Evaluation of Alligator Gar Hooking and Delayed Capture Mortality Using Juglines in the Red River, Arkansas

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Abstract: Hooking and delayed mortality rates are poorly documented for capture of alligator gar (*Atractosteus spatula*) with standard sampling gears and fishing tackle. A recent study documented over 81% hooking mortality for alligator gar captured from Lake Texoma, Oklahoma, using overnight jugline sets with treble hooks. The Arkansas Game and Fish Commission uses active-set juglines rigged with 3-prong treble hooks to conduct alligator gar population assessments. We evaluated hooking and delayed capture mortality of alligator gar by using juglines set with either treble or circle hooks. Twenty-nine alligator gar were captured from a 16-km segment of the Red River, Arkansas. Twenty-two individuals were caught using treble hooks and seven were caught using circle hooks. Two fish expired prior to translocation from hooking-related injuries. Surviving fish were translocated and held in a nearby 3.2-ha observation pond for 18 to 24 days post-capture. Of fish caught using treble hooks, 64% were internally hooked, compared to 29% of those caught using circle hooks. Hooking mortality was 7% regardless of anatomical hooking location or hook type. Mortality of fish caught with treble and circle hooks was 5% and 14%, respectively. Of the 27 successful alligator gar translocations, one died during the observation period, presumably from handling procedures as the necropsy revealed no hooking-related injuries. However, delayed mortality due to hooking was not observed. Three fish died during this study because of either hooking or handling factors, resulting in a 10% total mortality rate. Although this is reasonably low, long-lived species with periodic life-history strategies are extremely sensitive to mortality. Alligator gar managers need to consider the impact mortality may have on populations when abundance is uncertain or low and select a sampling gear within those mortality thresholds. Based on our results, utilizing internal hooking methods should only be used when abundance is great enough to sustain some level for sampling mortality.

Key words: circle hook, delayed mortality, jugline, treble hook

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Alligator gar (*Atractosteus spatula*) are the largest freshwater fish species in Arkansas and among the state's few true large-game fish species, capable of reaching impressive trophy sizes. Over the past century, range-wide alligator gar population declines have been evident (Robison and Buchanan 2020) due to overexploitation and habitat alteration disrupting natural flow regimes. Since 2008, substantial effort has been initiated to improve understanding of and inform responsible management of alligator gar populations within the state.

The Arkansas Game and Fish Commission (AGFC) uses modified juglines with treble hooks to conduct alligator gar assessments. This gear works well when gar are congregated near feeding sites in late summer and water temperatures exceed 30 C. However, a recent study by Snow and Porta (2021) documented over 81% mortality of alligator gar captured from Lake Texoma, Oklahoma, using a similar jugline gear. Their study showed fish hooked in the stomach or esophagus were more likely to succumb to mortality, indicating deeper hooking locations equated to a higher likelihood of death.

Given the sparsity of recaptures in an ongoing mark-recapture study for alligator gar in the Red River, Arkansas, and the high mortality rates presented by Snow and Porta (2021), AGFC needed to evaluate the impacts of our standard sampling jugline gear and handling protocols on alligator gar survival. Since 2018, 380 individuals have been implanted with Passive Integrated Transponder (PIT) tags but despite hundreds of hours of jugline effort, only four alligator gar have been recaptured. In conjunction, exploration into alternative sampling methods that discourage internal hooking is needed by managers. Many conservation-minded rod-and-reel anglers preferentially chose circle hooks over other tackle to reduce the likelihood of internal fish injury (Cook and Suski 2004), however, jugline methods using circle hook are still in their infancy. Therefore, the objectives of this study were to 1) evaluate mortality over time for alligator gar captured with juglines from

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the Red River, Arkansas; and 2) compare mortality from juglines set with treble hooks vs. those set with circle hooks.

