# Alligator Gar Reproduction, Growth, and Recruitment in Falcon Reservoir, Texas

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*Abstract:* Research on alligator gar (*Atractosteus spatula*) has increased during the last two decades; however, assessments of reproduction, growth, and recruitment remain limited for reservoir populations. We collected a total of 562 alligator gar from Falcon Reservoir, Texas, in 2014 and 2018 to estimate onset of maturity, fecundity, timing of spawning, and growth. Additionally, we modeled the relationship between spawning habitat availability and strong year-class occurrence. Age of maturity (50% mature) was 5.6 years for females and 1.2 years for males. Fecundity ranged from 79,518 to 530,398 and averaged 240,183 eggs per female (SE = 16,547). Timing of spawning could not be determined because minimal spawning occurred during our study years and only 2 of 191 mature females had spawned. Females grew faster and larger than males. On average, females attained 152 cm TL in 4.5 years, but it took males 9.1 years to reach this length. Females reached trophy size (≥180 cm TL) in 8.3 years on average. Six strong year-classes were produced over a 17-year period, and strong year-classes were more likely when reservoir size at the start of the spawning season and change in reservoir size over the course of the spawning season increased. Results of our study advance understanding of the species, particularly in reservoirs, and our logistic model allows for assessment of alligator gar recruitment success in Falcon Reservoir without extensive sampling effort.

*Key words: Atractosteus spatula*, maturity, fecundity, year-class strength

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Alligator gar (*Atractosteus spatula*) inhabit diverse aquatic habitats (rivers, reservoirs, and gulf coast estuaries) in the southern United States. The species was designated as "vulnerable" by the American Fisheries Society in 2008 due to declining range and population abundance (Jelks et al. 2008) and had received limited study prior to this designation. Thus, there was a shortage of information concerning alligator gar biology and population dynamics (Binion et al. 2014, Buckmeier et al. 2015). Subsequently, numerous studies were conducted that advanced knowledge about the species and led to increased protection for many populations. However, population dynamics of a species can differ across habitat types (Hayes et al. 1996) and reservoir populations of alligator have received minimal investigation. Additional study of reservoir populations is needed to evaluate for differences in biology and population dynamics across habitats and to properly manage the species.

Fecundity, onset of maturity of fishes (Smokorowski and Pratt 2007), and fish growth (Isely and Grabowski 2007) can be influenced by habitat; however, reproduction and growth measures for alligator gar are sparse. We found only one estimate of fecundity which was pooled for three estuarine populations (Ferrara 2001). Similarly, age at maturity has only been estimated for estuarine populations (Ferrara 2001, DiBenedetto 2009, Felterman 2015), and these estimates varied among locations. Alligator gar growth differs between sex (García de León et al. 2001, Binion et al. 2014, Daugherty et al. 2019), and sex-specific annual growth has been estimated for only Texas rivers (Daugherty et al. 2019) and Louisiana estuaries. We are not aware of studies that estimated fecundity, maturity, and annual growth of alligator gar in reservoirs.

Timing of spawning is important information for alligator gar management because fishing closures during spawning have been used in some states to protect against overharvest (Wegener et al. 2017). Information in the literature indicates alligator gar spawning is protracted, occurring from March (DiBenedetto 2006) to August (García de León et al. 2001). Spawning often coincides with increased spawning habitat availability due to water-level rises (Inebnit 2009, Kluender et al. 2016, Buckmeier et al. 2016, Robertson et al. 2018) and typically occurs in water less than 1.2 m deep containing recently inundated terrestrial and wetland vegetation (Buckmeier et al. 2016). Variable annual recruitment of alligator gar has been linked to availability of spawning habitat. Strong year-classes in the Trinity River and Choke Canyon Reservoir, Texas, were attributed to increases in spawning habitat availability resulting from spring and summer flood pulses (Buckmeier et al. 2016, Robertson et al. 2018). Similarly, Inebnit (2009) associated high reproductive success of alligator gar in an Arkansas river to timing and duration of flood events. Models that predict recruitment success of alligator gar would be important tools in monitoring and managing alligator gar populations (Buckmeier et al. 2016). Thus, our study objectives were to estimate timing of spawning, onset of sexual maturity, fecundity, and growth of alligator gar, and to model the relationship between recruitment and spawning habitat availability to predict year-class strength in Falcon Reservoir, Texas.

