al. 2000; Woll et al. 2001).

We found that overall 48-h mortality percentages of deep-hooked adults were similar between J-hooks and nonoffset circle hooks. When swallowed, the light-wire circle hooks seemed to easily penetrate the stomach wall and liver, causing the fish to hemorrhage and die quickly. The size of the hook may have resulted in an elevated number of fish that were deep hooked by nonoffset circle hooks. In a 12-year tagging study of adult red drum captured with 14/0 Mustad circle hooks (O. Mustad and Son A.S., Gjøvik, Norway), the deep-hooking rate was about half (1%) that we observed (G. Ulrich, SCDNR, unpublished data). Aguilar et al. (2002) also used somewhat heavier-gauge circle hooks (16/0 Mustad) than we did; those authors observed no mortality. If our study had been performed with heavier-gauge circle hooks, deep hooking and subsequent mortality rates might have been further reduced. Since J-hooks became embedded in deep tissue more frequently and produced a lower CPUE than did nonoffset circle hooks, more adult red drum were potentially able to pull free from J-hooks and such fish would have been lost before landing. The survival of these fish is unknown. We may have underestimated the mortality associated with deep hooking on J-hooks simply because many of these fish were never seen aboard the research vessel.

There is currently a thriving catch-and-release fishery for adult red drum near the mouth of Charleston Harbor and other estuaries throughout South Carolina. The popularity of this fishery has grown, in part, due to several publications in recreational fishing magazines (Arrington 2004; Olander 2004). The most recent red drum population model assumes that there is no fishing mortality on the adults (Vaughan and Carmichael 2002; i.e., catch-and-release mortality is assumed to be zero and compliance with the adult release regulation is assumed to be 100%). However, our study indicates that there is some catch-and-release mortality of adults. In addition, adults in South Carolina are targeted primarily during the spawning season near spawning locations (Wenner et al. 1990). During these fishing episodes, adults are brought to the surface from depths of 10–20 m and the average landing time is 10 min. Most fish are able to right themselves and return to the bottom after a

few minutes. However, fish appear to recover more slowly during the spawning season and may be subjected to higher predation or decreased spawning success after a catch-and-release event. When the water is warm, the fish are more metabolically active and the carrying capacity of oxygen in water is low. The fish also devote large energy reserves to reproduction. Aguilar et al. (2002) did not find a correlation between water temperature and survival of adult red drum in North Carolina. However, Latour et al. (2001) observed an average mortality of 19.1% for large red drum (>550 mm TL) caught with trammel nets and tagged at water temperatures above 28°C in South Carolina, whereas no fish died when temperatures were cooler. There are currently no data describing spawning success or other health effects after a catch-and-release event. However, since red drum remain near the coast after spawning is complete and when water temperatures are cool, anglers should be encouraged to wait until later in the year to catch them. Cooke and Suski (2005) suggested that refraining from targeting fish during the known spawning season is a guideline that should be in place for most recreational fisheries.

Results of the large-hook bottom longline study suggest that whether a deeply embedded hook is removed or left in place, it will eventually result in the death of the fish. It has been shown previously that leaving a hook in place rather than removing it resulted in decreased short-term (3–5 d) mortality for deep-hooked fish (Malchoff et al. 2002; Aalbers et al. 2004). Some fish have been shown to shed hooks within a few weeks or months (Bartholomew and Bohnsack 2005). However, growth rates of juvenile white seabass *Atractoscion nobilis* were reduced over a 90-d period when the hook was lodged in the esophagus or stomach (Aalbers et al. 2004). Aalbers et al. (2004) also found that hooks lodged in the tissue degraded only in areas directly exposed to seawater and were still present in the fish 150 d after the catch-and-release encounter. For the adult that died immediately in our study and was found to contain a J-hook from a prior angling event, we were unable to accurately estimate how long the hook had been in place and we did not know the number of times the fish had been caught and released since that prior hooking incident. Although the J-hook was left in place and degraded, apparently the fish had not fully recovered.