Methods

Study Area

Alligator gar were collected from the main-stem Red River and the mouth of the Sulphur River in Arkansas. Sampling occurred over 8 days between 22 August 2022 and 1 September 2022. Effort was centralized around a single boat access on Miller County Highway 4, located near Bradley, Arkansas, hereafter, the Spring Bank Access. This location was chosen based on catch rates of alligator gar during previous samples as well as its close proximity to a pay-lake facility that provided a controlled environment for post-capture observations. Following capture, alligator gar were translocated into a 3.2-ha pond that was 4 km driving distance from the Spring Bank Access. Public fishing access was restricted for the duration of the study and pay-lake staff monitored water quality parameters for any deviances outside of their normal operations.

Jugline Sampling Methods

Four crews sampled within discrete 3.2-km river segments during each sampling day. Crews utilized modified jugline fishing systems to sample alligator gar using methods by Brinkman et al. (2017). A jugline set consisted of 25 individual baited juglines, left to free-float within the assigned river segment. As juglines approached the bottom of the segment, they were retrieved and re-deployed near the top of their designated river km. Two sampling crews concurrently fished above and below the access, respectively. Jugline effort was standardized to 6 consecutive hours of fishing time (Brinkman et al. 2017). Alligator gar were collected within 16 km or less from the Spring Bank Access to minimize transportation time and stress. Separate crews transported alligator gar from their capture locations to the Spring Bank Access which allowed sampling crews to actively check gear.

Individual juglines consisted of a single bullet-style float, with capped PVC inserted through the float (Figure 1). Monofilament line (200 lb.) was attached to the bottom of the PVC with a 2/0 swivel snap, a 3/0, 3-prong steel treble hook attached to a monofilament-loop via a steel leader. Bait was oriented above the treble hook (Figure 1; Brinkman et. al. 2017). Hooks were baited with large chunks of fish cut into 0.5-kg to 0.9-kg pieces. Species used as bait included common carp (*Cyprinus carpio*), buffalo (*Ictiobus* spp.), or gizzard shad (*Dorosoma cepedianum*). One crew fished a subset of the 25 juglines (12) rigged with 2/0 steel circle hooks attached to a monofilament-loop via a 300-lb. hollow-core braided fishing line to test the efficacy of circle hooks. Bait was oriented below the circle hook, with the goal of achieving a shallower hooking location. Treble hooks were fished over all 8 days of the study, while circle hooks were fished for 3 consecutive days.

