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A Comparison of Circle Hook and Straight Hook Performance in Recreational Fisheries for Juvenile Atlantic Bluefin Tuna

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Abstract.—Catch quotas, bag limits, and minimum sizes have been the primary management tools to limit mortality in U.S. Atlantic bluefin tuna *Thunnus thynnus* fisheries. As a result of these regulations, increasing numbers of bluefin tuna are released annually by recreational and commercial fishermen. Post-release survival is highly dependent on the degree of physiological stress and physical trauma experienced by the fish. The type of terminal fishing tackle strongly influences hook location in the fish, as well as the degree of hook damage. This study compared the performance of circle hooks to straight hooks, relative to hooking location, damage, and catching success in natural bait fisheries for bluefin tuna that are practiced on the U.S. Atlantic coast. During the summers of 1997–1999, fishing trips were made offshore of Virginia and Massachusetts to catch juvenile bluefin tuna with comparable size circle hooks (sizes 10/0–12/0) and straight hooks (sizes 5/0–8/0), while drifting with natural bait. A total of 101 bluefin tuna was caught and dissected to quantify hooking location and to assess the extent of hooking damage. There was a significant association between hook type and hook location ($p < 0.05$). Ninety-four percent of the bluefin tuna caught on circle hooks were hooked in the jaw, and four percent were hooked in the pharynx or esophagus. Fifty-two percent of the bluefin tuna caught on straight hooks were hooked in the jaw, and thirty-four percent were hooked in the pharynx or esophagus. Based on the observed hook damage, we estimated that release mortality would have occurred in four percent of the bluefin tuna caught on circle hooks and twenty-eight percent caught on straight hooks. The ability of each hook type to hook and hold tuna was significantly different; however, overall catching success was similar. This comparison indicates that circle hooks cause less physical damage than straight hooks, while catching juvenile bluefin tuna, using natural baits and can be a valuable conservation tool in these recreational fisheries.

Introduction

The North Atlantic bluefin tuna *Thunnus thynnus*, the largest of the scombrid species, is widely distributed in the Atlantic Ocean. Bluefin tuna migrate to the U.S. continental shelf to feed during the warm months and attract popular and economically important fisheries at many locations (Mather et al. 1995). Commercial and recreational fisheries in the U.S. have targeted Atlantic bluefin tuna since the late 19th century, using purse seine, trap net, harpoon, and hook-and-line gear. The predominant gear has been hook and line during the last two decades. A traditional component of these fisheries has been recreational fishing for juvenile or school (< 150 cm curved fork length [CFL]) bluefin tuna with rod and reel.

The spawning stock biomass of western North Atlantic bluefin tuna is estimated to be well below the level that would allow maximum sustainable yield, and the western stock has been designated as overfished (National Marine Fisheries Service 1999). Numerous regulatory measures have been in effect over the last decade to reduce fishing mortality and to manage the U.S. Atlantic quota. Under the current management system, a relatively small quota (< 300 mt) of juvenile bluefin tuna must be divided among more than 10,000 permitted boats in the U.S. recreational fishery. To reduce the catch of juvenile bluefin tuna, bag limits and minimum sizes for both commercial sale and recreational landings have been established. These restrictions have greatly limited the retention of this species in U.S. fisheries and, along with a growing conservation ethic, have resulted in a dramatic increase in the catch and release of bluefin tuna in recent years.

Post-release survivorship is highly dependent on the degree of physiological stress and physical trauma experienced during fishing (see Muoneke and Childress 1994, for review). It is generally accepted that jaw-hooked fish experience less physical trauma and have a higher probability of survival than fish hooked in the pharynx or gut (deep-hooked). The type of terminal fishing tackle used can have a strong influence on hooking location. Circle hooks have gained popularity in several recreational fisheries because of their propensity to lodge in the hinge of the jaw, resulting in less physical damage to the fish (Grover et al; Prince et al; both this volume).

Concern over the survival of bluefin tuna caught and released in recreational fisheries grew in response to the development of a winter fishery for bluefin tuna off Cape Hatteras, North Carolina in the early 1990s (Skomal and Chase 1996). Very high catch rates were achieved in this rod and reel fishery, which used baited hooks in conjunction with chumming methods. Federal fishery restrictions mandated that a large number of these bluefin tuna be released. Consequently, North Carolina fishing captains in this catch-and-release fishery adopted the circle hook, after seeing very low numbers of deep-hooked fish while using this hook type. Observations of the successful use of circle hooks in the Cape Hatteras fishery inspired us to conduct a comparative study on hooking location, tissue damage, and catching success of circle hooks and traditional straight hooks used in natural bait fisheries for juvenile bluefin tuna.