## Study Area

Falcon Reservoir is an impoundment of the Rio Grande River encompassing 33,854 ha at conservation pool elevation. The reservoir experiences substantial water-level fluctuations, averaging 5.8 m annually (International Boundary and Water Commission [IBWC], unpublished data). At low water levels, terrestrial vegetation colonizes the exposed reservoir bottom, including huisache (*Acacia farnesiana*), salt cedar (*Tamarax ramosissima*), retama (*Parkinsonia aculeate*), mesquite (*Prosopis glandulosa*), and various grasses. Inundated terrestrial vegetation creates ideal alligator gar spawning habitat (Inebnit 2009, Buckmeier et al. 2016, Robertson et al. 2018). A commercial fishery using monofilament gill nets exists on the Mexico side of the reservoir primarily targeting blue tilapia (*Oreochromis aureus)* and catfishes (Ictalurid species); however, commercial and recreational harvest of alligator gar has not been observed or known to have occurred on the Mexico side (author's observations; Texas Parks and Wildlife Department Law Enforcement, personal communication). Angler harvest of alligator gar on the Texas side of the reservoir was unregulated prior to 1 September 2009, after which it was regulated with a one-fish-daily bag limit until 1 September 2015, when a five-fish-daily bag limit was implemented to increase harvest opportunity for anglers.

## Methods

Alligator gar were collected in April, June, August, and October 2014 and in April and September 2018 using multifilament gill nets. One hundred fish were targeted for collection in each month. Fewer collections were made in 2018 because of budget and time constraints. Gill nets (61-m long and 3-m deep) were constructed of a single bar-mesh of #21 black twine, sizes 89, 102, 114, 127, 140, and 178 mm, and affixed with a 19-mm foam-core float line and a 9-kg lead line. Schlechte et al. (2016) estimated low retention (50%) of large alligator gar (>210 cm TL) in multifilament gill nets having a mesh size ≤140 mm; therefore, we employed a 178-mm mesh size net to minimize under representation of large fish in our catch. One gill net of each mesh-size (six nets) comprised a net array. Three net arrays were fished simultaneously in three different major tributary arms on the Texas-side of the reservoir for up to three 24-h periods or until 100 fish were captured each month. Gill net sites were non-random and set at biologist's discretion in water depths ranging from 2.7 to 7.6 m to maximize catch. Gill nets were fished during both night and day in 2014 but only during night in 2018 because of low catch rates during the day in 2014. Captured fish were measured (TL, cm), weighed to the nearest pound (subsequently converted to g), and examined internally to determine gender as described by Ferrara and Irwin (2001). Mean alligator gar catch rate (CPUE) in night gill net sets was computed for each collection year and month combination and were compared between collection years for similar months using one-way ANOVA (SAS Institute 2011). Size structure was compared between females and males within collection year and across collection years using Kolmogorov-Smirnov two-sample tests. All comparisons were considered significant at $P < 0.05$.

Gonads were inspected to determine maturity status (mature or immature). Females having enlarged ovaries laden with eggs were classified as non-spawned mature fish. Females having ovaries partially full of eggs with a flaccid ovarian sac were classified as spawned-mature individuals. Testes were bisected and if flow of milt occurred under slight pressure, males were considered mature. Gonads were removed, weighed (g), and the gonadosomatic index (GSI; Snyder 1983) was computed for mature fish to estimate timing of spawning. Differences in mean monthly GSI within gender were evaluated using one-way ANOVA with Tukey's multiple comparison test (SAS Institute 2011).

Fecundity was estimated for non-spawned mature females collected from a sample of fish between April and August 2014 for up to eight fish per 8-cm TL group per month. Ovaries were bagged, placed on ice, and returned to the lab for processing. Eggs were removed from four-six random locations in ovaries until total weight of subsampled eggs exceeded 20 g for each fish. The subsampled eggs were placed into individual 118-ml plastic cups containing Coca-Cola that contains 0.017% phosphoric acid for up to 48 h to loosen ovarian tissue adjoining eggs (H. Glenewinkel, Texas Parks and Wildlife Department, personal communication). Fecundity was calculated as number of eggs contained in the subsample divided by subsample weight multiplied by ovarian weight. Average number of eggs $g^{-1}$ of body weight was calculated for comparison to published estimates. The relation between fish TL and fecundity was described by regressing $\log_{10}$ fecundity against $\log_{10}$ TL. Proportion of alligator gar identified as mature was calculated for each 10 cm TL group and age by gender. Onset of sexual maturity (i.e., ≥50% of individuals mature) was estimated using probit regression (Trippel and Harvey 1991, SAS Institute 2011).