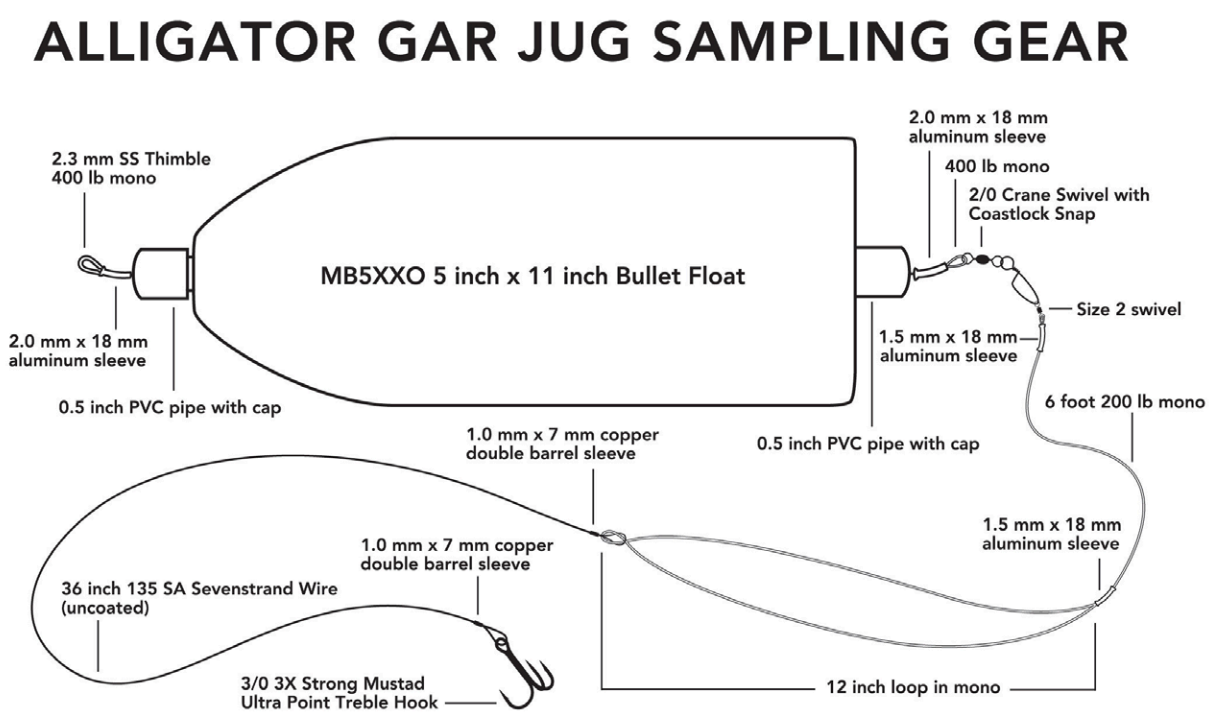

Figure 1. Schematic of typical modified juglines fishing system used by the Arkansas Game and Fish Commission for conducting alligator gar assessments during summer months.

Tagging and Morphometric Data Collection

Morphometric data recorded included total length (TL), standard length, snout-eye length, anal fin length, and pelvic girth recorded to the nearest millimeter (mm). Sex was estimated following methods by McDonald et al. (2018). Weight was measured to the nearest kg by suspending fish from a digital scale using a mesh cradle. Hook type and hooking location, either mouth-hooked or internally hooked (i.e., swallowed), were also recorded. Swallowed hooks were left intact to minimize internal organ damage therefore, the steel leader was cut at the corner of the fish's mouth. All alligator gar were scanned for a PIT tag. Unmarked fish were intramuscularly implanted with a PIT tag at the posterior base of the dorsal fin. After implantation, all tags were re-scanned to ensure they were operational.

Tempering, Translocation, and Monitoring

Alligator gar were acclimated to observation pond water temperatures prior to translocation. Tempering procedures began by filling 2.4 m, round stock tanks with aerated water from the Red River. Pond water was then pumped into the tanks for a minimum of 15 min or until temperature equilibrium had been reached. Daily pond water temperatures (26–28 C) varied by less than 2 C from the Red River. Additionally, to minimize stress and support slime-coat production, a 3% NaCl (i.e., sodium chloride rock salt) solution was added per volume of water in the tanks. Tanks were covered using large netting and alligator gar were driven to the observation pond. Upon arrival, they were transported into the pond using poly-mesh cradles and released upon their ability to maintain buoyancy and swim freely.

Survival was evaluated for 18 to 24 days between 22 August 2022 and 15 September 2022, beginning after the first translocation. Daily perimeter searches of the pond were conducted from the shoreline, and survival was assumed unless a dead individual was observed. The AGFC Fish Pathologist and Wildlife Health Veterinarian performed necropsies on all alligator gar that expired during this study. Details about internal hooking injuries, hooking location, and other abnormalities were annotated. At the end of the observation period, all remaining fish were extracted from the pond, identified via PIT tag, and released into the Red River at the Spring Bank Access.

Time Series Data

Time series data were recorded during each phase of the study to document capture and handling procedures and their effect on mortality. Time series transitions were as follows: hook-up to landing time documented time spent "fighting" the fish; handling time was the time spent collecting morphometric data; boat transportation time documented the travel time to the Spring Bank Access; tank transfer time was amount of time for fish to be placed into a tempering tank following weight measurement; tempering time documented the time fish spent in the hauling tanks during tempering; driving time represented the time to travel between the Spring Bank Access and the observation pond; and release and recovery time included the time the fish needed to maintain buoyancy and swim without assistance. Although it was not possible for sampling crews to know the exact time an alligator gar took the jugline bait, crew leaders made their best attempts to approximate time.

Statistical Analysis

A relative length frequency histogram was used to describe the size distribution of alligator gar captured using juglines. Two-sample *t*-tests were performed to evaluate differences across time series data. We compared the effect of hook type on landing and hook-up time, landing time and anatomical hooking location, and total handling time and fate (dead or alive). Statistical tests used $\alpha = 0.05$ to determine significance. All analyses were performed using Program R (R Core Team 2022).

