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ARTICLE

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Abstract

Growing interest in catfish angling, particularly for trophy-sized fish, has resulted in new regulations that limit the harvest of large Blue Catfish *Ictalurus furcatus* in several states. For these regulations to be effective, released fish must survive to further contribute to the fishery, either through reproduction or subsequent recapture. We investigated the effect of capture depth, hook type, water temperature, and fish size on the delayed hooking mortality of Blue Catfish caught on juglines. Blue Catfish ($N = 559$) were caught from three Oklahoma reservoirs with either 5/0 circle hooks or J-hooks fished for 24-h sets. One experimental fish (captured via jugline) and one control fish (captured via low-frequency electrofishing) were then placed in field enclosures ($N = 25$) and monitored for mortality after 72 h. Mean mortality was low at 8.50% (range, 0.00–37.50%; SE, 1.81%). Mortality decreased significantly with decreasing water temperatures ($P < 0.01$; odds ratio 1.1). Mortality was highest (mean = 25.31%) at water temperatures >20°C and decreased to 3.89% in water temperatures <20°C. We observed 0% mortality in water temperatures <14°C. Hook type did not significantly affect mortality, nor did the depth in the water column where the fish was hooked. For every 100-mm increase in total length, fish were six times less likely to die (odds ratio 0.17). Mean mortality for preferred-size fish was low at 2.50%, and no mortalities were observed for memorable or trophy-size fish. These results suggest that length regulations limiting the harvest of preferred-size or larger fish should be effective as a large proportion of released fish should survive to further contribute to the fishery.

Angler harvest has the potential to alter population size structure and reduce the abundance of fishes (Gigliotti and Taylor 1990; Beard and Essington 2000; Faust 2011). To prevent this, managers often implement length restrictions and bag limits, which require anglers to release fish. These restrictions assume that a large proportion of released fish, otherwise known as "regulatory discards," survive to further contribute to the fishery, either through reproduction or subsequent recapture by an angler. Delayed hooking mortality of teleosts is highly variable and ranges from less than 1% (Dotson 1982; Childress 1989a; Clapp and Clark 1989; Parks and Kraai 1991) to as high as 70–90% postrelease mortality (Martin et al. 1987; Childress 1989b; May 1990; Siewert and Cave 1990). There have been no peer-reviewed studies that adequately assess the delayed hooking mortality of Blue Catfish *Ictalurus furcatus*, and, if postrelease mortality is high, bag limits or length regulations may only irritate anglers rather than benefiting the fishery. However, with a better understanding of the conditions responsible for mortality, seasonal closures, gear restrictions, or other types of regulations could be effective management tools when high postrelease mortality occurs.

Angling for Blue Catfish has become increasingly popular over the past two decades (Michaletz and Dillard 1999; Mauck and Boxrucker 2006; Kuklinski and Boxrucker 2010; Makinster and Paukert 2008), with many anglers being attracted to this species due to its large size potential (Arterburn et al. 2002). Although historic accounts from the 1800s indicate that Blue Catfish had impressive growth potential (e.g., numerous accounts of 56–140 kg individuals), individuals over 50 kg are less common in modern times (Graham 1999; Mauck and Boxrucker 2006; Homer and Jennings 2011). This is most likely caused in part by the overharvest of larger individuals (Graham 1999).

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While there has been a recent increase in catfish angling across the USA, most agencies have been slow to adopt trophy catfish management strategies. In fact, only 2% of the state agencies surveyed by Arterburn et al. (2002) emphasized trophy management for any of the three largest North American catfishes (Channel Catfish *Ictalurus punctatus*, Blue Catfish, or Flathead Catfish *Pylodictus olivaris*). This is in direct contrast to the 75% of the anglers surveyed who favored the development of trophy catfish fisheries (Arterburn et al. 2002). Therefore, many state agencies have recently become interested in managing catfish populations, but the lack of information on both the life history and general biology of Blue Catfish (Graham 1999; Mauck and Boxrucker 2006) and Flathead Catfish (Makinster and Paukert 2008) has been a hindrance. In particular, there is a need for information about the utility of length and harvest regulations (e.g., maximum length or "one over" length restrictions) to modify the size structure of Blue Catfish populations through reduced mortality (harvest and discard mortality) of rare, large individuals.

