Population Dynamics of Alligator Gar in Choke Canyon Reservoir, Texas: Implications for Management

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Abstract: Historical eradication efforts, increasing fishing pressure, and growing anthropogenic impacts have resulted in decreased abundance or extirpation of the alligator gar (*Atractosteus spatula)* throughout much of its historic distribution. Current population status has prompted states to actively manage stocks; however, efforts are hindered by a lack of data necessary to make informed management decisions. To begin addressing these data needs, we investigated alligator gar population dynamics and exploitation in Choke Canyon Reservoir, Texas. A total of 754 fish (total length [TL] range, 678 to 2275 mm) was collected with multifilament gill nets from 2008 through 2013; 656 individuals collected from 2011 through 2013 were tagged and released as part of a mark-recapture study to estimate abundance and exploitation. Alligator gar age ranged from 0 to 27 yrs. Growth in length followed a typical von Bertalanffy function with greatest growth occurring through age 5, then considerably slowing among older age classes. Growth in weight, per unit length, was greatest in fish ≥1700 mm TL. Length-at-age of females was significantly greater than male length-at-age; TL of female fish was about 278 mm greater than male fish of the same age. Adult alligator gar (TL ≥1100 mm) abundance was estimated at 5437 (95% CI; 3215 to 9195) individuals, conferring a density of 0.5 (0.3 to 0.9) fish ha^{-1} at conservation pool. Annual exploitation based on tag returns was less than 3%; bowfishing tournament data indicated a bow angler harvest rate of 0.01–0.02 fish angler $hour^{-1}$. Results of our study provide important information for the management of alligator gar populations in Texas and throughout its distribution.

Key words: Atractosteus spatula, abundance, exploitation, age structure, growth

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The alligator gar (*Atractosteus spatula)* is among North America's most ancient, distinctive, and historically disliked fishes (Scarnecchia 1992). Recreational anglers have long viewed alligator gar as direct competitors for preferred game fishes, and commercial fishers considered their large body size, bony scales, and prominent teeth significant threats to fishing gears (O'Connell et al. 2007). The unfavorable opinions of anglers were historically shared by fisheries managers, and efforts to eradicate gars (Lepisosteidae) were undertaken for a century or more (Scarnecchia 1992). The success of these removal efforts, coupled with increased loss of critical habitat in aquatic systems, resulted in decreased abundance or extirpation of alligator gar throughout much of its native range (e.g., Gilbert 1992, Etnier and Starnes 1993, Ross et al. 2001). Damming of rivers and riparian development reduced the availability of vegetated, littoral habitats believed to provide suitable spawning areas (Pringle et al. 2000, O'Connell et al. 2007). Currently, of the 14 states known to historically support populations of alligator gar, the species is considered extremely rare or extirpated from six (Jelks et al. 2008). Abundance of alligator gar in Florida is declining, and population status in the remaining seven states is currently unknown. As a result, the American Fisheries Society (AFS) recently identified the alligator gar as "vulnerable" (Jelks et al. 2008).

In contrast to the historic aversion toward alligator gar, attitudes and opinions have changed in recent decades. Their large body size, predatory nature, and distinctive characteristics have become desirable trophy attributes (Scarnecchia 1992), and hook-and-line and bow fishing for alligator gar have become popular (Ross et al. 2001). Increased interest in alligator gar angling, as well as support for maintaining biodiversity in aquatic ecosystems (O'Connell et al. 2007), have resulted in efforts to actively manage alligator gar populations. Seven states have imposed fishing regulations that restrict or prohibit harvest.

Despite increased interest in managing alligator gar populations, fisheries managers know relatively little about population dynamics and biology of this species compared to other fishes. While current regulations are based on the best available science, data needed to properly manage the species are lacking. Information on population dynamics, life history, and exploitation is needed to better manage alligator gar stocks. Therefore, we began to address these data needs in Choke Canyon Reservoir, Texas. Our objectives were to: 1) estimate adult abundance, 2) quantify exploitation, and 3) describe age structure, size structure, and length-weight relationships. The results of our study will provide important information for the management of alligator gar populations in Texas and throughout its distribution.