Results

Effort and Morphometric Data

Jugline sets were fished for a total of 192 h, equating to 4800 h of individual jugline effort. In total, 29 alligator gar were captured for a catch-per-unit effort (CPUE) of 0.15 alligator gar jugline set per hour. Of the 29 captured alligator gar, 22 were caught using treble hooks and seven were caught using circle hooks (Table 1). Per McDonald et al. (2018) methods for nonlethal sex determination of alligator gar, 7 (24%) were estimated to be male vs. 22 (76%) female. Total length ranged from 993 mm to 2230 mm (mean = 1589; SE = 49; Table 1, Figure 2). Weight ranged from 5.9 kg to 76.2 kg (mean = 26.9; SE = 3; Table 2).

Hooking and Mortality

Hooking mortality was observed with both hook types but only for internally hooked alligator gar. Internal hooking (i.e., the hook was swallowed) occurred during 64% of captures using treble hooks compared to 29% with circle hooks (Table 1). Mouth-hooking occurred during 36% of captures using treble hooks compared to 71% with circle hooks (Table 1). Of the 29 alligator gar captured, two died prior to translocation (7% cumulative hooking mortality). One treble-hooked fish died 64 min after landing (TL = 1080 mm) and another circle-hooked individual died 194 min

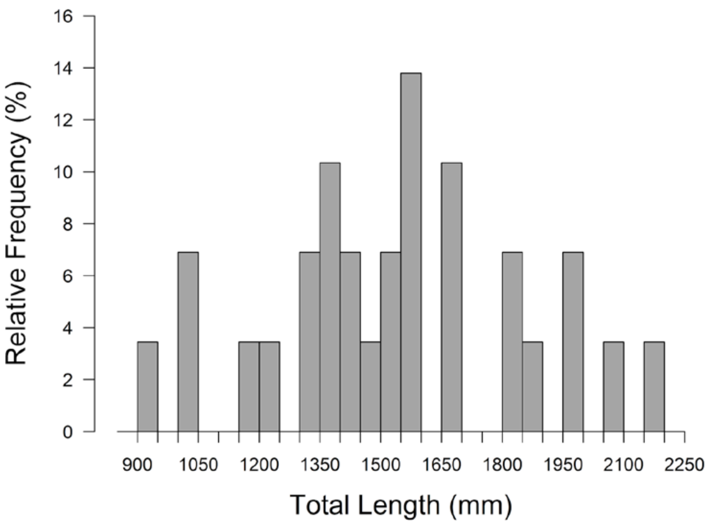

Figure 2. Relative length frequency distribution for alligator gar captured from the Red River, Arkansas, in 2022 using jugline methods.

Table 1. Hooking and mortality metrics for 29 alligator gar captured during jugline sampling in 2022 in the Red River, Arkansas.

Metric	Number	Total	%
Captures			
Caught using treble hooks	22	29	76
Caught using circle hooks	7	29	24
Hooking Location			
Swallowed hooks	16	29	55
Swallowed treble hooks	14	22	64
Swallowed circle hooks	2	7	29
Mouth hooked	13	29	45
Treble mouth hooked	8	22	36
Circle mouth hooked	5	7	71
Mortality and Survival			
Total mortality	3	29	10
Mortality: treble hook	2	22	9
Mortality: circle hook	1	7	14
Post-capture survival	26	27	96
Post-capture delayed mortality	1	27	4

after landing (TL = 1550 mm). Both swallowed hooks and veterinary inspection confirmed internal tears were present from hooking-related injuries.

In addition to the two hooking mortalities, a single mortality occurred during the observation period, resulting in a total mortality rate of 10% (3 of 29 fish). This individual, a female, was observed struggling to maintain buoyancy at the surface prior to death and died 2 days post-translocation on 29 August 2022. A necropsy revealed that despite swallowing a treble hook, no internal organs were punctured and the cut-bait was still fully intact within the stomach. Veterinary staff documented severe hemorrhaging around the heart as well as a swim-bladder irregularity that affected its ability to properly deflate, suggesting death was due to capture or handling stress. No other mortalities were observed prior to extraction.

