Hooking Mortality Rates and Factors Influencing Mortality of Alligator Gar Caught Using Two Hook-and-Line Methods

Richard A. Snow
Oklahoma Department of Wildlife Conservation, Oklahoma Fishery Research Laboratory, Norman, OK 73072

Michael J. Porta
Oklahoma Department of Wildlife Conservation, Oklahoma Fishery Research Laboratory, Norman, OK 73072

Abstract: The Alligator Gar (*Atractosteus spatula*) has become a recreationally popular species due to its trophy potential. Hook-and-line angling is one of the most popular methods for catching Alligator Gar and most anglers practice catch-and-release, however delayed mortality rates associated with these fishing methods are unknown. Therefore, we evaluated hooking mortality and factors affecting mortality for Alligator Gar caught using two hook-and-line fishing methods, juglines and rod and reel. Juglines were used to catch Alligator Gar from Texoma Reservoir, Oklahoma. Once caught, fish were placed into pools and hooking mortality was evaluated over a 120-h observation period. For the rod and reel component of the study, 32 Alligator Gar were captured from Texoma Reservoir using gillnets and transported to ponds at the Tishomingo National Fish Hatchery. Rod and reel angling was conducted in the ponds until 16 gar were caught and those fish were monitored for 268-d post-release. Following capture using either method, the tag number, water temperature, total length (mm), hooking depth, and anatomical hooking location for each Alligator Gar was recorded. A total of 74 Alligator Gar were caught using juglines, of which 60 died (mortality rate = 81.1%) during the observation period. Of the 16 Alligator Gar caught using rod and reel, one fish died (hooking mortality = 6.3%) during the observation period. No control fish died during either experiment. Mean hooking depth of Alligator Gar caught using juglines was 247 mm, which was significantly deeper than those caught using rod and reel angling (101 mm). A multiple logistic regression model indicated no significant relationship between gear type (juglines vs. rod and reel) and the fate (mortality or survival) of Alligator Gar, suggesting that most jugline mortality could be explained by deeper hooking depths. Additionally, temperature, total length, and hooking depth affected survival of Alligator Gar. Results from this study can be used to inform fisheries biologists of mortality associated with juglines and hook and line when managing recreational fisheries that permit these fishing methods or if they are considering implementation of these techniques for sampling Alligator Gar.

Introduction

Mortality rates and variables contributing to delayed hooking mortality have been described for numerous fish species (Muoneke and Childress 1994, Tomcko 1997, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Coggins et al. 2007, Hühn and Arlinghaus 2011, Schmitt and Shoup 2013). The majority of this research has focused on fish species that are economically and recreationally important, or have received considerable outdoor media attention (Muoneke and Childress 1994). Reported mortality rates associated with catch-and-release angling have ranged from 0 to 95% across freshwater and marine species (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005). The wide range of reported mortality rates is attributed to a number of factors, including fish species, body size, bait type (natural vs. artificial), hook design (single, treble, barbed vs. barbless), gear types, hooking location, fish handing practices, water depth where fish was caught (barotrauma), and water quality where fish were caught and released (Muoneke and Childress 1994, Tomcko 1997, Bartholomew and Bohnsack 2005, Hühn and Arlinghaus 2011, Schmitt and Shoup 2013). Although delayed hooking mortality has been evaluated for many fish species, it is unknown how Alligator Gar (*Atractosteus spatula*) are affected by catch-and-release angling.

Historical negative perceptions towards Alligator Gar are rapidly changing, as this species has become recreationally popular and valuable due to its trophy potential (i.e., growth to >1,828 mm TL; Buckmeier et al. 2016, Adams et al. 2019). Hook-and-line angling is one of the most popular recreational methods for catching Alligator Gar and most anglers practice catch-and-release after documenting their experience with photographs. Catch-and-release angling operates under the assumption that released fish survive and continue to reproduce or are allowed to grow to a more desirable size before harvest thus limiting population effects (Coggins et al. 2007, Schmitt and Shoup 2013). If released fish do not survive, population size structure and abundance can be altered when sufficient proportions of the population are captured (Daugherty and Bennett 2019), which ultimately affects the sustainability of a fishery (Wydoski 1977, Coggins et al. 2007). Additionally, since management biologists use these methods to sample Alligator Gar (Buckmeier et al. 2016), high delayed fishing mortality rates could affect population structure or bias the sampling data.

Alligator Gar is considered vulnerable across its current range by the American Fisheries Society (Jelks et al. 2008), so it is critical to understand threats to this species, including the potential impacts of recreational angling. Alligator Gar exhibit a periodic life-history strategy (high longevity, delayed maturation, and specific spawning habitat requirements, which regulates recruitment and population densities; Buckmeier et al. 2017). These characteristics make this species particularly vulnerable to anthropogenic impacts on the environment and overfishing, which have historically resulted in significant population declines (Buckmeier et al. 2017, Smith et al. 2018). A small increase in angling mortality could have a negative impact on Alligator Gar populations as a result of its periodic life history characteristics (Coggins et al. 2007, Smith et al. 2018, Daugherty and Bennett 2019). Across the current range of Alligator Gar, unlimited catch-and-release angling (using hook-and-line methods) is permitted, however information regarding delayed hooking mortality associated with these methods is unknown.