Methods

Bluefin tuna were collected during the summers of 1997–1999 on sampling trips conducted primarily 30–50 km southwest of Martha's Vineyard, Massachusetts (Figure 1, Area A), as well as on Stellwagen Bank in the Gulf of Maine (Figure 1, Area B) and offshore of Chincoteague, Virginia (Figure 1, Area C). These areas support active fisheries for juvenile bluefin tuna on the continental shelf off the eastern United States. All trips were made on chartered sportfishing boats or research vessels of the Massachusetts Division of Marine Fisheries. Bluefin tuna were caught using the standard sportfishing technique of drifting baited lines while chumming. Two paired treatments of terminal tackle were offered to feeding bluefin: one with Mustad[1] circle hooks (sizes 10/0, 11/0, and 12/0) and the other with Mustad[1] #9174 straight hooks (sizes 5/0, 6/0, 7/0, and 8/0; Figure 2). Straight hooks are also commonly called "J hooks." Although manufacturers use different units to size circle hooks and straight hooks, the sizes selected for the two hook types were comparable (Figure 2). Other than hook types, the gear and handling methods used were the same for both treatments. Hooks were baited with chunks of butterfish *Peprilus triacanthus* or silver hake *Merluccius bilinearis*, and chunks of bait were routinely chummed around the lines to attract bluefin tuna. Rods were placed in rod holders, and line was stripped from the reel to present the baited hook to fish at desired depths. Upon detecting a bite on the baited line, the angler would increase the reel drag to set the hook. Anglers were instructed not to actively set the hook, but to allow the rod to react to the bite in the rod holder or in the angler's hands.

Information on hook type, hook size, line test, and fight time was recorded for each fish. The "hooking