Methods

Study Site

Choke Canyon Reservoir is a 10,517-ha impoundment of the Frio River located in McMullen and Live Oak counties, Texas. The reservoir was created in 1982 to provide water storage and recreational opportunities. Maximum depth of the reservoir is about 29 m, with annual water-level fluctuations ranging from 3 to 4.5 m (Texas Parks and Wildlife Department [TPWD], unpublished data). The reservoir supports fisheries for largemouth bass (*Micropterus salmoides*) and catfishes (Ictaluridae), and is a popular destination among bow anglers. Alligator gar are currently managed with a one-fish daily bag in all Texas waters.

Fish Collections

We used multifilament gill nets to collect alligator gar annually during April through August from 2008 through 2013. Gill nets were 61-m long, 3-m deep, and constructed of 19-mm foam-core float line, #21 black-twine mesh, and a 9-kg lead line. Typically, one to three individual nets with bar-mesh sizes ranging from 89 to 128 mm were deployed about each sampling site. Sampling sites ranged in depth from 2 to 4 m, and were concentrated in tributary arms, on main-lake coves, and on main-lake flats, primarily in the upper half of the reservoir. All sampling sites were subjectively selected and concentrated in areas where alligator gar surface activity was observed. One or two additional nets with bar-mesh sizes of 140 and 152 mm were also set when catch rates were low (e.g., <1 fish h^{-1}) in attempt to increase catch. Each net was fished so that the float line remained visible on the water surface with four to five buoy-style PVC floats attached. Alligator gar entangled in the nets commonly submersed the float line or floats, facilitating visual observation of fish capture. Gill nets were monitored continuously to allow for rapid removal, processing, and release (if applicable) of captured fish.

Upon indication of capture, the net was lifted, fish were removed, and the net reset. Fish collections from 2008 through 2010 occurred with minimal fishing effort as alligator gar were collected solely for age and growth analysis; fish were measured for total length (TL), weighed (kg), sacrificed, and sagittal otoliths extracted. Fish collected during 2011 through 2013 were tagged with an external T-bar anchor tag (model FD-94; Floy Tag, Seattle, Washington) at the lateral base of the dorsal fin and a passive integrated transponder (PIT; model HPT9; Biomark, Boise, Idaho) at the posterior base of the dorsal fin, measured (TL), and scanned for previous marks. To facilitate angler reporting of tagged fish, T-bar tags included TPWD contact information. Weight was also recorded for a subsample of fish (up to 10 per 100-mm TL group) using a 100-kg digital scale. To minimize the potential for immediate recapture, fish were transported approximately 200 m away from the sampling site following processing and released. Incidental alligator gar mortalities were recorded, measured (TL), and otoliths extracted for age and growth analyses. Gender of sacrificed fish and incidental mortalities was recorded based on internal examination of the gonads as described by Ferrara and Irwin (2001).

Data Analyses

Population Abundance. Adult alligator gar abundance was estimated using the POPAN formulation (Schwarz and Arnason 1996) of the Jolly-Seber model in Program MARK (Cooch and White 2014). We used Jolly-Seber because the data best met the assumptions of an open population model (i.e., the population was demographically open during the study period). We considered each year of the mark-recapture study a sampling occasion ($n = 3$). We limited our inference to the adult population given the gill-net mesh sizes used selected for fish ≥1100 mm (Figure 1), which corresponds to the TL at the onset of reproductive maturity (Ferrara 2001). The abundance estimate was then used to estimate fish density, expressed as the population estimate divided by the reservoir surface area at full pool. Annual mean catch-per-unit-effort (CPUE; fish h-1) was calculated in 2011–2013 using the mean of