The Oklahoma Department of Wildlife Conservation (ODWC) began using hook-and-line (juglines and rod and reel; Buckmeier et al. 2016) sampling in addition to gill netting (Bodine et al. 2015; Schlechte et al. 2016) to increase the number of Alligator Gar collected during mark-recapture efforts to attain a population estimate in Texoma Reservoir. However, soon after initiating these sampling methods, we realized numerous difficulties (jug design, hook type, bait type, sampling location, and rod and reel setup) that prohibited success of these sampling approaches. The first attempts to collect fish via hook-and-line methods relied on the use of J-style and circle hooks, but no Alligator Gar were landed using these hook types. To improve our methods we contacted professional fishing guides in Oklahoma and Texas that specialize in catching Alligator Gar. All of the guides suggested the use of size 3/0 or 4/0 treble hooks and recommended increasing treble hook size if fish were still being missed. However, these recommendations came with the warning that increased treble hook size would increase hooking mortality rates. Upon switching to 4/0 treble hooks, our ability to hook and land Alligator Gar improved, but all of the fish that were caught (7 with juglines and 5 with rod and reel) died from hooking-related injuries. Consequently, hook size was decreased to a size 3/0 treble hook and observed hooking mortality decreased but continued to occur. Use of hook-and-line techniques to mark and recapture Alligator Gar for estimation of population size was abandoned due to associated hooking mortality. However, these preliminary results identified the need to evaluate delayed hooking mortality of Alligator Gar using hook-and-line methods. Therefore, we sought to evaluate hooking mortality rates associated with two commonly used hook-and-line fishing methods (juglines and rod and reel) and to describe factors influencing the mortality of caught and released Alligator Gar.

Methods

Juglines

Jugline fishing for Alligator Gar occurred from June through September 2018 in the upper third of both river arms (Red and Washita rivers) of Texoma Reservoir. Side scan sonar was used to locate concentrations of Alligator Gar (Fleming et al. 2018), and once found juglines were set in these areas. Juglines were set just prior to sunset and lifted at sunrise the following morning (< 12 h set time). Juglines were similar in design to those used by Snow and Porta (2020), which consisted of inserting a PVC pipe through a swimming pool noodle and caps were added to each end of the pipe. Holes were drilled through each cap and 33.5 meters of 113 kg test jug line was run through the PVC pipe. Once the line was fed through pipe, a snap swivel was tied to one end for attaching a 0.45 kg weight and a 91.4 cm steel leader (84 kg test) with a snap swivel was added to the opposite end. This design allowed Alligator Gar to surface to breathe, without interference from the weight. Juglines were baited with cut or whole fish of various species (Snow and Porta 2020). The juglines were set to allow the bait to rest on the bottom of the lake.

Alligator Gar caught on jugs were played by hand. Once brought boat-side, the fish was noosed behind the pectoral fins with a rope, lifted onto the boat, and placed into a holding tank, which is commonly practiced by anglers. Once onboard, Alligator Gar were measured for total length (TL, mm) and implanted with a PIT tag (Biomark, Inc., Boise, Idaho) and stainless steel dart tag (FH-69W; Floy Tag and Manufacturing, Inc., Seattle, WA) for identification purposes. In cases when the baits were swallowed (fish not caught in a location where hook could be removed), the leader was cut at the corner of the mouth where the upper and lower jaws meet. The remaining section of leader was measured to determine the hook depth and anatomical hooking location (i.e. external [outside of mouth], mouth, esophagus, stomach) was recorded. Anatomical hooking location estimated using leader measurements was predicted with 86.7% accuracy, which was verified through dissection of mortalities.

Alligator Gars were then transported to one of two holding pools (4.6 m diameter x 1.2 m deep; Intex Recreation Corp., Long Beach, California) located on the shoreline of Texoma Reservoir at the University of Oklahoma Biological Station near Kingston, Oklahoma. Pools were filled using water from Texoma Reservoir, and water quality (temperature, dissolved oxygen, and pH) in each pool was monitored daily over the course of the study to ensure conditions were similar to those in the reservoir. An equal number of control fish (captured using multifilament gillnets; Schlechte et al. 2016) and treatment fish (caught using juglines) were placed into each pool. Densities of Alligator Gar did not exceed 6 individuals (3 control and 3 treatment) per pool. Fish were monitored daily for 5 d. When mortality occurred, that fish was removed from the pool and processed for TL and weight, and a necropsy was performed to determine the hooking location and document any internal injuries caused by hooking.

Rod and reel

In February 2018, Alligator Gar (n=32) were collected during winter using multifilament gill nets (Bodine et al. 2015, Schlechte et al. 2016). Side scan sonar was used to locate concentrations of Alligator Gar in the Washita River arm of Texoma Reservoir, and once found, gill nets were deployed in these areas (Fleming et al. 2018). Once captured, Alligator Gar were measured, weighed, implanted with a PIT tag and dart tag, and transported to the boat ramp where they were transferred into one of three fish hauling tanks. Water in the hauling tanks contained a 1% NaCl solution and a mild concentration (10 mg/l) of MS-222 to reduce handling and hauling stress while in transport to the Tishomingo National Fish Hatchery (TNFH; Porta et al. 2019). Alligator Gar were distributed evenly (n=8) among four 0.4 ha earthen ponds at the TNFH and ample live fish forage was added to each pond. Alligator Gars were allowed to acclimate to the ponds for 6 months prior to initiating the experiment. The experiment began in July 2018, but was quickly paused due to overabundant vegetation in the hatchery ponds that made fishing impossible. The fishing trials were successfully completed in May 2019 prior to extensive growth of vegetation in the ponds.

To mimic recreational Alligator Gar angling methods, a medium-heavy action rod with a spinning reel spooled with 36.3 kg test braided line was used. A 91.4 cm steel leader (84 kg test) was added to the braided line and a snap swivel was used to attach a size 3/0 treble hook. Hooks were baited with cut or whole fish (Common Carp [*Cyprinus carpio*], Gizzard Shad [*Dorosoma cepedianum*], River Carpsucker [*Carpiodes carpio*], or Smallmouth Buffalo [*Ictiobus bubalus*]) and fished on the bottom of the ponds with no weight. When an Alligator Gar picked up the bait, it was allowed to swim, stop to orient the bait in its mouth, and begin swimming again before setting the hook (time recorded from initial bait pickup to hook set averaged 6.43 min). Once an Alligator Gar was hooked, the fish was reeled to the shoreline, noosed behind the pectoral fins with a rope and brought on to the shore where the tag number was recorded, and the hook was removed (if caught in the mouth). When fish swallowed the bait (hooked in a location where hook could not be removed), the leader was cut at the corner of the mouth where the upper and lower jaws meet and the remaining section of leader was measured to determine the hook depth and anatomical hooking location. Alligator Gar were released into the same pond where they were captured. Fishing ceased once 4 Alligator Gar were caught from each pond. After all fish were caught, TNFH staff monitored the ponds daily for mortalities. When mortality of an Alligator Gar occurred, the date and time was recorded to determine the number of days following a fishing event and the fish was removed from the pond. All Alligator Gar mortalities were processed for TL and weight, tag number was recorded, and a necropsy was performed to determine the hooking location and internal injuries caused by hooking. In March 2020, 268-d following capture of the last fish, all four 0.4 ha earthen ponds at the TNFH were drained and tag numbers of the remaining Alligator Gar were recorded to determine if fish were caught and released (treatment fish) or never captured (control fish). All live Alligator Gar were transported back to Texoma Reservoir and released.