Time Series Data

Mean time spent on the hook (i.e., landing) was 7 min (SE = 1.0; range = 2 to 25; Table 3). Handling time for morphometric data collection averaged less than 10 mi (SE = 1.1; range = 1 to 35). Average total handling time (i.e., time from hook up to release) into the observation pond was 116 min (SE = 7.7; range = 36 to 235 min; Table 3).

All fish that succumbed to mortality during this study had landing and handling times that were below the average time frames reported for all captured fish. Total handling time was not significantly different for alligator gar that succumbed to mortality compared to those that survived ($P = 0.47$). Both fish that died due to

Table 2. Summary of alligator gar morphometric measurements for jugline sampling on the Red River, Arkansas, in 2022. Alligator gar ($n = 29$) were caught and measured using methods required for non-lethal sex determination provided by McDonald et al. (2018).

Metric	Minimum	Maximum	Mean	SE
Snout-eye length (mm)	130	339	239	10
Anal fin (mm)	38	181	91	5
Standard length (mm)	854	1950	1416	54
Total length (mm)	993	2230	1589	49
Pelvic girth (mm)	63	940	602	32
Weight (kg)	5.9	76.2	27	3

Table 3. Time series data for alligator gar captured from the Red River, Arkansas, using modified juglines in 2022. Time series transitions were as follows: Landing: hook-up to landing time for time spent "fighting" the fish; Handling: handling time for morphometric data collection; Boat transfer: boat-transportation time for boat-travel time to the Spring Bank Access from capture location; Tank transfer: amount of time for fish to be placed into a tempering tank; Tempering: time fish spent in the hauling tanks during tempering; Driving: driving time between the Spring Bank Access and the observation pond; Recovery: release and recovery time included the time the fish needed to maintain buoyancy and swim without assistance.

Time Metric (min)	Minimum	Maximum	Mean
Landing	2	25	7
Handling	1	35	10
Boat transfer	1	27	12
Tank transfer	1	59	16
Tempering	13	147	43
Driving	5	12	9
Recovery	3	72	19
Total	*36*	*235*	*116*

hook-related injuries were handled and landed within 6 and 9 min, respectively. The fish that expired presumably from capture and handling stress was landed in 4 min and handled for <10 min. All other time series metrics fell within the range of average reported timeframes compared to fish that survived.

Although not statistically different, alligator gar caught using circle hooks generally required less landing (P = 0.39), handling (P = 0.06), and recovery times (P = 0.33), but sample sizes between hook types were unequal. Total handling time between hook types and anatomical hooking locations were not significantly different (P = 0.52, P = 0.13), however, circle-hooked fish were handled for 20 min less (SE = 9.2).

On average, circle-hook caught fish were landed within 5 min (SE = 1.5) compared to 7 min (SE = 1.1) for those caught using treble hooks. Handling circle-hooked fish took less than half the time of treble-hooked fish (i.e., 5 min versus 11 min) and recovery was 7 min faster on average for circle-hook caught fish.

Discussion

Mortality and delayed hooking mortality are of particular concern for long-lived species such as alligator gar because population recovery after decline can take several decades. Alligator gar exhibit many characteristics of a periodic life-history strategy (Winemiller and Rose 1992) including extended longevity (>60 yr, Daugherty et al. 2019), late maturity, high fecundity, and variable recruitment success (Ferrara 2001, Buckmeier et al. 2012, Buckmeier et al. 2016, Buckmeier et al. 2017). Their vulnerability to overexploitation makes understanding the factors influencing mortality such as body size, hooking location, hook type and design, duration of hooking, bait type, water temperature, and water quality crucial for effective management (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Coggins et al. 2007, Schmitt and Shoup 2013, Daugherty and Bennett 2019). Given the conservation status of alligator gar as "vulnerable" across its current range (Jelks et al. 2008), and as a Species of Greatest Conservation Need in Arkansas (Fowler and Anderson 2015), understanding mortality and associated factors is a priority for alligator gar resource managers, especially with respect to sampling gear using to monitor alligator gar populations. While we did not estimate exploitation in this study, mortality related to sampling gear can be conservatively used as a proxy for exploitation. When modeling population responses of alligator gar to various length-based regulations, Smith et al. (2018) found that exploitation rates exceeding 7% resulted in a 50% reduction in population size over a 100-yr simulation period. Further, recruitment overfishing was evident around exploitation rates near 6.5% when no length restrictions were in place and suggested the use of length limits may provide options for sustaining trophy alligator gar harvest. Like other long-lived fishes, this indicates alligator gar populations are particularly sensitive to stock collapse without sufficient protection of smaller, juvenile fish. Given their sensitivity to mortality, it is imperative that managers consider the long-term effects of sampling gears on instantaneous or delayed mortality to ensure population sustainability.