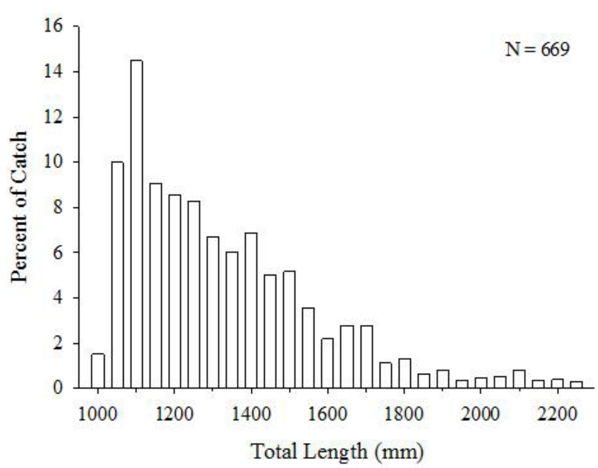

Figure 1. Total length distribution of alligator gar collected in Choke Canyon Reservoir, Texas, adjusted for gear selectivity.

the ratios approach (Pollock et al. 1994). Fishing effort was not recorded in years 2008–2010.

Exploitation. Voluntary angler tag return data was used to calculate annual exploitation rates by dividing the number of tags returned by the total number of tagged fish at large. We assumed tag loss to be negligible (Buckmeier and Reeves 2012). Annual estimates were adjusted for observed handling mortality (<3% annually). Because tag reporting rates were unknown, we estimated exploitation over a range of possible tag reporting rates consistent with the literature (i.e. 20 to 80%; Miranda et al 2002, Meyer et al. 2012). To facilitate voluntary reporting of tagged alligator gar catches, notices were placed at all boat access points and in local and online media.

Alligator gar harvest data during nighttime bowfishing tournaments provided a means to estimate maximum harvest rates, per unit effort, by bowfishers. We attended all known bowfishing tournaments held at Choke Canyon Reservoir during the study period and recorded the number of participants, tournament length (h), and number of alligator gar harvested. Otoliths of harvested fish were also collected to increase sample sizes for age and growth analyses. We estimated bowfishing harvest rates by dividing the total number of alligator gar harvested by the total effort for each tournament.

Age and Growth. Otoliths were processed and aged as described by Buckmeier et al. (2012). Age was assigned for each fish independently by two readers without knowledge of fish TL; disagreements between readers were reconciled with a subsequent concert read. Total length and age-at-capture data were used to construct a von Bertalanffy growth model for the population. Differences in TL-at-age among male and female fish were assessed using Analysis of Covariance (ANCOVA) with gender as the covariate. Gender specific TL-at-age data was truncated to include only the age class range for which TL-at-age data for both male and female fish existed. We also included the interaction of sex and age in the model to test for differences in regression slopes between the sexes. We further described alligator gar growth as a function of weight, expressed as the standard weight-length power function (Pope and Kruse 2007). All statistical analyses were conducted using SAS Enterprise Guide 4.3 (SAS Institute 2014) and considered significant at $P \leq 0.05$. To obtain an accurate size composition, alligator gar size structure data were corrected for size-related gear biases according to methods described by Millar and Fryer (1999).

Results

A total of 754 alligator gar (total length [TL] range, 678 to 2275 mm; Figure 1) were collected during the study period. From 2011 through 2013, 656 fish were tagged and released as part of the mark-recapture study. Age and growth analyses were conducted for a total of 98 fish. Gender could only be determined for 59 of the aged individuals (non-sexed individuals recorded as immature or indeterminate). The female to male sex ratio was 1:4% (12 females, 47 males).

Sixteen previously marked individuals were recaptured during the study, conferring a population estimate of 5437 (95% confidence limits = 3215 to 9195) individuals. All recaptured individuals had retained both the T-bar anchor and PIT tags. Adult alligator gar density was estimated at 0.5 fish ha^{-1} at conservation pool (95% CI, 0.3 to 0.9 fish ha^{-1}). Catch-per-unit-effort of alligator gar varied (range: 0.73 – 4.93 fish $hour^{-1}$) by year and increased over the study period (Table 1).

A total of five tagged fish were reported by anglers during the study period. Four fish were harvested by bow anglers during July and August of 2012 and 2013, a fifth was reported caught-and-released on a jugline in May of 2012. Annual exploitation was low during the study period, varying from 0 in 2011 to as high as 2.3% (95% CI, 1.4% to 3.2%) in 2013, assuming a non-reporting rate of 20% (Figure 2). Two night bowfishing tournaments were held at Choke Canyon Reservoir during April and June of 2011. In each tournament, 2 alligator gar were harvested (TL range, 490 to 670 mm) at rates of 0.01 and 0.02 fish angler $hour^{-1}$, respectively.