Statistical analysis

A length frequency histogram was used to describe the size distribution of Alligator Gar captured during this study for each method. A two-sample t-test was performed to determine if mean hooking depth differed between catch-and-release mortalities and survivors for juglines. Differences in the proportion of Alligator Gar mortalities between treatment (caught and released) and control (not caught) groups were analyzed using a chi-square test for rod and reel caught fish. Anatomical hooking location, fate (mortality or survival), and hooking depth was documented for each Alligator Gar for both methods. A logistic regression was performed to determine differences in mortality among anatomical hooking locations. A one-way ANOVA was performed to determine differences in hooking depth between anatomical hooking locations. If a significant difference was detected a Tukey Post-hoc test was performed.

A Pearson's correlation test was performed to ensure variables (temperature, total length, hooking depth, and ratio of hooking depth to Alligator Gar TL) were not correlated (Table 1). Variables were considered to be correlated at a level $\geq$0.60. Two variables: hooking depth and ration of hooking depth to alligator gar total length (% of TL) were correlated, so hooking depth was removed from further analyses. A logistic regression model was used to understand the relationship between juglines and rod and reel, while fitting temperature, total length, and

Table 1. Pearson correlation matrix of variables used in the multiple logistic regression model. Variables with bold values are strongly correlated (≥ 0.60). Hooking depth and hooking depth (% of TL) were correlated, therefore only hooking depth (% of TL) was used in the logistic model.

Variables	Temperature (°C)	Total Length (mm)	Hook Depth (mm)	Hooking Depth (% of TL)
Temperature (°C)		-0.34	0.46	0.34
Total Length (mm)	-0.34		-0.23	0.16
Hooking Depth (mm)	0.46	-0.23		**0.89**
Hooking Depth (% of TL)	0.34	0.16	**0.89**	

hooking depth (% of TL) to a binary variable (0 = survived, 1 = died) to understand if these variables affected the fate (mortality or survival) of Alligator Gar following capture. All analyses were performed using XLSTST 2020 (Addinsoft Inc., New York City, NY). All significance tests were evaluated at $P \leq 0.05$.

Results

Juglines

A total of 74 Alligator Gar were caught on juglines during summer 2018. Surface water temperatures ranged from 22.2ºC to 32.2 ºC during jugline fishing efforts. Alligator Gar ranged from 678 to 2,274 mm TL (Figure 1a). Of the 74 fish caught on juglines, 60 died from

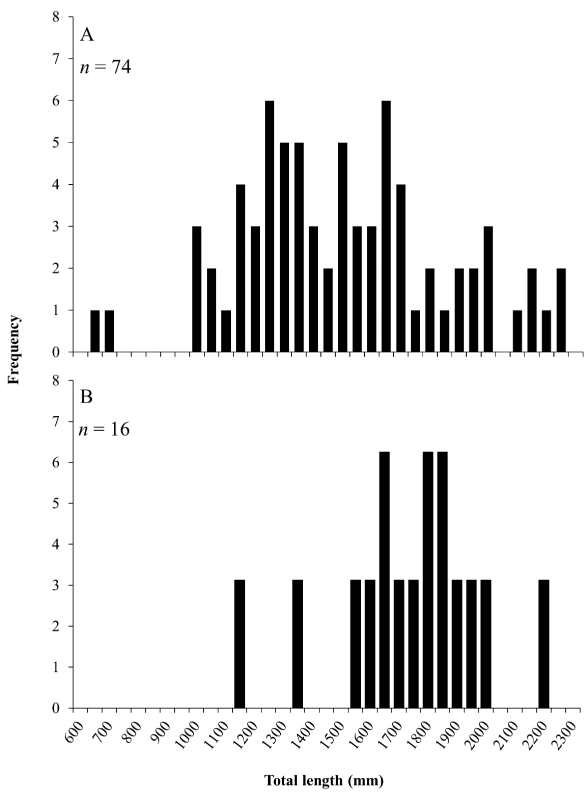

Figure 1. Length frequency histograms of Alligator Gar caught using (A) juglines and (B) rod and reel fishing methods. Alligator Gar caught using juglines were captured from Texoma Reservoir, Oklahoma. Alligator Gar caught using rod and reel were captured during fishing trials conducted in ponds at the Tishomingo National Fish Hatchery.

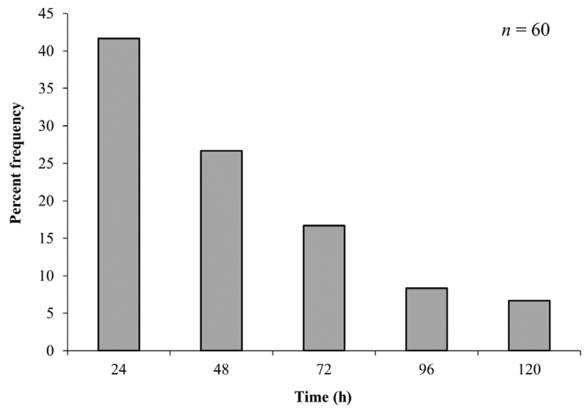

Figure 2. Daily (24 h period) mortality rates of Alligator Gar caught using juglines from Texoma Reservoir, Oklahoma during a post-capture 120 h observation period.