1. Use of brand names does not imply government endorsement.

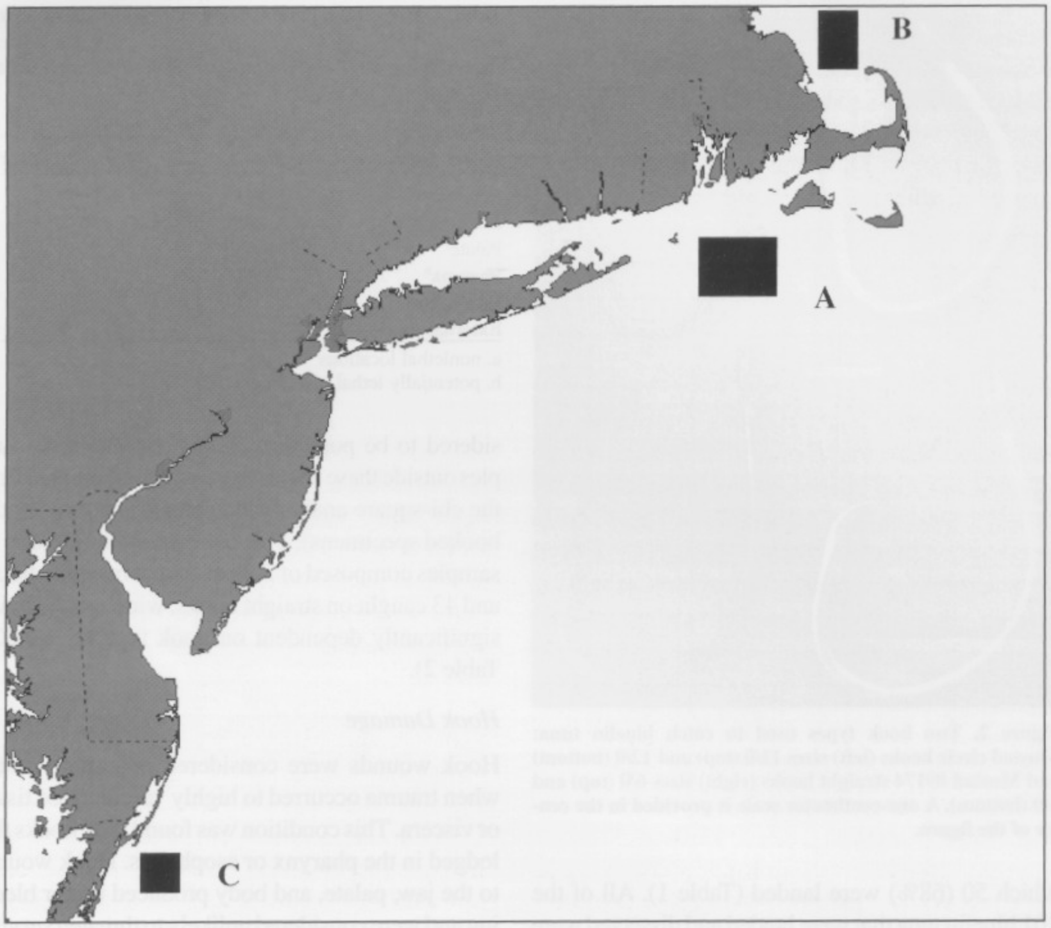

Figure 1. Study areas where juvenile Atlantic bluefin tuna *Thunnus thynnus* were sampled with circle and straight hooks: (A) 30–50 km southwest of Martha's Vineyard, Massachusetts, (B) Stellwagen Bank in the Gulf of Maine, and (C) offshore of Chincoteague, Virginia.

outcome" of each feeding attempt by bluefin tuna on a baited hook was recorded by three categories: biting the bait but not hooking, hooked fish that were not captured or "lost" during angling, and landed fish. The hooking outcome categories reflect on the catching success (landed fish/bites) of each hook type. Hooking outcome data were only recorded when it was certain the observation involved bluefin tuna. Hooked bluefin tuna were brought quickly to the boat, landed, and sacrificed to conduct a detailed dissection of hooking location and associated hook damage and potential mortality. The mouth, pharynx, esophagus, and abdominal cavity of each fish were inspected for hook location and tissue damage. All bluefin tuna were measured (CFL), and ages were assigned based on Mather and Schuck (1960) length-age classification.

Chi-square analysis was conducted on hook location data to test the null hypothesis that hooking location was independent of hook type. The two treatments (hook types) were offered evenly, and it was assumed that the selection of hook type was random. A two-by-two contingency table (Category 1) was constructed, and a correction was made for continuity (Zar 1984)). Chi-square analysis was also conducted to test the hypothesis that unsuccessful hooking outcome was independent of hook type.

Results

Hook Location

From 1997 to 1999, a total of 142 bluefin tuna bites were recorded: 69 with circle hooks of which 51 (74%) were landed, and 73 with straight hooks of

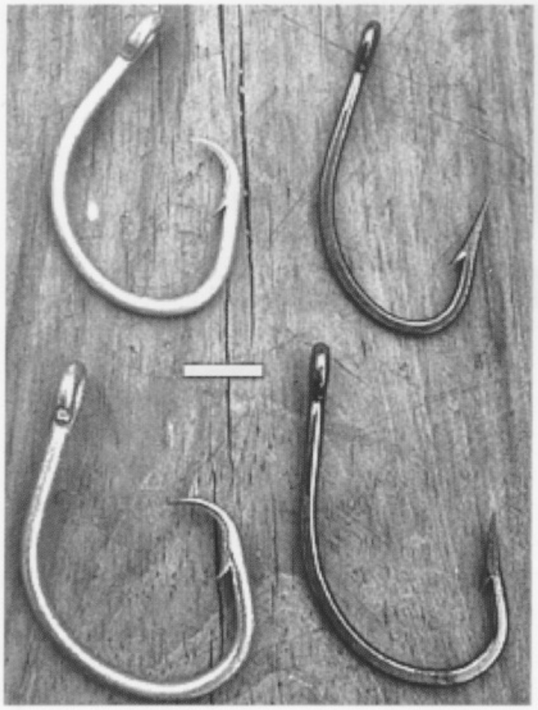

Figure 2. Two hook types used to catch bluefin tuna: Mustad circle hooks (left) sizes 11/0 (top) and 12/0 (bottom) and Mustad #9174 straight hooks (right) sizes 6/0 (top) and 7/0 (bottom). A one-centimeter scale is provided in the center of the figure.