Alligator gar ages ranged from 0 (i.e., young-of-year) to 27 years (Figure 3). The von Bertalanffy growth model indicated rapid growth in length through age-5 with growth slowing significantly after that (Figure 3). Sex-specific, TL-at-age data was available for both male and female fish 9 year of age and older. Total length-at-age significantly differed between male and female fish (ANCOVA; $F = 190.84$, df = 1, $P < 0.0001$). Intercept values indicated that TL of female fish was about 278 mm greater than male fish of the same age. The interaction term was not significant ($F = 0.76$, df = 1,

Table 1. Total catch, effort (h), and mean CPUE (fish h^{-1}) of alligator gar collected from 2008–2013. Catch-per-unit-effort was calculated using the mean of the ratios approach. Standard deviation in parenthesis.

Year	Total catch	Total effort	Mean CPUE
2008	1		
2009	23		
2010	48		
2011	178	771	0.73 (2.3)
2012	293	408	2.68 (8.1)
2013	211	105	4.93 (11.9)

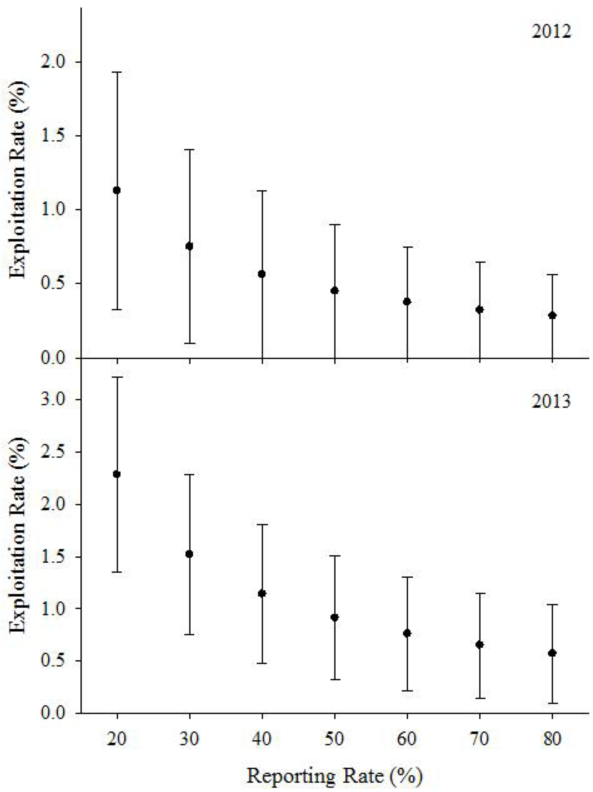

Figure 2. Annual exploitation estimates of alligator gar in Choke Canyon Reservoir, Texas, during 2012 and 2013. Error bars represent 95% confidence limits.

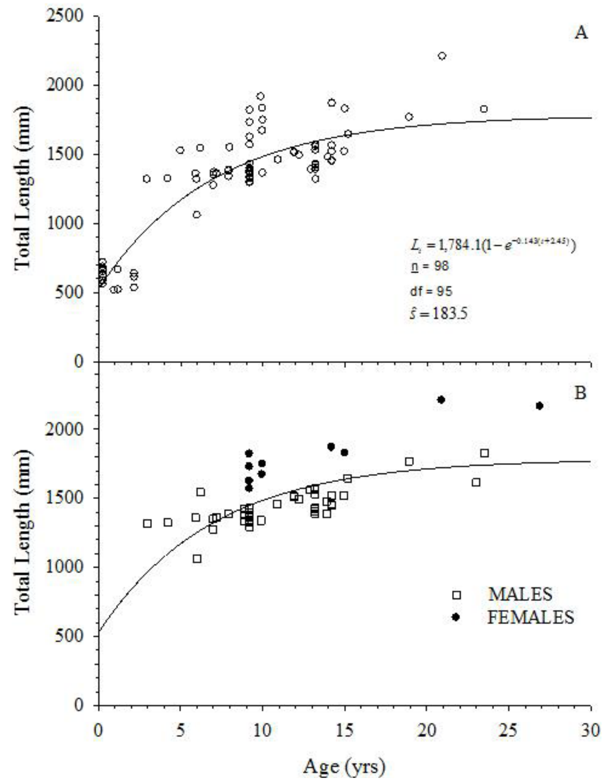

Figure 3. Length-at-age and fitted von Bertalanffy growth equation (t = age in years; L^t = total length at age t; Panel A) and gender specific length-at-age (Panel B) for alligator gar in Choke Canyon Reservoir, Texas.