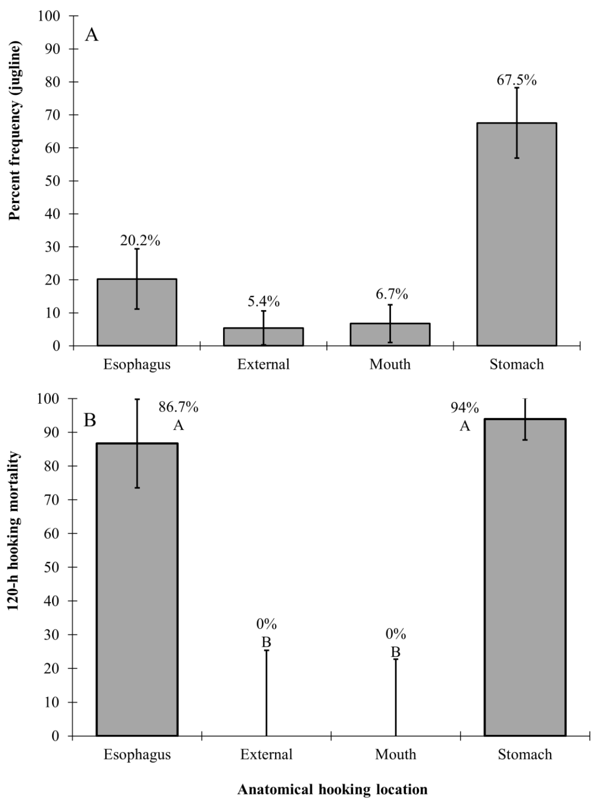

Figure 3. Percent of total fish (A) and mortality rate (B) by anatomical hooking location for Alligator Gar caught using juglines at Texoma Reservoir, Oklahoma during June-September 2018. Error bars represent 95% confidence intervals. A difference in letters above bars reflects statistical significance at P > 0.05.

hooking injuries (mortality rate = 81.1%). Delayed morality occurred within the first 24-h for 42% of the Alligator Gar. Although the mortality rate decreased with increasing time, mortality events occurred over the entire 120-h observation period (Figure 2), suggesting mortalities could have occurred beyond 120-h. No control fish died during the 120-h observation

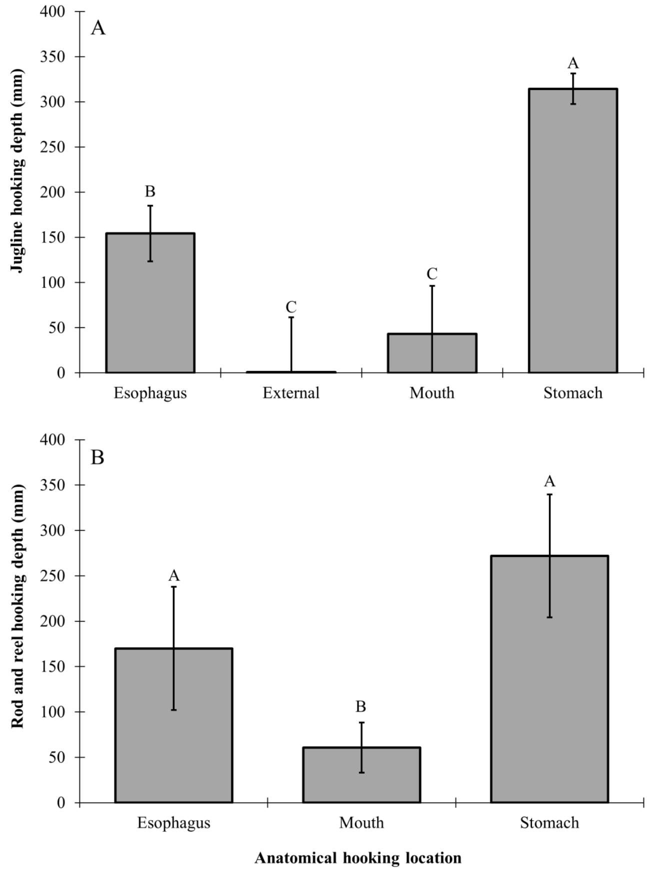

Figure 4. Mean hooking depth of Alligator Gar caught using (A) juglines and (B) rod and reel by anatomical hooking locations. Error bars represent 95% confidence intervals. A difference in letters above bars reflects statistical significance at P > 0.05.

period.

The majority of Alligator Gar caught with juglines were hooked in the stomach (67.5%). The remaining fish were hooked in the esophagus (20.2%), mouth (6.7%), or externally (5.4%; Figure 3a). Alligator Gar hooked in the esophagus or stomach experienced a mortality rate exceeding 86%. There was no significant difference in mortality rate between esophagus- and stomach-hooked fish. However, Alligator Gar hooked in the esophagus and stomach had a significantly higher mortality rate (X^2 = 14.516, df = 3, P < 0.01) than both external- and mouth-hooked Alligator Gar (Figure 3b). No mortality was observed for Alligator Gar hooked in the mouth or externally.

Table 2. Results of multiple logistic regression model examining hooking mortality of Alligator Gar in relation to temperature (°C), TL (mm), hooking depth (% of TL), and gear type (juglines and rod and reel). Variables with bold P-values were significant at an alpha level = 0.05.