which 50 (68%) were landed (Table 1). All of the 101 bluefin tuna that were landed and dissected were classified as ages one to four (63–131 cm CFL, with about 50% age-1, 25% age-2, and 25% age-4). Almost all bluefin tuna caught on circle hooks were hooked in the jaw (94%) with most hooked in the jaw hinge (84%) (Table 1; Figure 3). Only two (4%) of the circle hook caught fish were hooked in the esophagus or pharynx, areas considered potentially lethal (Table 1). Greater variability in the hooking location was observed for bluefin tuna caught on straight hooks: 52% in the jaw, 32% in the esophagus, 10% in the oral cavity or palate, and 6% at other locations (Table 1).

To simplify the comparison and avoid sparsity rule violations for chi-square analysis, the contingency table was arranged for the two hook types and the two major hooking locations (Table 2). Hooks found in the jaw hinge and any other part of the jaw were classified as "jaw" and not considered to be life threatening. Hooks found in the pharynx or in the esophagus were classified as "deep" and con-

Table 1. Hooking locations for circle hooks ($N = 51$) and straight hooks ($N = 50$) used to catch juvenile bluefin tuna during 1997–1999 on the Continental Shelf off the U.S. Atlantic Coast.

Hooking location	*Circle hook (no.)*	*Straight hook (no.)*
Jaw hinge[a]	43	24
Jaw (other)[a]	5	2
Palate[a]	0	5
Pharynx[b]	1	1
Esophagus[b]	1	16
External (body)[a]	1	2

a. nonlethal locations
b. potentially lethal locations

sidered to be potentially lethal. Bluefin tuna samples outside these two categories were excluded from the chi-square analysis (five palate and three body-hooked specimens). This comparison resulted in 93 samples composed of 50 fish caught on circle hooks and 43 caught on straight hooks, with hook location significantly dependent on hook type ($p < 0.001$; Table 2).

Hook Damage

Hook wounds were considered potentially lethal when trauma occurred to highly vascularized tissue or viscera. This condition was found with hooks that lodged in the pharynx or esophagus. Hook wounds to the jaw, palate, and body produced minor bleeding and were considered unlikely to threaten survival upon release. Bluefin tuna possess a wide gape that provides easy passage of food from the oral cavity past the pharynx and into the esophagus. The transition from the posterior pharynx to the esophagus and to the anterior lumen of the stomach is continuous and contains little variation in the dense muscle tissue that is heavily striated anterior to the pylorus. The esophagus passes through the transverse septum, a thin membrane that separates the pericardial cavity from the peritoneal (abdominal) cavity. Of the 101 bluefin tuna sampled, 19 were hooked in locations that were considered potentially lethal (Table 1); 17 of these hook locations were a few centimeters anterior or posterior of the transverse septum.

Only two (4%) of the fifty-one bluefin tuna caught on circle hooks were deep-hooked. One age-4 fish had a circle hook protruding through the lumen of the anterior stomach (Figure 4). The exposed hook point ripped tissue that supports viscera in the