The growth of Blue Catfish in southern reservoirs can be poor (Graham 1999; Mauck and Boxrucker 2006; Boxrucker and Kuklinski 2008), especially when compared with growth in lotic systems (Jolley and Irwin 2011; Rypel 2011). Poor growth in reservoirs is often attributed to increases in fish densities, which leads to greater intraspecific competition and ultimately results in resource limitation (Conder and Hoffarth 1965; Freeze 1977). This pattern of poor growth in lentic systems has become evident in several of Oklahoma's large impoundments. In a recent survey of nine major Oklahoma reservoirs, only 0.7% of Blue Catfish sampled were preferred size or larger (762 mm total length [TL]; Gabelhouse 1984) and it took fish, on average, 13–16 years to reach preferred size (Boxrucker and Kuklinski 2008). Additionally, growth of Blue Catfish in reservoirs is highly variable (Boxrucker and Kuklinski 2008), which may suggest that certain fish are genetically predisposed to grow quickly and these fast growing fish are more likely to survive to reach trophy size. By removing these large fish from the gene pool, fishermen may be artificially selecting for slower-growing, smaller fish. Due to limited numbers of large fish, several state agencies have recently enacted regulations limiting the harvest of large Blue Catfish (Dorsey et al. 2011; Eder 2011; Kuklinski and Patterson 2011; CMTC 2012) in an effort to increase survival of these rare individuals. However, little is known concerning the delayed hooking mortality of Blue Catfish, and these types of regulations will only be successful if a substantial proportion of the regulatory discards survive to further contribute to the fishery.

Trotlines and juglines are commonly used by catfish anglers and commercial fishermen in the southern United States (White 1956; Kuklinski and Boxrucker 2010). Many states only require trotlines and juglines to be checked once daily, so fish captured by these methods may be hooked for up to 24 h. Prolonged hooking can increase stress (Tomasso et al. 1996), lead to poor condition (Thorstad et al. 2003), and increase the probability of mortality (Schisler and Bergersen 1996). Due to prolonged hooking, posthooking mortality rates for catfish captured with passive gears likely exceed those of fish captured with rod and reel (Muoneke and Childress 1994). If high posthooking mortality rates exist for Blue Catfish caught on juglines, this could negate the intended benefit of bag restrictions, maximum length limits, or "one over" limits designed to increase survival of large fish, necessitating the implementation of other regulations to assist in the development of trophy fisheries (i.e., gear or seasonal restrictions).

Whereas delayed hooking mortality has been well studied in species such as Largemouth Bass *Micropterus salmoides* (Rutledge 1978; Schramm et al. 1987; Kwak and Henry 1995; Wilde 1998) and Atlantic Salmon *Salmo salar* (Warner and Johnson 1978; Warner 1979; Thorstad et al. 2003), very little research has addressed delayed hooking mortality of catfishes in general and Blue Catfish are particularly poorly studied in this regard. This is especially problematic given the prolonged hooking times associated with the passive gears commonly used to capture catfishes (i.e., trotlines, limb lines, and juglines). These prolonged hooking times suggest these fishes may have higher posthooking mortality rates than other species that have been studied. Studies evaluating delayed hooking mortality with Channel Catfish or Flathead Catfish have found mortality was variable but could be as high as 50% under some conditions (Muoneke 1993; Ott and Storey 1993). Only one study has measured delayed hooking mortality for Blue Catfish (Muoneke 1993). The researcher found a mean postrelease mortality of 5.1% for Blue Catfish after a 72-h assessment period; however, that study was conducted on only one reservoir, did not standardize hook type or fishing duration, had limited replication (only four sampling dates and 35 or 47 total fish for winter and summer trials, respectively), and lacked control fish (Muoneke 1993). Therefore, additional research is needed to determine the delayed hooking mortality of catfishes caught with passive fishing gears, particularly those gears with prolonged hooking durations.