Sagittal otoliths were removed from a maximum of 10 fish per 10 cm TL group per gender in 2014 and 5 fish for each 10 cm TL group per gender in 2018 to estimate year-class (hatch year). Otoliths were prepared according to Buckmeier et al. (2012) and independently examined by three-four individuals experienced in aging alligator gar. If year-class assignments differed among individuals, otoliths were reexamined by all individuals to mutually determine year-class. Annulus formation was assumed to occur during summer months (Buckmeier et al. 2012). Fish were assigned a 1 June hatch date as alligator gar spawning has been repeatedly observed in spring and summer months (Buckmeier et al. 2016). Age was calculated as the number of years elapsed between hatch and date of capture. The relationship between TL and age by gender was described using a von Bertalanffy growth model, with data pooled for both years. A modified age-length key (age was replaced with year-class) was used to assign year-class to unaged fish (Ricker 1975).

Annual year-class strength of alligator gar was indexed using residuals of weighted-catch curves (Maceina 1997). Weighted-catch curves produce less biased estimates of instantaneous total mortality rate than unweighted catch curves (Smith et al. 2012). Residuals reliably discern very strong and very weak year-classes (Tetzlaff et al. 2011) and perform best when recruitment variation exceeds 50% for long-lived species (Catalano et al. 2009). Highly irregular recruitment has been reported for alligator gar resulting in populations dominated by few year-classes (Buckmeier et al. 2016). Thus, we assumed residual deviation in unweighted-catch curves was largely a consequence of recruitment variation. Separate unweighted-catch curves were generated for fish collected in 2014 (13 years; 1999–2011) and 2018 (17 years; 1999–2015) using the Fishery Analysis and Modeling Simulator program (Slipke and Maceina 2014). Beginning age for both was age 3, because high catch of age-3 fish in 2018 (2015 year-class) indicated that fish ≥ age 3 were fully recruited to the gear. No fish hatched before 1999 were collected in 2018 and few fish hatched prior to 1999 ($n = 7$, age range = 23–56 years) were collected in 2014. Therefore, both catch curves were truncated at the 1999 year-class to reduce bias caused by infrequent catch of older fish (Dunn et al. 2002) and to more reliably compare year-class strength among included years. Residuals were divided by corresponding $\log_e$ predicted fish number to calculate deviation between observed and predicted $\log_e$ fish number (DEV). Year-classes having DEV values exceeding 0.5 were considered strong.

We evaluated the relation between strong alligator gar year-class occurrence and spawning habitat availability using logistic regression. Due to topography, the relation between reservoir size and water-level elevation is nonlinear for Falcon Reservoir according to the reservoir controlling authority's water-level elevation-area curve (unpublished data, IBWC). A water-level increase when the reservoir is mostly full yields proportionately greater inundation (spawning habitat) than if the same increase had occurred at lower reservoir volumes. As such, reservoir size more accurately depicts spawning habitat availability than actual water-level measures. Predictor variables in our model were reservoir size increase (ha) during the alligator gar spawning season (RCH, 1 April to 31 August) and reservoir size (ha) at the beginning of the spawning season (RST, 1 April). Spawning habitat availability may be a product of past water-level increases persisting into a spawning season (Buckmeier et al. 2016). Values of RCH and RST were computed for each year from 1999 to 2015 using daily water-level records (IBWC gauge 08-4612.00) and the water-level elevation-area curve for the reservoir. We assessed goodness-of-fit and rank correlation of the logistic model using the Hosmer and Lemeshow goodness-of-fit test (HL) and the value of c, respectively (SAS Institute 2011). Due to low sample size (17 years) and only two years of collection data, an alpha of 0.10 was used in declaring significance of model fit and predictor variables.

## Results

A total of 362 alligator gar were collected in April, June, August, and October 2014 using day and night gill-net sets, and 200 alligator gar were collected in April and September 2018 when night gill-net sets were used exclusively. Night gill-net sets accounted for 316 of the 362 fish collected in 2014. Mean catch rate (CPUE) in night gill-net sets combined for April and September 2018 (4.52 fish net-night$^{-1}$; SE = 0.69; $n = 46$ net-nights) was greater than CPUE in night gill-net sets combined for April and October 2014 (1.54 fish net-night$^{-1}$; SE = 0.17; $n = 84$ net-nights; $F = 28.8$; df = 1, 128; $P < 0.0001$).

Size structure differed between females and males in 2014 ($n = 362$; $D = 0.68$; $P < 0.0001$) and 2018 ($n = 200$; $D = 0.65$; $P < 0.0001$). Females averaged 159 cm TL in 2014 and 166 cm TL in 2018 and males averaged 128 cm TL in 2014 and 132 cm TL in 2018 (Figure 1). Size structure of females differed between years ($n = 388$; $D = 0.23$; $P = 0.0002$), but size structure of males did not ($n = 174$; $D = 0.20$; $P = 0.0739$). Females composed the majority of the catch in both 2014 (71%) and 2018 (66%).