Although previous studies have retained fish for at least 72 h to assess short-term survival of sport fish after catch and release (e.g., Taylor et al. 2001; Aguilar et al. 2002; Cooke et al. 2003a), several have noted that 80–100% of mortalities occurred within 24 h of capture (Taylor et al. 2001; Cooke et al. 2003a; Aalbers et al. 2004). These prior results, along with our observations

that most mortality occurred within 3 h of capture and that all mortalities were associated with gross internal hemorrhaging, suggest that a 48-h holding period is sufficient to assess short-term hooking mortality in red drum. However, because of the difficulty of predicting mortality from hook placement or external bleeding upon capture, fish should not be categorized as "likely survivors" or "likely mortalities," as has been the practice in a few recent freshwater studies (Cooke et al. 2003b, 2005).

We combined an estimate of hook types used and hooking mortality for each hook type to determine total catch-and-release mortalities within the South Carolina red drum fishery. According to the MRFSS, 498,537 individual red drum were caught and released alive (termed "B2" fish; "B1" indicates fish that are retained) in South Carolina in 2005. Since most of the fish caught throughout the year are subadults, we used subadult mortality rates. Under an assumption of 7% mortality for fish caught on J-hooks (which constitute 47.5% of the hooks used to fish for red drum: Vecchio 2006), 16,576 fish died after J-hook capture and release. Under an assumption of 2% mortality for nonoffset circle hooks (34.4% of hooks used: Vecchio 2006), 3,429 fish captured by this hook type died after release. If 10% mortality is assumed for all other hook types (18.1% of hooks used: Vecchio 2006), then the estimate of postrelease mortality is 9,023 fish. These estimates indicate that during 2005, approximately 29,000 red drum were killed as a result of catch-and-release fishing in South Carolina. If all South Carolina anglers used nonoffset circle hooks when fishing for red drum, only 9,971 fish would have died during catch-and-release events; this translates to a 66% reduction in mortality.

The most recent population estimate for red drum includes a 10% B2 mortality rate for subadults throughout the Atlantic states (Vaughan and Carmichael 2000). Our results suggest that this estimate is sufficiently conservative when considering subadults in South Carolina. However, the population analysis does not include any fishing (B1 or B2) mortality for adults. The next red drum stock assessment should include the B2 estimates for adults from this study and from Aguilar et al. (2002). In addition, an effort should be made to assess compliance with current regulations that mandate the release of all adult red drum.

Our results demonstrate that nonoffset circle hooks are the best choice for red drum fishers using natural bait in a variety of settings. Bottom longline studies revealed that these hooks actually retain more adults than do similar-sized J-hooks. In addition, nonoffset circle hooks of both sizes deep hooked and killed significantly fewer red drum than did other hook types.

Since over 75% of red drum caught in South Carolina are released alive, anglers should always be encouraged to use the hook type that is most successful for releasing fish with minimal complications.

Although most hook-related mortality occurred within the first few hours of a hooking encounter for both adults and subadults, neither mortality nor survival of individual fish was readily predictable upon capture. Short-term mortality cannot be predicted from hook placement or bleeding. In addition, fish may die months later if the hook is left in place, or they may die of hooking complications if the hook is retrieved. Anglers who retain fish because they mistakenly assume that the fish "will die anyway" might induce greater fishing mortality than is necessary.

Research should continue to focus on catch-and-release mortality for subadult and adult red drum. Since many of the small circle hooks on the market today are sold slightly offset, it would be instructive to determine whether these hooks produce catch-and-release mortality results similar to the nonoffset circle hooks or to the severely offset hooks used in this study. Kahle hooks, which are intermediate in shape between a circle hook and a J-hook, are gaining popularity in the red drum fishery as well. Future research efforts should also focus on short-term mortality rates using these hooks. Long-term (several months) survival of red drum should also be examined. It would be useful to determine whether adult red drum experience diminished spawning success or higher predation rates if they are caught and released during the warmwater spawning season. Finally, the current red drum population model must be reexamined, at least for South Carolina fish, to account for catch-and-release mortality and potentially lowered fecundity in adults.

Acknowledgments

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