Variable	df	X^2	*P*-value
Temperature (°C)	1	3.741	**0.05**
Total length (mm)	1	7.946	**<0.01**
Hooking depth (% of TL)	1	14.198	**<0.01**
Gear	1	0.327	0.58

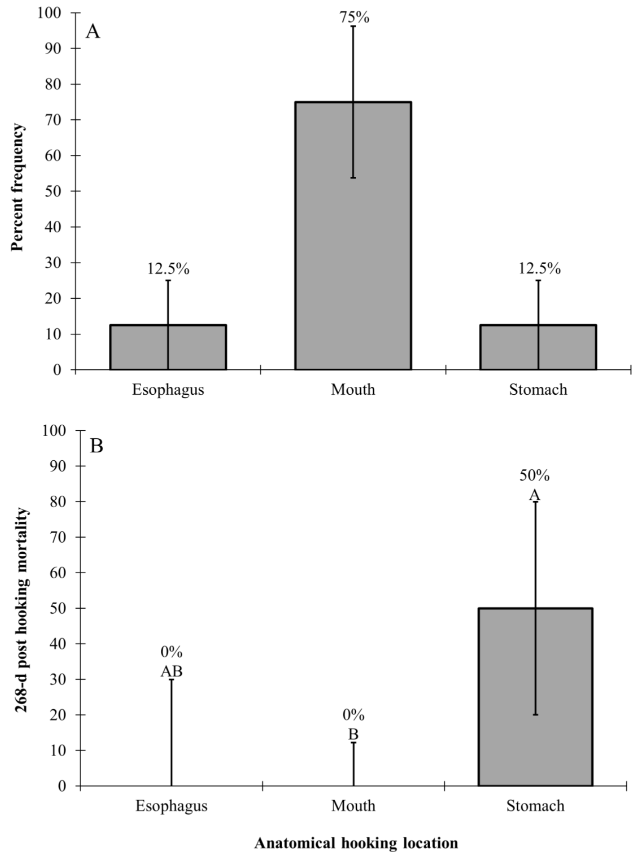

Figure 5. Percent of total fish (A) and mortality rate (B) by anatomical hooking location for Alligator Gar caught using hook and line angling in ponds at Tishomingo National Fish Hatchery during May 2019. Error bars represent 95% confidence intervals. A difference in letters above bars reflects statistical significance at P > 0.05.

Mean hooking depth of Alligator Gar caught using juglines was 247 mm (range = 218.1 – 275.9 mm). The mean hooking depth resulting in Alligator Gar mortality (270 mm, range = 244.5 – 295.5 mm) differed significantly ($t = 4.3$, df = 72, $P < 0.01$) from the mean hooking depth of Alligator Gar that survived (125 mm, range = 29.5 – 220.5 mm). Additionally, a significant difference was detected between hooking depths among anatomical hooking locations ($F_{3, 70} = 75.647$, $P < 0.01$; Figure 4a), particularly for Alligator Gar hooked in the stomach. No difference in hooking depth was detected for Alligator Gar hooked externally or in the mouth.

Rod and reel

A total of 16 Alligator Gar were caught using rod and reel during May 2019. Water temperature of the TNFH ponds ranged from 19.7ºC to 22.3ºC. Alligator Gar ranged from 1,168 to 2,215 mm TL (Figure 1b). Of the 16 Alligator Gar caught using rod and reel angling, only one died (mean mortality rate = 6.3%) over the 268-d post-release observation period. The mean hooking depth of Alligator Gar that survived the catch-and-release process was 101 mm (range = 55.2 -146.8 mm). No control fish died during the 268-d post-release observation period. The proportion of Alligator Gar that survived catch-and-release angling did not significantly differ from the proportion of control fish remaining at the end of the study period ($X^2 = 0.065$, df = 1, $P = 0.79$).

The majority of rod-and-reel-caught Alligator Gar were hooked in the mouth (75%), followed by esophagus (12.5%) and stomach (12.5%; Figure 5a). No Alligator Gar were hooked

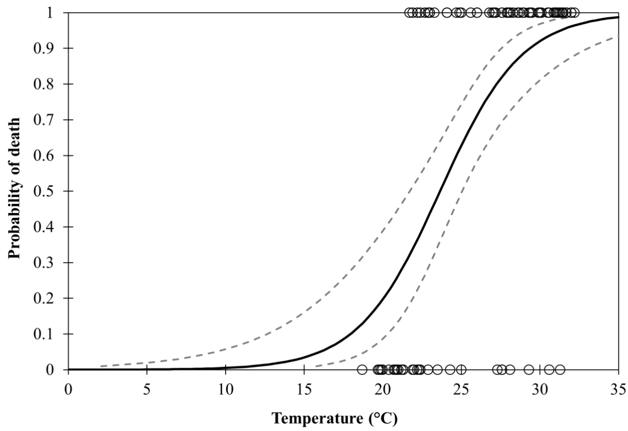

Figure 6. Logistic regression curve displaying relationship between temperature (°C) and fate (mortality or survival) of Alligator Gar following catch-and-release angling. Grey dashed lines represent the 95% confidence intervals.

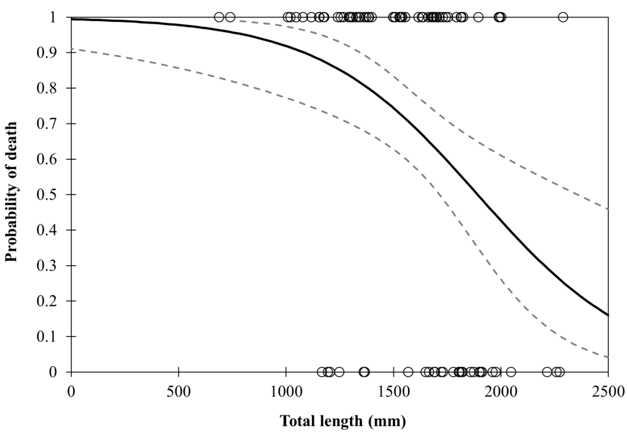

Figure 7. Logistic regression curve displaying relationship between total length (mm) and fate (mortality or survival) of Alligator Gar following catch-and-release angling. Grey dashed lines represent the 95% confidence intervals.

externally. Mortality associated with hooking location varied and was significantly different ($X^2 = 6.971$, df = 2, $P = 0.03$). Mortality rate of stomach-hooked Alligator Gar was significantly different than the morality rate of fish hooked in the esophagus and mouth (Figure 5b). The one Alligator Gar that died from hooking-related injuries was caught in the stomach at a depth of 267 mm. Additionally, a significant difference was detected between hooking depth and anatomical hooking location ($F_{2, 13} = 22.189$, $P < 0.01$; Figure 4b). Alligator Gar hooking depth for stomach- and esophagus-hooked fish were not significantly different, but differed from fish hooked in the mouth.