While one study exists evaluating the postrelease mortality of Blue Catfish captured with trotlines, there is no research addressing the postrelease mortality of fish captured with juglines. Although the previous trotline study had a prolonged hooking component, it may not accurately reflect mortality for fish caught on juglines. Trotlines are generally set horizontally, whereas juglines are set vertically. Trotlines can be set on the surface or on the bottom, but anchored juglines will always be in contact with the bottom. This often results in anglers setting some hooks below the thermocline in hypoxic conditions, presumably increasing mortality of fish that become hooked there (juglines are often anchored in position with several kilograms of weight). Additionally, juglines are quite effective in deep water, particularly during the winter months, and fish captured from greater depths generally exhibit greater postrelease mortality because of rapid depressurization (Muoneke and Childress 1994). To quantify the delayed hooking mortality of Blue Catfish caught on juglines, field trials were conducted seasonally at three different Oklahoma reservoirs over a 2-year period. The objectives were to address the effects of hook type, water temperature, capture depth, and anatomical hooking location on the delayed hooking mortality of Blue Catfish. This information is needed to determine the effectiveness of mandatory release policies used for the conservation of large Blue Catfish.

METHODS

From May 2010 to March 2012, Blue Catfish were captured using weighted juglines at Kaw (6,896 ha), Keystone (9,550 ha), and Sooner (2,182 ha) lakes in northeastern Oklahoma, which are all man-made impoundments. Trials were conducted seasonally at all reservoirs so that mortality estimates could be made across the full range of water temperatures. More effort was directed towards warmer water temperatures because the probability of mortality typically increases with water temperature (Muoneke and Childress 1994), but jugs were deployed on at least five dates in each reservoir below the median water temperature observed in our study ($\leq$16°C). All juglines were baited with freshly killed Gizzard Shad *Dorosoma cepedianum*, Common Carp *Cyprinus carpio*, or buffalo *Ictiobus* spp., depending upon bait availability. All hooks were baited with the same bait type during each replicate, and all bait types were used proportionally across all reservoirs and seasons.

Juglines were constructed using a 3.79-L jug for floatation and a 2.3-kg anchor made from QuickCrete with 295-lb-test seine twine (#30) for the main line (between jug and anchor) and 126-lb seine twine (#15) for the dropper lines (lines to which hooks are attached). Three dropper lines were attached to the main line at intervals of $\geq$1 m using trotline clips. To quantify mortality of fish that were hooked in the hypolimnion, where hypoxic to anoxic conditions can exist, vertical dissolved oxygen (DO) profiles (1-m intervals) were measured using a YSI 556 multi-probe system (Yellow Springs Instruments, Yellow Springs, Ohio) during the summer of 2010. This information was used to ensure two hooks were set above the thermocline and one hook was set below it during times of the year when hypoxic hypolimnetic conditions existed. No trials were conducted below the thermocline on Sooner Lake because the main lake did not stratify during our study. No hooks were set in the hypolimnion in 2011 because after 11,680 hook-hours of fishing effort in 2010, no Blue Catfish had been captured.

Dropper lines were equipped with either 5/0 Mustad Biggun' J-style hooks or 5/0 Diachii Circle-Chunk Light hooks, both of which had nonoffset points. To quantify the effect of hook type on mortality, equal numbers of jugs with 5/0 J-hooks and 5/0 circle hooks were set in the same locations during each collection period (all three hooks on a given jugline were the same type). In order to intersperse the two hook styles and reduce bias, the juglines were deployed in series that alternated by hook type.

We tried to imitate the behaviors of typical jug fishermen as much as possible throughout this study, so jugs were fished for 24 h, which is the maximum time allowed by Oklahoma Department of Wildlife Conservation. Hooks were removed from all captured catfish after retrieving the jug, even though removing the hook from a deeply hooked fish can increase the probability of mortality (Mason and Hunt 1967; Warner and Johnson 1978; Warner 1979; Weidlein 1989; Vincent-Lang et al. 1993, Aalbers et al. 2004). This was done based on the anecdotal observation that most jug anglers retrieve their hooks. Hooks were removed by hand or with pliers, and, after the removing hook, we recorded total length, anatomical hooking location, capture depth, water temperature, and hook type for each fish. Following hook removal, fish were marked by clipping the soft portion of the left pectoral fin and placed into individual field enclosures (square, 1.25 m on each side) constructed of galvanized, 12.5-gauge fencing with 51-mm $\times$ 102-mm openings. During sampling dates when thermal stratification created the potential for hypoxic hypolimnetic conditions, DO was monitored using a YSI 556 multi-probe system (Yellow Springs Instruments, Yellow Springs, Ohio) and cages were never suspended in areas with less than 5.8 mg/L DO, which is well above the minimum DO suggested for the culture of Channel Catfish (4.0 mg/L; Tucker 1991).