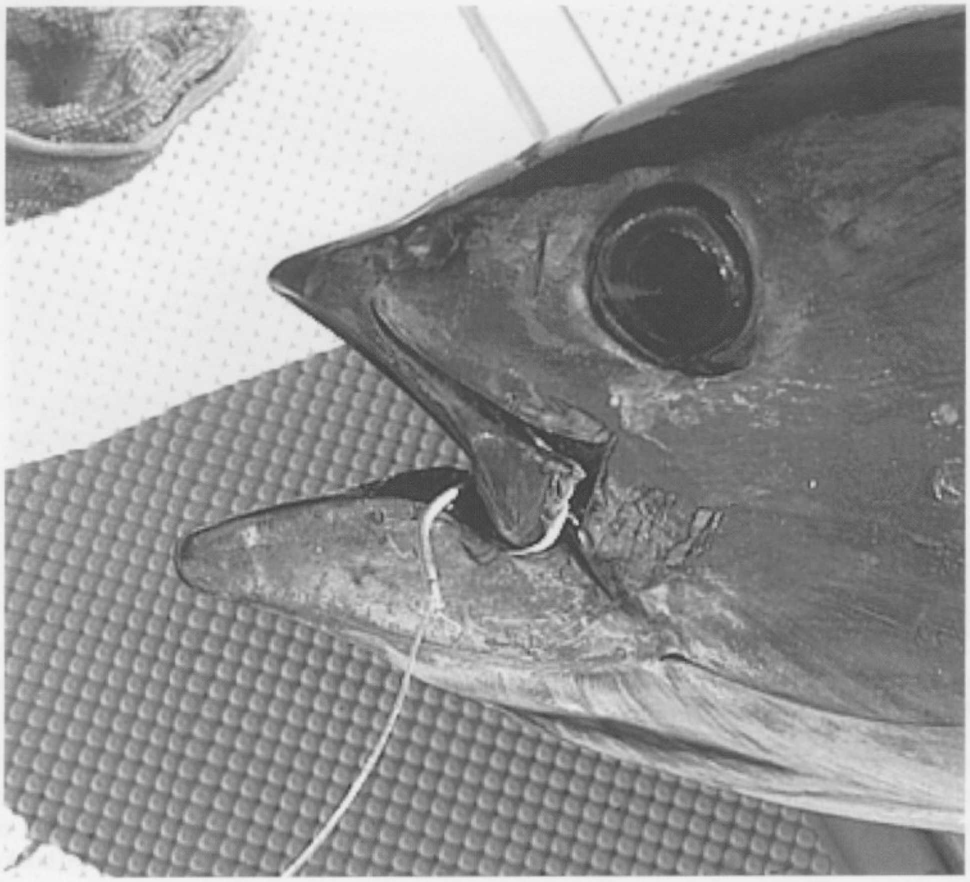

Figure 3. Typical hooking location in the "hinge" of the jaw of 88-cm CFL bluefin tuna caught on circle hook.

abdominal cavity and caused internal bleeding. An age-1 fish had a circle hook that lodged between two gill arches in the pharynx and caused extensive bleeding from gill filament damage. Seventeen (34%) of the fifty bluefin tuna caught on straight hooks were deep-hooked. Only one of these was lodged in the gill arches of the pharynx and caused gill filament damage. The rest were in close proximity to the transverse septum and caused a variety of traumatic wounds.

Two important factors influenced the extent of

Table 2. Chi-square analysis of hooking location dependence on circle hooks ($N = 50$) and straight hooks ($N = 43$). The null hypothesis (H_0: hooking location is independent of hook type) is rejected ($X^2 = 15.84$; $P < 0.001$).

Hooking location	*Circle hook (no.)*	*Straight hook (no.)*
Jaw	48	26
Deep (esophagus or pharynx)	2	17

internal wounds: the exposure of the hook point and barb and the location of exposed hook in the abdominal cavity. Three of the deep-hooked fish had hooks embedded in the thick muscle tissue of the esophagus or posterior pharynx. These hook wounds resulted in much less tissue damage and bleeding than wounds where the hook was exposed and free to lacerate other tissues. In most instances where hooks penetrated the abdominal cavity, tissues and blood vessels supporting viscera were damaged. Hooks positioned close to the transverse septum with the point facing anteriorly would often tear the septum and sever the hepatic veins leading to the sinus venosus (Figure 5). Hooks positioned closer to the pylorus were observed to damage the anterior liver lobe. No observations were made of hook damage to vascular retes or the pericardium, although it is expected such wounds could occur with the specific placement of a large hook.

In addition to the potentially lethal internal hook

Figure 4. A 106-cm CFL bluefin tuna with a circle hook protruding through the lumen of the anterior stomach, between the esophagus and pylorus (severed in foreground).

wounds, we observed external hook damage that may not be lethal but would have a metabolic cost to repair tissues. For example, large hooks embedded in the jaws of age-1 fish could result in scraping of facial tissue. This occurred primarily in age-1 bluefin tuna hooked in the jaw with size 11/0 circle hooks and appeared to be related to the angle of the circle hook point (90°). Nine of the 25 fish caught in the jaw with circle hooks larger than 10/0 had external damage caused by the hook point and barb. In two of these cases, the hook point caused severe damage to the eye socket. Extensive hook point damage to facial tissue was not observed in age-4 bluefin tuna and occurred only once with straight hooks (eye socket damage to an age-1 bluefin from a 6/0 straight hook).