Comparison between gears

The logistic regression model indicated that temperature, total length and hooking depth (% of TL) significantly affected survival of Alligator Gar, but gear type (rod-and-reel or juglines) did not (Table 2). Mortality occurred more frequently at higher temperatures (Figure 6), with shorter Alligator Gar (mm TL; Figure 7), and greater hooking depths (% of TL; Figure 8). For every 1°C increase in water temperature, mortality was 1.23 times more likely (odds ratio 1.227). For every 1 mm increase in total length, Alligator Gar mortality decreased by one percent (odds ratio .0994). Hooking depth (% of TL) had the greatest effect on fate of

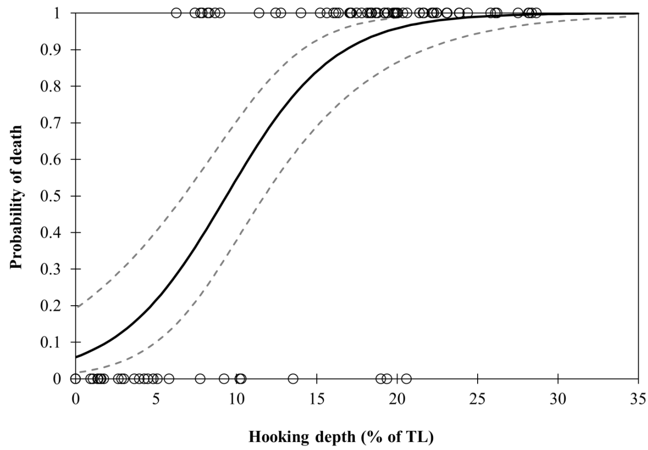

Figure 8. Logistic regression curve displaying relationship between hooking depth and fate (mortality or survival) of Alligator Gar following catch-and-release angling. Grey dashed lines represent the 95% confidence intervals.

caught-and-released Allgator Gar, which were 1.57 times more likely to die for every one percent increase in hooking depth (odds ratio 1.570). For example, the probability of death increases to ≥50% when hooking depth is ≥10% of Alligator Gar TL. When hooking depth is ≥30% of Alligator Gar TL mortality is 100%. The logistic regression line never reaches a probability of death equaling 0% for total length and hooking depth (% of TL), indicating that low rates of fish mortality are possible regardless of total length or hooking depth.

Discussion

Our results suggest that catch-and-release mortality rates of Alligator Gar can be very high, but depends upon hooking depth (% of TL), hooking location, total length of fish and water temperature. We found that hooking mortality associated with juglines (81%) was substantially higher than with rod and reel (6%), and appeared to be a function of hooking depth (hooking depth = 16.4% of TL for juglines vs. 5.5% of TL for rod and reel). Although both are passive angling approaches, there are differences between these methods that may explain the disparities in observed mortality rates. Juglines were set overnight, whereas rod and reel angling occurred over a shorter duration and employed a more immediate hook set. Bartholomew and Bohnsack (2005) found that passive fishing approaches, such as juglines, results in higher morality than active fishing methods (rod and reel with lure). While fishing with rod and reel, we allowed Alligator Gar to pick up the bait, swim until they stopped to orient the bait in their mouth, and the hook was set when the fish began swimming again. The longer duration that juglines are fished compared to rod and reel may explain why the majority (86%) of Alligator Gar caught with this gear were hooked in the esophagus or stomach (more time to consume and digest the bait). However, the majority of Alligator Gar caught using rod and reel were hooked in the mouth (75%). Differences in hooking locations, and associated hooking depths, have been observed to influence mortality rates.

The anatomical location of a hooking wound is often determined by bait type and the manner in which the bait is ingested (Muoneke and Childress 1994, Tomcko 1997, Bartholomew and Bohnsack 2005). Fishing with natural baits increases the risk of deep hooking, because fish voluntarily ingest the bait (Daugherty and Bennett 2019). Alligator Gar anglers use natural baits (cut or whole fish) when fishing with juglines or rod and reel, which we found can result in deep hooking and increased mortality rates. Similarly, Wilde et al. (2000) found

Striped Bass (*Morone saxatilis*) caught with live bait were more likely to be deep hooked, which resulted in increased mortality. Payer et al. (1989) compared mortality rates of Walleyes (*Sander vitreus*) caught using different bait types and found artificial lures tended to catch fish in the mouth and resulted in low mortality, whereas fish caught with natural baits were hooked deeper (esophagus or stomach) and had higher mortality rates. In Northern Pike (*Esox lucius*), Tomcko (1997) found when fish consumed natural baits they were generally hooked deeply, and that these wounds inflicted internal damage that resulted in greater hooking mortality. In this study, Alligator Gar mortality was high (particularly for jugline-caught fish) when hooked in the esophagus or stomach, and the proximity of these hooking injuries to vital organs likely resulted in the high observed mortality rates.

During necropsies of deceased Alligator Gar, we observed that fish hooked in the esophagus or stomach often had lacerations or punctures to adjacent organs. Reeves and Bruesewitz (2007) documented high mortality rates of Walleye when deep hooking wounds resulted in damage to major internal organs. Similarly, Loftus et al (1988) reported high mortality rates (71.4%) of Lake Trout (*Salvelinus namaycush*) when hooking wounds affected vital organs. Alligator Gar hooked in the esophagus often experienced injuries to the heart or surrounding vasculature and those hooked in the stomach often sustained injuries to the swim bladder and liver. In cases where the liver was affected, the hepatic vein and other vasculature was typically lacerated. Injuries to the heart or liver vasculature resulted in rapid mortality, often occurring within 24 h, which has been documented for numerous fish species when suffering similar injuries (Muoneke and Childress 1994).