After retrieving all of the jugs, boat-mounted electrofishing equipment (either Smith-Root Model 7.5 GPP or 5.0 GPP; 15 pulses per second DC; ~4 amps) was used to collect control fish, which served to identify any mortality related to cage confinement or other unforeseen causes. One control fish (marked by clipping the soft portion of the right pectoral fin) was placed with the jugline-captured fish in each field enclosure and mortality was quantified after 72 h. Because Blue Catfish can be cannibalistic (Schloesser et al. 2011), control and treatment fish in each enclosure were of similar size ($\pm$25% in length) to prevent predation. To determine if a significant amount of mortality occurs after the initial observation period, 56 fish were observed at both 72 h and 7 d. These trials were conducted during the winter and summer at both Kaw and Sooner lakes. Whereas most posthooking mortality is expected to occur in the first 24 h (Muoneke 1992; Muoneke and Childress 1994; Schill 1996), we used a 72-h mortality evaluation period, because a substantial amount of mortality can sometimes occur after several days (Grover et al. 2002). A 72-h observation period is supported by the findings of several mortality studies (Warner and Johnson 1978; Ott and Storey 1993; Stunz and McKee 2006; James et al. 2007).

We modeled the binary probability (1 = dead, 0 = alive) of survival using Proc Glimmix in SAS 9.3 with a logit link function and a binary probability distribution (SAS 2011). Separate repeated-measures analyses, where reservoirs were treated as subjects, were used to test for significant differences in the mortality rates for each explanatory variable (water temperature, hook type, fish size, capture depth, and anatomical hooking location). Hook type, fish size (100-mm groupings), anatomical hooking location, and depth (above or below the thermocline) were treated as categorical variables; water temperature

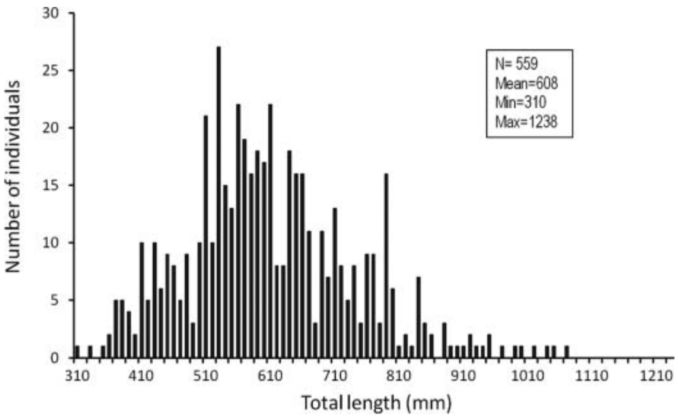

FIGURE 1. Length frequencies of 559 Blue Catfish caught on juglines in Kaw, Keystone, and Sooner lakes, Oklahoma, 2010–2012.

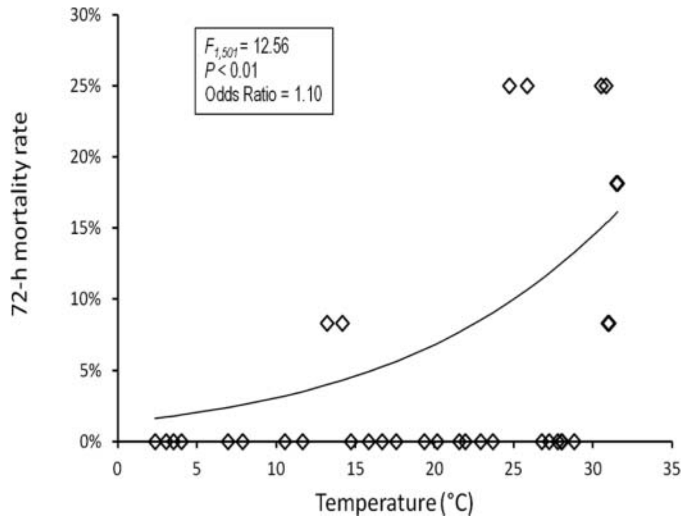

FIGURE 2. Relationship between temperature and 72-h posthooking mortality of Blue Catfish caught on juglines at Kaw, Keystone, and Sooner lakes, Oklahoma, 2010–2012.

was treated as a continuous variable. For significant tests with categorical variables that were unordered (i.e., hook type and anatomical hooking location), a Tukey's post hoc test was used to test all pairwise combinations. Odds ratios were used to describe differences between levels of continuous and ordered categorical variables. Significance was assessed with $\alpha = 0.05$ for all analyses.