Hooking Outcome

In addition to the 101 landed bluefin tuna, 41 observations were made of "lost" bluefin, 18 with circle hooks and 23 with straight hooks (Table 3). Hooking outcome for bluefin that were lost during angling was significantly dependent on hook type (p = 0.041; Table 3). The data collected coupled with field observations indicate that this result is influenced by the propensity of straight hooks to hook the fish more readily when bit and for circle hooks not to pull out once the fish is hooked. Despite this difference in the way bluefin were lost, overall catching success was similar for the two hook types. Sixty-eight percent of recorded straight hook bites and seventy-four percent of circle hooks bites resulted in landed tuna.

Other Species

Four other species were caught incidentally while fishing for bluefin tuna. No species was taken in high enough numbers to conduct a statistical analysis of hook location data. Less than ten were caught of each of the following species: six spiny dogfish

Table 3. Chi-square analysis of hooking outcome dependence on hook type: circle hooks (n = 18) and straight hooks (n = 23). Occurrences when bluefin tuna interacted with the baited hook but were not landed were classified according to whether they were hooked and lost or were not hooked during the initial bite. The null hypothesis of hooking outcome is independent of hook type was rejected (X^2 = 4.266, P = 0.041).

Hooking outcome	*Circle hook (no.)*	*Straight hook (no.)*
Bite-not hooked	13	8
Hooked and lost	5	15

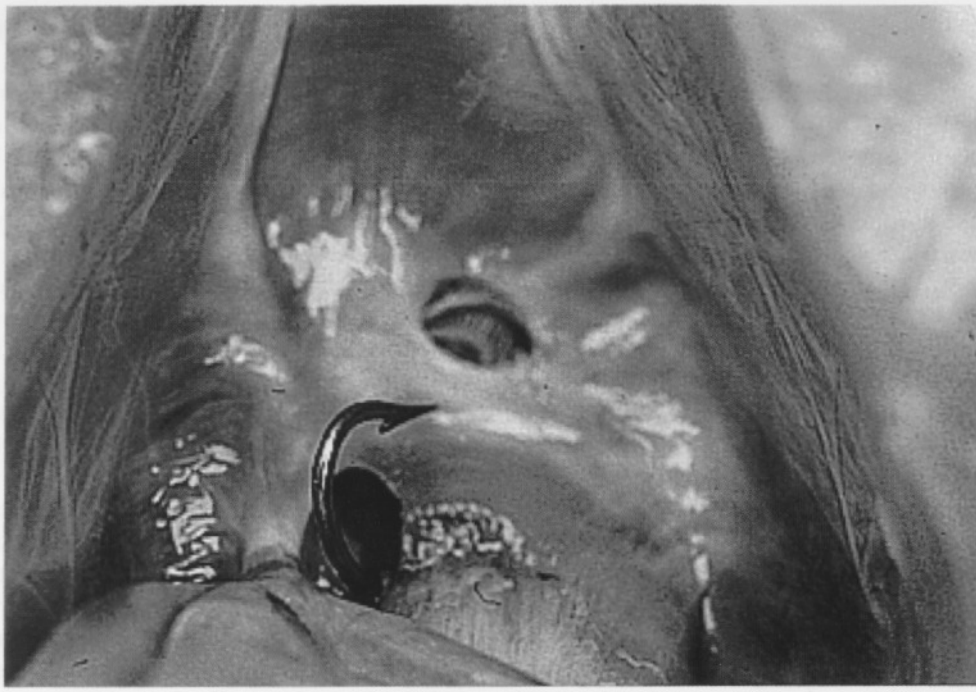

Figure 5. An 88-cm CFL bluefin tuna deep-hooked with a straight hook. This hook was embedded close to the transverse septum with the point facing forward. A liver lobe is present in the foreground, and the heart can be seen through the transverse septum in the background.

Squalus acanthias; five blue sharks *Prionace glauca*; and nine bluefish *Pomatomus saltatrix*, and for each catch on circle hooks, the hook location was the jaw hinge. Observations were recorded for 22 Atlantic bonito *Sarda sarda*, of which 9 were caught on straight hooks and 13 were caught on circle hooks in the jaw hinge. For the straight-hooked bonito, three hooks were in each of the following locations: jaw, palate, and deep-hooked. It was observed that these relatively smaller tuna (2–5 kg) did not easily swallow the larger hooks, but could still experience extensive damage anterior to the gut (gill filaments and eye socket).