We observed few spawned females and detected no abrupt decrease in mean monthly GSI for mature females, which would be indicative of a large-scale spawning event. In 2014, only two of 97 mature females had spawned and both were collected during August. None of the 94 mature females collected in 2018 had spawned. Mean GSI for females in 2014 was 24% lower in October than April; GSI in the other two months were intermediate and similar to April and October ($F = 2.9$; df = 3, 93; $P = 0.0401$; Figure 2). Mean GSI values for males in 2014 were 54% lower in August and October compared to April and June ($F = 35.5$; df = 3, 101; $P < 0.001$). In 2018, mean GSI differed between April and September for females ($F = 9.1$; df = 1, 80; $P = 0.0034$) and males ($F = 93.7$; df = 1, 59; $P < 0.0001$); however, female mean GSI was still over 9 in September (Figure 2).

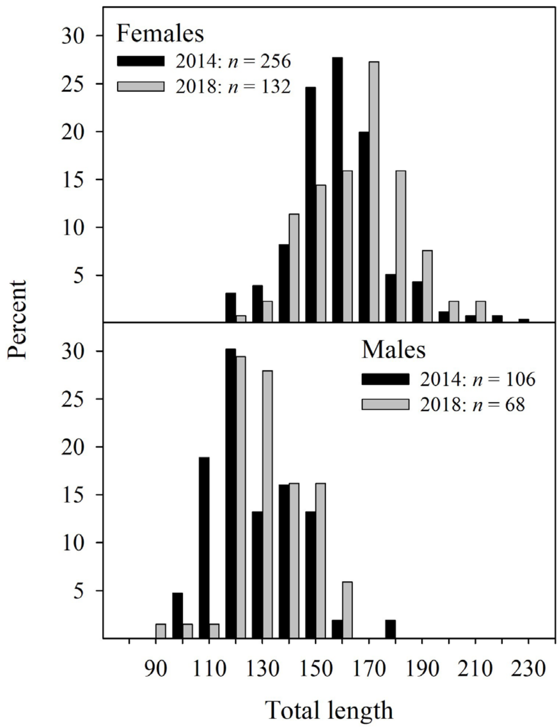


**Figure 1.** Length frequencies (10-cm groups) of female and male alligator gar collected in Falcon Reservoir, Texas, using gill nets in 2014 and 2018.

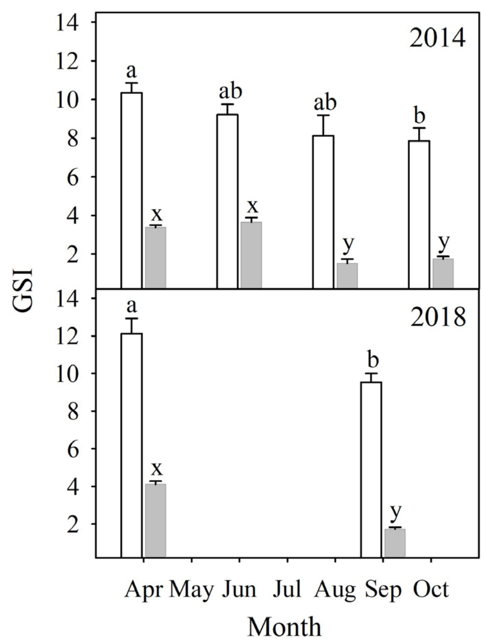


**Figure 2.** Monthly mean gonadosomatic index (GSI) with standard error bar for female (open bars) and male (shaded bars) alligator gar collected in Falcon Reservoir, Texas, in 2014 and 2018. Monthly mean GSIs having the same letter were not different.

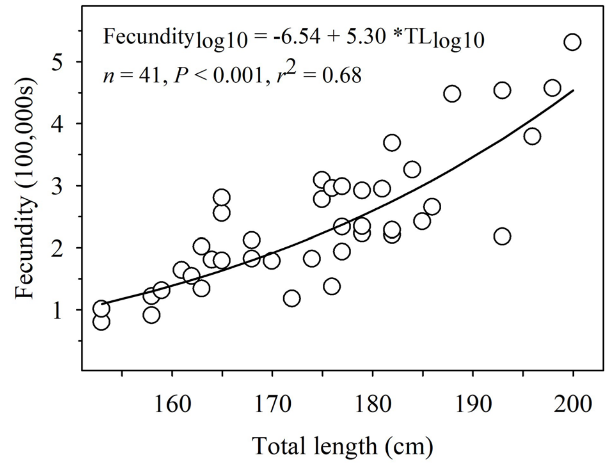


**Figure 3.** Relationship between total length (cm) and fecundity for female alligator gar collected in Falcon Reservoir, Texas, in 2014.