RESULTS

Combining trials from Kaw, Keystone, and Sooner lakes, 97,200 hook-hours of total effort were expended from May 2010 to March 2012. Water temperatures ranged from 2.30°C to 31.60°C. A total of 559 Blue Catfish were captured, ranging in size from 310 mm to 1,238 mm TL (Figure 1). Jugs were deployed on 54 separate occasions. Hooking mortality rates were similar across reservoirs so reservoir data were pooled (Kaw = 11.0%, Keystone = 9.9%, Sooner = 6.4%; $F_{2,511} = 0.65$, $P = 0.53$). Mean overall mortality for hooked fish was low at 8.54% (range = 0.00–37.50%, SE = 1.81%) and subtracting mean control mortality (1.64%) from mean hooking mortality results in an overall adjusted mortality of 6.9%. Of the 56 fish that were observed for mortality for 7 d, no mortalities were observed after 72 h, suggesting that 72 h was sufficient for observing delayed hooking mortality in Blue Catfish. A total of 11,680 hook-hours of effort were expended beneath the thermocline. Depth (above or below the thermocline) was not a significant driver of Blue Catfish mortality, as we found Blue Catfish are not frequently captured in the hypolimnion. Whereas Channel Catfish were caught occasionally ($N = 6$; three of which were dead upon retrieval of the jug), no Blue Catfish were ever captured below the thermocline.

Mortality was significantly related to several of the tested factors. Mortality rates increased with increasing water temperature ($F_{1,501} = 12.56$, $P < 0.01$), and for every 1°C increase in temperature, Blue Catfish were 1.1 times more likely to die (odds ratio 1.1; Figure 2). Mortality also declined significantly with increasing fish size ($F_{7,10} = 4.58$, $P < 0.02$). For every 100-mm increase in TL, Blue Catfish were about six times less likely to die (odds ratio 0.16; Figure 3). Mortality of fish >762 mm (preferred size) was low at 2.4% ($N = 83$). No mortalities were observed in memorable or trophy-sized fish ($N = 16$).

Hooking location also influenced mortality (Figure 4). The majority of fish (72.2%) were hooked in the corner of the mouth, though many of the smaller fish also had damage to the eye due to its close proximity to the mouth. These "eye-hooked" fish were categorized separately and accounted for 20.6% of the fish caught. Fish that were hooked externally, usually in the cheek, the bottom of the jaw, or the opercula, accounted for 4.79% of the fish captured. Only 15 fish (2.4%) were hooked in the stomach or esophagus. Mortality among all hooking locations was significantly different, with the exception of externally hooked fish

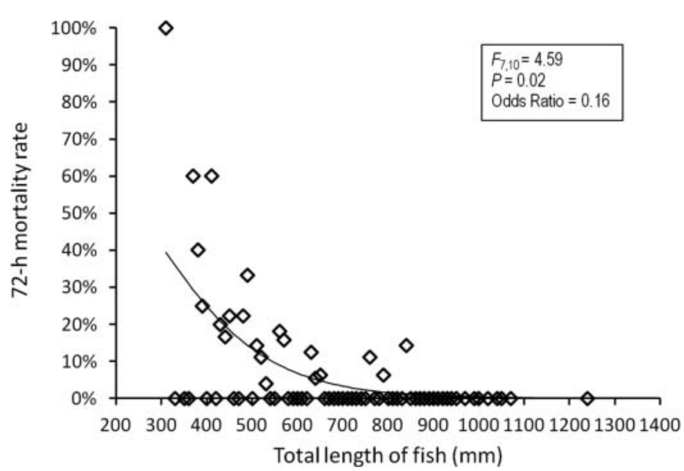

FIGURE 3. Seventy-two-hour mortality rate as a function of total length (100-mm length classes) for Blue Catfish caught on juglines at Kaw, Keystone, and Sooner lakes, Oklahoma, 2010–2012.