Discussion

The results of this study are comparable to the authors' observations that circle hooks used in the catch-and-release fisheries for larger bluefin tuna (primarily 50–150 kg) off North Carolina supported live release. Our current study shows that nearly 95% of juvenile bluefin tuna caught on circle hooks were consistently hooked in the jaw as opposed to straight hooks that were hooked in the jaw for about half the cases. Greater variation was observed in the location where straight hooks embedded, with nearly a third lodged in the esophagus.

In addition to hook location data, this study documents the damage that hooks can cause in the pharynx and abdominal cavity. Wounds to the pharynx were not common, occurring in 2% of the landed bluefin tuna; in both cases however, the hooks lodged between the gill arches and severely damaged gill filaments. The hard surface area of the buccal cavity and the gill arches are adapted to receive sharp or abrasive objects during feeding, and this protection appears to minimize hooking in the pharynx and buccal cavity regions. The region that experienced the most traumatic injuries was between the pylorus of the stomach and the transverse septum. Hooks that penetrated the muscle of the esophagus in this region could encounter the transverse septum as well as a variety of support tissues for the viscera. The orientation of the hook point once exposed in the abdominal cavity was critical to the resulting damage. An exposed hook close to the transverse septum could tear this sensitive membrane and sever the hepatic veins running from the liver to the sinus venosus. An exposed hook closer to the pylorus could tear connective tissues for the viscera (observed), the liver (observed), or visceral retes (not observed). Severe internal bleeding accompanied most wounds when the hook penetrated the esophagus, but was not detected in the three cases where the hook point remained buried in the muscle of the esophagus.

In the absence of published studies on bluefin tuna, the documentation of hook wounds presents an opportunity to discuss the potential for release mortality. Overall, only wounds occurring in the pharynx and esophagus appeared to cause enough physical trauma to threaten immediate survival upon release. Of the wounds in these deep-hooked locations, only those that lacerated sensitive tissues and/or caused internal bleeding were considered potentially lethal. Under this assumption, about 4% of circle hook wounds and 28% of straight hook wounds were considered potentially lethal. These estimates do not take into account the potential for delayed mortality associated with less traumatic internal and external wounds.

Patterns of tissue damage external to the mouth appeared to be influenced by hook size and the orientation of the circle hook point. Larger circle hooks (11/0 and 12/0) caused extensive scraping of facial tissue between the jaw hinge and eye socket in more than a third of age-1 bluefin tuna caught with these hook sizes. This occurred only once with the straight hook and not at all in any age-4 bluefin. This damage is probably not lethal and can be avoided by selecting a smaller hook size for catching age-1 or age-2 bluefin tuna. However, eye socket damage found in three of the bluefin sampled (two circle, one straight), could cause blindness, thereby impacting feeding and potentially causing mortality (Prince et al.,[2] this volume).

A comparison of the relative catching success of the two hook types is essential to convince anglers to adopt the potentially less damaging circle hook. We found that catching success outcome was similar with the two hook types; however, there was a significant dependence in the way that fish were lost on hook type, which probably reflects the physical attributes of each hook. The small sample size in the analysis limits the strength of this finding, but several trends are apparent from the data and field observations. The circular shape and bent point of the circle hook reduces the probability of a lodged hook coming loose once hooked. Moreover, the tendency for this hook to embed in the corner of the mouth may result in fewer fish lost after hooking. The greater gap of the straight hook provides more chance for the hook to rip loose if not firmly embedded. The difference in gap width may diminish the effectiveness of circle hooks under certain conditions. When bluefin tuna are feeding cautiously, the bent point and narrow gap of the circle hook may have a reduced probability of hooking when the bait is picked up. When surface waters were calm with high water visibility, there was a tendency to hook more successfully with a straight hook during the initial bite. Under most conditions of active feeding, the circle hook was as effective as the straight hook at hooking upon initial bite.

In summary, this comparison of circle hooks and straight hooks should help convince recreational anglers to adopt circle hooks, which under most conditions caused less physical damage, had a greater tendency to hold tuna once hooked, and had similar overall catching success as straight hooks. Therefore, circle hooks can be an effective and important conservation tool in bait fisheries for juvenile Atlantic bluefin tuna.

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