Our study revealed a significantly lower mortality rate for alligator gar captured using standard jugline sampling methods in the Red River, Arkansas, compared to previous research. We observed a total mortality rate of 10% with only 7% attributed to hooking mortality. This contrasts with the 81% mortality rate reported by Snow and Porta (2021) for similar jugline gear in Lake Texoma, Oklahoma where 60 out of 74 individuals died within 5 days post-capture. A supplemental study by Snow et al. (2022) simulating population sensitivity of alligator gar to exploitation predicted a high probability of population collapse within 100 yr if fishing mortality exceeded 10%. Even low hooking mortality rates (<5%) can have significant population level impacts on long-lived species like alligator gar, especially in heavily exploited systems (Coggins et al. 2007). While some mortality is inevitable with any sampling gear, our findings coupled with the low perceived fishing pressure on alligator gar in the Arkansas portion of the Red River (D. Hann, AGFC, personal communication), and infrequency of annual population assessments suggest that our standard jugline methods have not substantially contributed to population declines and infrequency of recapture events.

Hooking duration (i.e., time spent on the hook) is an important factor influencing mortality of captured fish. While internal injury from the hook is often the primary cause of mortality, the prolonged struggle and stress can exacerbate the damage, increasing the likelihood of death. A key difference between our study and Snow and Porta (2021), which may explain the disparity in mortality rates, is the duration of hooking time. Although juglines are considered a passive sampling gear, we actively tended our juglines, which resulted in an average hooking duration of 7 min. Snow and Porta (2021) used a passive approach where juglines were set prior to sunset and retrieved at sunrise for a maximum possible hooking duration of 12 h. This prolonged hook exposure, particularly for internally hooked fish, likely contributed to their significantly greater mortality rate. Similarly, many states allow 24-hr jugline sets (Schmitt and Shoup 2013), which can lead to extended hooking times and increased mortality rates. Given the recognized need for Best Management Practices (BMPs) for catch-and-release alligator gar fishing (Daugherty and Bennett 2019), our study strongly supports discouraging the use of passively set juglines to minimize mortality.

Hook type and bait presentation significantly influence where an alligator gar is hooked, playing a crucial role in its survival (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005). Alligator gar hook-and-line methods most commonly use natural baits, therefore increasing the likelihood of ingestion and deep-set internal hooking (Daugherty and Bennett 2019). Our study confirmed this trend, as 55% of alligator gar captured using juglines were hooked internally, and 7% of mortality was attributed to hooking-related injuries. Unfortunately, internal hooking was most common using treble hooks, occurring during 64% of captures. Snow and Porta (2021) found that treble hooks most frequently resulted in stomach (68%) or esophagus (20%) hooking with associated mortality rates of 94% and 87%, respectively. Other mortality events were observed in AGFC population assessments on the Ouachita and Red Rivers (Brinkman et al. 2017). During both surveys, two individuals died following capture using standard jugline gear with treble hooks. While treble hooks are effective for capturing alligator gar due to multiple hooking points, their tendency to promote deep hooking is associated with greater mortality rates. In contrast, circle hooks are designed to lodge in the mouth, reducing the occurrence of internal hooking, and therefore improving survival. This has been demonstrated in various species, including sailfish (*Istiophorus platypterus*) and blue marlin (*Makaira nigricans*; Prince et al. 2002), channel catfish (*Ictalurus punctatus*; Ott and Storey 1993), striped bass (*Morone saxatilis*; Caruso 2000), and chinook salmon (*Oncorhynchus tshawytscha*; Grover et al. 2002). However, these studies were not specific to jugline methods.