$P = 0.3887$), indicating no difference in the rate of growth between male and female fish over the age range examined. The weight-length relationship was significant ($r^2 = 0.99$, $P < 0.0001$); growth in weight, per unit length, was greatest in fish over 1700 mm TL.

Discussion

Previous studies have used gill nets to collect alligator gar (e.g., Ferrara 2001, García de León et al. 2001, Brinkman 2003, O'Connell et al. 2007); however, differences in net specifications, sampling methods, and data reporting confounded our ability to make meaningful comparisons of catch rates among systems. For example, O'Connell et al. (2007) used gill nets (specifications undisclosed) at fixed sampling stations to collect alligator gar in Lake Pontchartrain, Louisiana, and reported catch rates as fish year^{-1}. Ferrara (2001) and Brinkman (2003) used multifilament gill nets with 64-, 76-, and 127-mm bar mesh, which differed from those employed in our study. García de León et al. (2001) reported gill-net catches of alligator gar in Vicente Guerrero Reservoir, Mexico, as fish day^{-1}. Passive gears, such as gill nets, must be set in areas where target fish are located, fish must encounter the net, and be of a body size vulnerable to entanglement (Holt 1957, Hubert et al. 2012); all of these factors are affected by sampling design and gear specifications. Although gill nets appear to provide an efficient means to collect alligator gar, standardization of gear types, sampling methodologies, and reporting metrics among studies are critical for future comparisons among systems.

Annual exploitation of alligator gar in Choke Canyon Reservoir was low and similar to rates in the upper Trinity River, Texas, in 2008 and 2009 (2.8% and 3.7%, respectively; TPWD, unpublished data). Our highest estimate of exploitation in 2013 (3.2%, upper 95th percentile based on reporting response rate of 20%) was below current TPWD management objectives (<5%) and recommended target levels of exploitation (<10%) for other fishes with life histories similar to alligator gar (Walters and Pearse 1996, Codling et al. 2005). The length-frequency distribution of alligator gar in Choke Canyon Reservoir provided additional evidence for low exploitation, as well as the potential for trophy management. Ferrara (2001) estimated the mean TL of the alligator gar population to be 1518 mm in the Mobile-Tensaw Delta, Alabama, which was greater than populations in Lake Pontchartrain (1239 mm) and the Sabine National Wildlife Refuge, Louisiana (SNWR; 1241 mm). The author suggested that these contrasting size structures may have been due to higher exploitation of alligator gar in Lake Pontchartrain and the SNRW. Mean TL of alligator gar in Choke Canyon Reservoir (1535 mm) was comparable to that reported for the Mobile-Tensaw Delta population of alligator gar, suggesting similar fishery characteristics in Choke Canyon Reservoir. Gabelhouse (1984) recommended relative stock density trophy (RSD-T) values of up to 5% when trophy-sized fish are desired. In addition, alligator gar 1800 mm TL and greater, considered by most anglers to represent trophy size classes (TPWD, unpublished data), comprised about 5% of our sample. Our exploitation estimates, coupled with the size structure data, suggest that current exploitation of alligator gar in Choke Canyon Reservoir is likely low enough to sustain a trophy fishery, if that management objective is desired.

Documented catch and harvest occurred only during spring and summer months (i.e., May through August), periods when alligator gar may be most vulnerable to angler catch or exploitation. Spawning alligator gar are known to congregate during spring and early summer in shallow, littoral areas associated with vegetation (Mendoza Alfaro et al. 2008), and can become highly abundant in specific areas for extended periods of time (Scarnecchia 1992). This behavior, coupled with increased activity and aerial breathing during warm-water periods (Winston 1967, Saksena 1975), suggests the potential for increased visibility to anglers and potentially greater catch rates during these periods. Further research is needed to quantify seasonal trends in alligator gar angler catch and harvest.