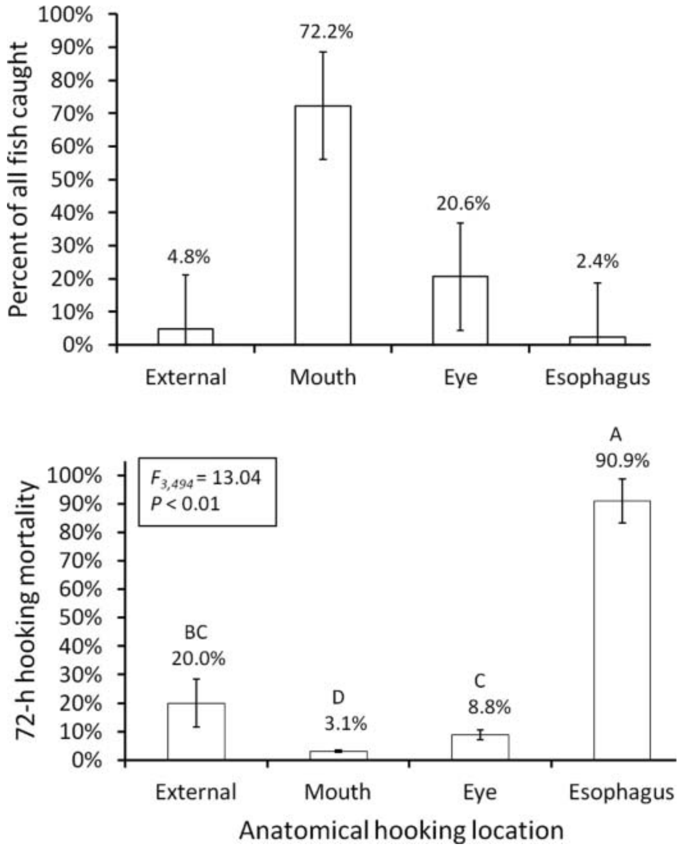

FIGURE 4. Total catch (top panel) and 72-h mortality rate (bottom panel) of Blue Catfish hooked in different anatomical locations by juglines at Kaw, Keystone, and Sooner lakes, Oklahoma, 2010–2012. Variables with nonsignificant differences share a letter; $P > 0.05$.

and eye-hooked fish ($P = 0.28$). Mortality was relatively high for esophagus-hooked fish (91%) and externally hooked fish (20%) and was low for all other anatomical locations (<10%).

Circle hooks accounted for 75.5% of the total catch, despite equal effort with both hook types. Mortality rates for circle hooks and J hooks were not statistically different ($F_{1,510} = 0.24$, $P = 0.62$). Circle hooks did not always set in the corner of the mouth, as they are designed to, which resulted in several fish (3.8%) being hooked externally or deep in the esophagus.

DISCUSSION

The mortality of Blue Catfish caught on juglines was very low, particularly at water temperatures less than 20°C. Managers should be able to effectively use length limits or bag limits because regulatory discards have a high probability of survival. However, mortality was significantly related to several of the tested factors. Our findings suggest that mortality could be problematic for some groups of fish, particularly smaller fish (i.e., <450 mm) captured in water temperatures ≥25°C.

Mortality decreased with increasing fish size. Higher mortality in smaller fish is consistent with Muoneke (1993), who found that 75% of the mortalities of Blue Catfish caught on trotlines were individuals <356 mm TL. Additionally, this inverse relationship between increasing fish size and mortality was found in Lake Trout *Salvelinus namaycush* (Loftus et al. 1988), Rainbow Trout *Oncorhynchus mykiss* (Schisler and Bergersen 1996), and Dusky Shark *Carcharhinus obscurus* (Romine et al. 2009), yet the mechanism causing this pattern is unclear. Damage caused by 5/0 hooks may be insignificant to large fish but proportionally more severe to small fish, as there is less space between the mouth and important organs, such as the eye or the esophagus, with decreased body size. Younger, smaller fish have less developed immune systems (Tatner 1986; Tatner 1997), presumably making them more susceptible to posthooking bacterial or viral infections. The low mortality rates observed in memorable and trophy-size fish are noteworthy for government agencies trying to manage for trophy fisheries, as our findings imply that managers can effectively use maximum length limits or restricted bag limits to conserve large Blue Catfish.