Our study supports the use of circle hooks for increasing mouth-hooking occurrence during alligator gar capture, as five out of seven individuals captured with circle hooks were hooked in the mouth, usually in the corner of the upper jaw as designed. Mortality was not observed for any mouth-hooked alligator gar. As part of a meta-analysis evaluating circle hooks as conservation tools for catch-and-release fisheries, Cooke and Suski (2004) found hooking mortality rates decreased by approximately 50% when using circle hooks rather than J-style hooks because deep-hooking was relatively rare. They also suggested the use of circle hooks could benefit a specialized trophy muskellunge (*Esox masquinongy*) fishery. Similarly, Schmitt (2012) found that juglines rigged with circle hooks resulted in a slightly lower mean mortality of blue catfish (*Ictalurus furcatus*) compared to J-style hooks, and concluded that anatomical hooking location was the most significant factor on hooking mortality. Overall, managers should seek sampling strategies that minimize the likelihood for internal hooking and promote conservation-minded gears for anglers.

While jugline methods using circle hooks need further refinement, this study also demonstrated mortality can still occur as a result of circle-hook related injuries. One fish sustained fatal internal injuries from swallowing a circle hook and died shortly after capture. Upon landing, biologists attempted to remove the hook which was lodged in the mouth. However, the fish was observed bleeding profusely from the gills and vent in the stock tank and was pronounced dead within 80 min from the time of initial hook-up. Necropsy revealed extensive tearing of the stomach and esophageal linings resulting in fatal blood loss. It seems likely this individual swallowed the bait and hook, but it dislodged during landing and re-snagged in the mouth. Schmitt and Shoup (2013) also noted that juglines rigged with circle hooks did not always set in the corner of the mouth resulting in external or deep esophageal hooking of blue catfish. Managers should be cautious in assuming that internal injuries are not present because a hook is observed in a fish's mouth. Additionally, given the fate of those that died due to hooking in this study where excessive bleeding was observed, extent of blood loss should be annotated alongside hooking location as an indicator of survivability, when present.

Several factors, beyond just hooking injuries, can contribute to delayed mortality in alligator gar. In our study, we observed only one instance of delayed mortality. This individual died 2 days post-capture due to factors unrelated to hooking, most likely capture or handling stress. Although we observed low rates of delayed mortality in our study, other research has shown it can be a significant issue. For instance, Snow and Porta (2021) documented 42% of alligator gar mortalities occurred within 24 hr, but deaths continued throughout their 5-day observation period. Further, they concluded that mortality occurred more frequently at warmer water temperatures and with shorter alligator gar. Similarly, Schmitt and Shoup (2013) found delayed mortality rates ranging from 3.9% to 25.3% for blue catfish caught using juglines fished for 24 hr, where greater mortality rates were associated with warmer water temperatures. While our findings suggest that hooking location and duration are key factors in alligator gar mortality, it is essential to consider the interplay of various stressors, including environmental conditions and individual fish physiology, to fully understand and mitigate delayed mortality.

This study aimed to evaluate mortality of alligator gar captured with actively attended juglines. Overnight jugline sets have been shown to result in high mortality rates (81%), raising concerns about their use as a standard sampling gear. However, our study estimated a significantly lower total mortality rate of 10%, and 7% attributed directly to hooking related injuries. Given their life history, even low mortality rates (i.e., <10%) can lead to population declines. Therefore, managers should consider regulations that require active attendance of juglines to minimize fishing mortality. Furthermore, this study highlights the need for careful evaluation of all sampling gears, with a preference for those that minimize mortality. Future research should investigate alternative methods, such as winter gill netting, particularly if greater catch rates can be achieved with lower mortality. Finally, our findings can inform gear restrictions for alligator gar, similar to those already in place for other species like *Esox* spp. and *Acipenser* spp. (Daugherty and Bennett 2019), which prohibit multi-point hooks. While formal BMPs for targeting alligator gar are still lacking, this study provides valuable data to improve our understanding of sampling-gear mortality in the Red River, Arkansas, and contribute to the development of effective conservation strategies.

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