Mortality of Alligator Gar was considerably slower when they suffered lacerations to the swim bladder. Difference in time to death between these injuries is likely due to the mechanism causing death (hemorrhaging vs. drowning). We observed Alligator Gar with lacerated swim bladders struggling to maintain buoyancy and equilibrium, and these fish were usually unable to rise to the water surface to breathe. The effects of swim bladder injuries may be intensified at higher water temperatures, as Alligator Gar become obligate air breathers with increasing water temperature (Rahn et al. 1971). When water temperatures warm (> 22°C), Alligator Gar transition to almost exclusively breathing atmospheric oxygen by consuming air at the water surface, which is processed by a highly vascularized swim bladder (Rahn et al. 1971). When fish were able to surface for air, consumed air appeared to enter the peritoneal cavity and was released through the vent or mouth without being processed. Upon dissection, we also determined that the peritoneal cavity of these fish was filled with water. The combination of these factors likely resulted in the fish drowning, which occurred more often when higher water temperatures increased the need for Alligator Gar to surface breathe. This likely explains why mortality rates increased with increasing water temperature in this study.

The relationship between water temperature and hooking mortality rates has been well described for other fish species (Muoneke and Childress, 1994; Bartholomew and Bohnsack 2005). For example, Titus and Vanicek (1988) reported that hooking mortality of Cutthroat Trout (*Oncorhynchus clarkia*) was low (2%) when water temperatures were cool (< 17°C), but increased dramatically (49%) when water temperatures were warmer (~21°C). Similarly, hooking mortality of cool water species (tiger muskellunge [*Esox lucius* × *E. masquinongy*] and Walleye) increases with warmer water temperatures (Newman and Storck 1986, Fielder and Johnson 1994, Reeves and Bruesewitz 2007). Further, seasonal effects on hooking morality (higher mortality rates in summer than winter because of higher water temperature) has been described for several warm water species (Striped Bass; Hysmith et al. 1994, Bettoli and Osborne 1998 and Blue Catfish and Flathead Catfish [*Pylodictis olivaris*]; Muoneke 1993, Schmitt and Shoup 2013). Our finding that warmer water temperatures resulted in higher mortality rates is concerning, because these angling techniques are typically conducted during summer months when water temperatures are the highest.

We found that mortality decreased with increasing size of Alligator Gar in this study. Previous studies evaluating hooking mortality of large-bodied fish have determined that handling times increase with increasing fish size, which results in higher angling mortality rates (Weithman and Anderson 1976, Muoneke and Childress 1994, Bartholomew and Bohnsack 2005). Because of their large size, we secured a rope around the body of Alligator Gar (usually behind the pectoral fins) following capture to aid in lifting the fish onto the boat (similar to methods used by anglers). Once on the deck of the boat, the weight of the fish may press on the hook or hooking wound, causing additional injuries. The combination of the rope constriction and body weight of the fish applying pressure on the hook inside of the fish may have contributed to the high mortality rates we observed for Alligator Gar caught on juglines. Additionally, Alligator Gar caught on juglines could have been hooked for up to 12-h depending when the bait was taken, and these fish required longer handling times (compared to those caught on rod and reel). Both stressors could have affected hooking mortality rates. Although not tested, it appears that handling stress could be reduced if Alligator Gar were not removed from the water, which could reduce mortality rates.

This study is the first to provide information regarding hooking mortality rates and associated factors affecting mortality of Alligator Gar, resulting in important management implications for this species. The mortality rates of jugline-caught Alligator Gar that we observed is concerning. Therefore, biologists tasked with managing recreationally exploited Alligator Gar populations should evaluate the potential population-level effects of high fishing mortality rates associated with juglines. Additionally, fisheries managers using juglines to sample Alligator Gar populations should consider alternate sampling methods, because mortality associated with this technique may be unacceptably high and could bias study results. For example, if estimating population size of Alligator Gar with juglines and tagged fish die due to high catch and release mortality rates, the population estimate could be artificially high since fewer tagged fish can be recaptured. It is difficult for us to make decisions about rod and reel angling based on the limited results of this study. While this study is an important first step to understand mortality associated with rod and reel angling, it was conducted in ponds using a small number of fish. We limited the number of fish used in this study due to the high mortality rates observed using juglines and because Alligator Gar are a species of concern in Oklahoma as a result of their limited range. Future rod and reel studies should be applied to wild Alligator Gar populations and consider the many variables that may affect catch-and-release mortality (bait type, fight time, fish size, handling methods and time, terminal tackle, and water temperature). Based on our results, fisheries managers should evaluate the potential effects of catch-and-release angling (juglines and rod and reel) on Alligator Gar populations in other states, as this species is sensitive in many areas of the native range.

Acknowledgments

We thank J. Bartinicki, M. Lyons, M. Waters and S. Jeter for assistance with field work. We thank K. Graves and staff at Tishomingo National Fish Hatchery for assistance with transporting and holding Alligator Gar. We thank Dr. Gary Wellborn and the OU Biological Station staff for allowing the use of their grounds and assistance with setup of holding pools. We thank K. Kuklinski (ODWC) and three anonymous reviewers from Texas Parks and Wildlife Department for reviewing an earlier draft of this manuscript. We thank Dr. D. Shoup (Oklahoma State University) and Dr. J. Long (Oklahoma State University) for statistical guidance and reviewing an earlier draft of this manuscript. Financial support was provided by U.S. Fish and Wildlife Service, Sportfish Restoration Grant F-86-D-1, F-50-R-25, and F-112-D-1 to the Oklahoma Department of Wildlife Conservation.

References

Adams, K. M., A. T. Taylor, R. A. Snow, and M. J. Porta. 2019. #GARWEEK: Insights from a social media outreach campaign about Alligator Gar in Oklahoma. Proceedings of the Oklahoma Academy of Science 99:31-40.

Bartholomew, A., and J. A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129-154.

Bettoli, P. W., and R. S. Osborne. 1998. Hooking mortality and behavior of striped bass following catch and release angling. North American Journal of Fisheries Management 18:609–615.

Bodine, K. A., D. J. Daugherty, J. W. Schlechte, and G. R. Binion. 2015. A strategy for increasing gill-net catch rates and minimizing sampling mortality of Alligator Gars. North American Journal of Fisheries Management 35:611-615.