Mortality rates decreased significantly with decreasing temperature and, at temperatures cooler than 15°C, posthooking mortality rates were similar to control mortality rates. This pattern of reduced mortality at cooler water temperatures is consistent with previous studies of Brook Trout *Salvelinus fontinalis* (Dotson 1982), Cutthroat Trout *Oncorhynchus clarkii* (Marnell and Hunsaker 1970), Largemouth Bass (Rutledge 1975), Striped Bass *Morone saxatilis* (Childress 1989a), Tiger Muskellunge (Muskellunge *Esox masquinongy* × Northern Pike *E. lucius*; Newman and Storck 1986), and Spotted Seatrout *Cynoscion nebulosus* (Matlock and Dailey 1981). Lower occurrences of mortality at cooler water temperatures likely result from decreases in metabolic rate, activity level, and bacterial concentrations (Muoneke and Childress 1994); however, the exact mechanism causing this pattern in Blue Catfish is unknown. Trophy Blue Catfish are most susceptible to capture during the winter months (Kuklinski and Boxrucker 2010), which is when we observed the lowest mortality rates. This further suggests that bag limits and maximum length limits should be particularly effective for conserving large fish (>762 mm TL).

Esophagus hooking was rare in this study but usually resulted in mortality (90.9% mortality). High mortality of esophagus-hooked fish is common with other fish species, especially when the hook is removed (Diggles and Ernst 1997; Butcher et al. 2006). Circle hooks can significantly reduce instances of deep hooking in billfish (Sailfish *Istiophorus platypterus* and Blue Marlin *Makaira nigricans*; Prince et al. 2002) and can reduce mortality in several other species (Channel Catfish, Ott and Storey 1993; Striped Bass, Caruso 2000; Coho Salmon *Oncorhynchus kisutch*, McNair 1997; Chinook Salmon *O. tshawytscha*, Grover et al. 2002; and Bluefin Tuna *Thunnus thynnus*, Skomal et al. 2002). This does not appear to be the case with Blue Catfish, as 40% of the deeply hooked Blue Catfish in this study were captured with circle hooks and there was no difference in mortality rates between the two hook types. The deep hooking of Blue Catfish with circle hooks may be related to feeding behavior. While pelagic piscivores like tuna are constantly chasing their prey, Blue Catfish are more opportunistic and often scavenge on wounded and dead prey (Graham 1999). The sedentary feeding behavior of Blue Catfish may give them time to swallow the bait before they swim off and could explain the deep hooking with circle hooks. Consequently, restrictions concerning hook type do not appear to be an effective management tool for this species. However, deeply hooked fish were extremely rare, so gear restrictions pertaining to hook type are unnecessary.

Although Blue Catfish may feed in the hypolimnion under certain conditions, no fish were captured beneath the thermocline in this study. Blue Catfish may be more sensitive to DO than Channel Catfish because they surface before Channel Catfish in fish kills caused by depleted oxygen levels (Graham 1999). Additionally, Grist (2002) found that Blue Catfish in Norman Lake, North Carolina, show a distinct preference for areas with much higher DO concentrations than the lake mean, particularly during the summer months, and were rarely found in areas with DO concentrations less than 7.0 mg/L.

Our results demonstrate that the delayed hooking mortality of Blue Catfish captured on juglines is low. This suggests that management agencies can effectively use harvest restrictions to reduce the mortality of Blue Catfish. In locations where density-dependent growth exists, management agencies may benefit from restricting the harvest of large fish while encouraging the liberal harvest of smaller fish. The removal of small fish from a system will reduce intraspecific competition and, with enough removal, improve growth rates and relative weights of the remaining fish. Growth of Blue Catfish in Oklahoma reservoirs is highly variable (Boxrucker and Kuklinski 2008), which may also indicate that only certain fish are genetically capable of growing to trophy size. Therefore, the overharvest of large individuals in a given system could ultimately eliminate that system's potential to produce trophy fish. This further emphasizes the need to conserve large fish, and maximum length limits may be an effective means of doing so. However, these approaches will only be effective if regulatory discards survive to contribute their genetics to subsequent cohorts or to provide recreational opportunity to anglers in the future.

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