Harvest rates of alligator gar during bow tournaments on Choke Canyon Reservoir in 2011 indicated that the average bow angler may harvest one alligator gar for every 50 to 100 hours of effort. Bennett and Bonds (2012) reported similar bowfishing harvest rates in the Trinity River, Texas (range, 0.016–0.023 per angler hour; $n = 9$). Nighttime bowfishing tournament harvest rates likely represent maximum rates as tournament results are commonly based on the number, size, and diversity of fish harvested. Therefore, non-tournament harvest of alligator gar is likely to be lower. These results, coupled with the low exploitation observed during our study, suggest that bowfishing likely has little population-level impact on alligator gar at current participation rates. Additional information characterizing both tournament and non-tournament angling effort, as well as trends in popularity of the sport, are needed for objective-based management of stocks.

Growth in length of fishes is commonly known to decline with age, whereas growth in weight commonly increases. Rapid growth in length among early life-history stages improves survival by both reducing vulnerability to predators and increasing the diversity of available prey (Wootton 1998). Reduced growth in length of alligator gar in our study was observed as fish reached about 1100 mm, which corresponds to the TL associated with the onset of reproductive maturity (Ferrara 2001). Growth in weight was greatest among older, larger age classes, particularly as fish approached trophy sizes. Although sample sizes were limited, our data suggested sex-specific differences in growth metrics for alligator gar; females were consistently larger than males. Ferrara (2001) reported similar sex-specific differences in growth. These results suggest potential for increased vulnerability of female fish to harvest when compared to males, especially during the spawning season when females are in the shallow, littoral areas of a reservoir.

In addition to sex-specific differences in growth, our results indicated a population dominated by male fish. It is unknown whether our observation is a natural occurrence in the population or the result of differential mortality among the sexes, gender-specific habitat use, or sample bias. Ferrara (2001) reported sex ratios of three alligator gar populations did not significantly differ from 1:1; however, male dominated populations have been reported for lepisosteids (e.g., Tyler and Granger 1984, Johnson and Noltie 1997, Ferrrara 2001). Hoenig and Hewitt (2005) attributed reduced female to male sex ratios to differential mortality experienced by female lumpfish (*Cyclopterus lumpus*) in a commercially exploited population off the Newfoundland Coast. Faster growth and greater maximum size of female alligator gar may result in selection for female fish in recreational fisheries. While these results should be viewed with caution due to limited sample size, disproportionate mortality experienced by female alligator gar could have significant effects on population reproductive capacity; assumptions of proportional abundance between the sexes in population models may underestimate simulated effects. Future studies of alligator gar should consider the collection of gender data to further understand the relative abundance of male and female fish in populations.

The application and use of age-length keys allow fisheries managers to utilize a sub-sample of aged individuals to estimate age distribution by assigning ages to fish in a specified length interval (Ketchen 1949, Isermann and Knight 2005); which can be further used to construct age-specific models of mortality and survivorship (Isely and Grabowski 2007). However, considerable variability in length about age could bias estimates of age composition limiting the utility of this approach. We observed considerable variability and overlap in total lengths within age-class for alligator gar during our study and felt application of an age-length key to estimate age structure and total annual mortality was inappropriate. Fisheries managers should consider variation in lengths within age-classes when applying use of age-length keys for age composition and mortality estimation.

Our results provide the first published estimates of population abundance and exploitation of alligator gar. These data will facilitate the ability of managers to make inter-population comparisons and help define the current population status of alligator gar. Additional research is needed to fill knowledge gaps that continue to hinder management of this species. Information on recruitment variability, life-stage specific mortality, and angler desires concerning alligator gar fisheries are required for determining appropriate management actions and fishery regulations. Data on fish movement and habitat use for all life stages are necessary to identify critical habitats and potential effects of changing hydrology on stocks. A comprehensive understanding of these factors is required in order to conserve, maintain, and enhance alligator gar populations throughout their distribution.

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