Buckmeier, D. L., N. G. Smith, J. W. Schlechte, A. M. Ferrara, and K. Kirkland. 2016. Characteristics and conservation of a trophy Alligator Gar population in the middle Trinity River, Texas. Journal of the Southeastern Association of Fish and Wildlife Agencies 3:33-38.

Buckmeier, D.L., N.G. Smith, D.J. Daugherty, and D.L. Bennett. 2017. Reproductive ecology of Alligator Gar: identification of environmental drivers of recruitment success. Journal of the Southeastern Associated of Fish and Wildlife Agencies 4:8-17.

Coggins, L. G., Jr., M. J. Catalano, M. S. Allen, W. E. Pine III, and C. J. Walters. 2007. Effects of cryptic mortality and the hidden costs of using length limits in fishery management. Fish and Fisheries 8:196-210.

Cooke, S. J., and C. D. Suski. 2005. Do we need species-specific guidelines for catch-and- release recreational angling to effectively conserve diverse fishery resources? Biodiversity Conservation 14:1195-1209.

Cooke, S. J., D. P. Philip, K. M. Dunmall, and J. F. Schreer. 2001. The influence of terminal tackle on injury, handling time, and cardiac disturbance of Rock Bass. North American Journal of Fisheries Management 21:333-342.

Daugherty, D. J., and D. L. Bennett. 2019. A review of hooking mortality associated influential factors, and angling gear restrictions, with implications for management of the Alligator Gar. Management Data Series No. 297, Texas Parks and Wildlife, Inland Fisheries Division.

Fleming, B. P., D. J. Daugherty, N. G. Smith, and R. K. Betsill. 2018. Efficacy of low cost, side-scan sonar for surveying Alligator Gars. Transactions of the American Fisheries Society 147:695-703.

Fielder, D. G., and B. A. Johnson. 1994. Walleye mortality during live-release tournaments on Lake Oahe, South Dakota. North American Journal of Fisheries Management 14:776–780.

Hühn, D., and R. Arlinghaus. 2011. Determinants of hooking mortality in freshwater recreational fisheries: a quantitative meta-analysis. American Fisheries Society Symposium 75:141-170

Hysmith, B. T., J. H. Moczygemba, and G. R. Wilde. 1988. Hooking mortality of Striped Bass in Lake Texoma, Texas-Oklahoma. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 46:413-420.

Jelks, H.L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. J. Schmitter-Soto, E. B. Taylor, and M. L. Warren, Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372-407.

Loftus, A. J., W. W. Taylor, and M. Keller. 1988. An evaluation of Lake Trout (*Salvelinus namaycush*) hooking mortality in the upper Great Lakes. Canadian Journal of Fisheries and Aquatic Science 45:1473-1479.

Muoneke, M. I. 1993. Seasonal hooking mortality of Flathead Catfish and Blue Catfish. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 45:392-398.

Muoneke, M. I., and W. M. Childress. 1994. Hooking mortality: a review for recreational fisheries. Reviews in Fisheries Science 2:123-156.

Newman, D. L., and T. W. Storck. 1986. Angler catch, growth, and hooking mortality of Tiger Muskellunge in small centrarchid-dominated impoundments. Pages 346–351 in 65 G. E. Hall, editor. Managing muskies: a treatise on the biology and propagation of muskellunge in North America. American Fisheries Society, Special Publication 15, Bethesda, Maryland.

Payer, R. D., R. B. Pierce, and D. L Pereira. 1989. Hooking mortality of Walleyes caught on live and artificial baits. North American Journal of Fisheries Management 9:188-192.

Porta, M. J., R. A. Snow, and K. G. Graves. 2019. Efficacy of spawning Alligator Gars in recreational-grade swimming pools. North American Journal of Aquaculture 81:126-129.

Rahn, H., K. B. Rahn, J. B. Howell., C. Gans, and S. M. Tenney. 1971. Air breathing of the garfish (*Lepisosteus osseus*). Respiration Physiology 11:285-307.

Reeves, K. A., and R. E. Bruesewitz. 2007. Factors influencing the hooking mortality of Walleyes caught by recreational anglers on Mille Lacs, Minnesota. North American Journal of Fisheries Management 27:443-452.

Schlechte, J. W., K. A. Bodine, D. J. Daugherty, and G. R. Binion. 2016. Size selectivity of multifilament gill nets for sampling Alligator Gar: modeling the effects on population metrics. North American Journal of Fisheries Management 36:630-638.

Schmitt, J. D., and D. E. Shoup. 2013. Delayed hooking mortality of Blue Catfish caught on juglines. North American Journal of Fisheries Management 33:245-252.

Smith, N. G., D. J. Daugherty, J. W. Schlechte, and D. L. Buckmeier. 2018. Modeling the responses of Alligator Gar populations to harvest under various length-based regulations: implications for conservation and management. Transactions of the American Fisheries Society 147:665-673.

Snow, R. A., and M. J. Porta. 2020. Seasonal Food Habits and Prey Selectivity of Alligator Gar from Texoma Reservoir, Oklahoma. Journal of the Southeastern Association of Fish and Wildlife Agencies 8:15–22

Titus, R. G., and C. D. Vanicek. 1988. Comparative hooking mortality of lure-caught Lahontan Cutthroat Trout at Heenan Lake, California. California Fish and Game 74:218-225.

Tomcko, C. M. 1997. A review of Northern Pike *Esox lucius* hooking mortality. Minnesota Department of Natural Resources Fish Management Report 32, Minneapolis.

Weithman, A.S., and R.O. Anderson. 1976. Angling vulnerability of Esocidae. Proceedings of the Annual Conference of the Southeast Association of Game and Fish Commissioners 30:99-102.

Wilde, G.R., M. I. Muoneke, P. W. Bettoli, K. L. Nelson, and B. T. Hysmith. 2000. Bait and temperature effects on Striped Bass hooking mortality in freshwater. North America Journal of Fisheries Management 20:810–815.

Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43-87 in R. A. Barhart and T. D. Roelofs, editors. National symposium on catch and release fishing. Humboldt State University, Arcata, California.

Submitted September 30, 2021 Accepted November 2, 2021