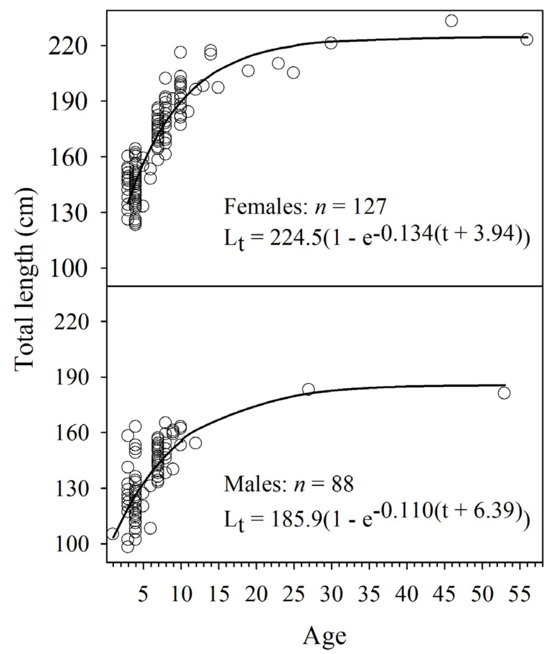


**Figure 4.** Total length at age of female and male alligator gar collected in Falcon Reservoir, Texas, in 2014 and 2018. The solid lines represent estimated total length at age based von Bertalanffy growth equations.

Fecundity was estimated for a total of 41 non-spawned mature females collected in April, June, and August 2014, ranged from 79,518 to 530,398 eggs per female, averaged 240,183 eggs per female (SE = 16,547), and was positively related to fish length (Figure 3). On average, females contained 6.2 eggs per g of body weight (SE = 0.27).

Alligator gar age estimates ranged from 3 to 56 years for females ($n = 127$ fish) and from 1 to 53 years for males ($n = 88$ fish). Females experienced faster growth and grew larger than males (Figure 4). Predicted TL was 14% greater for females than males at age 3 and

**Table 1.** Total length (TL, cm) and age (years) of maturity of alligator gar collected from Falcon Reservoir, Texas, in 2014 and 2018.

| | First mature | | 50% Mature | | 100% Mature | |
|---|---|---|---|---|---|---|
| | TL | Age | TL | Age | TL | Age |
| Females | 161 | 5 | 166 | 5.6 | 190 | 7 |
| Males | 102 | 1 | 103 | 1.2 | 140 | 5 |

**Table 2.** Number and percent total of alligator gar collected by year-class in Falcon Reservoir, Texas, in 2014 and 2018. Year-class strength was estimated using weighted catch-curves for each collection year. Catch-curve residuals were divided by corresponding $\log_e$ predicted fish number to obtain deviation (DEV) between $\log_e$ predicted and observed fish number. Strong year-classes (in parentheses) were those having DEV values >0.50 in at least one collection year. Year-classes without a DEV value were not included in catch curve analyses.

| | 2014 | | | 2018 | | |
|---|---|---|---|---|---|---|
| Year-class | *n* | % | DEV | *n* | % | DEV |
| (2015) | – | – | – | 70 | 35 | 0.9 |
| 2013 | 1 | 0.3 | – | 3 | 1.5 | −0.29 |
| 2011 | 2 | 0.6 | −0.66 | 7 | 3.5 | 0.24 |
| (2010) | 156 | 43.1 | 0.69 | 98 | 49 | 2 |
| (2009) | 11 | 3 | −0.1 | 14 | 7 | 0.95 |
| 2008 | 9 | 2.5 | −0.08 | – | – | – |
| (2007) | 141 | 39 | 1.17 | – | – | – |
| 2006 | 2 | 0.6 | −0.46 | 3 | 1.5 | 0.45 |
| (2004) | 29 | 8 | 1.17 | 3 | 1.5 | 1.06 |
| 2003 | 1 | 0.3 | −0.48 | – | – | – |
| 2002 | 1 | 0.3 | −0.37 | – | – | – |
| 2001 | 1 | 0.3 | −0.19 | – | – | – |
| (1999) | 1 | 0.3 | 0.8 | 2 | 1 | >3.0 |
| 1991 | 1 | 0.3 | – | – | – | – |
| 1989 | 1 | 0.3 | – | – | – | – |
| 1987 | 1 | 0.3 | – | – | – | – |
| 1984 | 1 | 0.3 | – | – | – | – |
| 1968 | 1 | 0.3 | – | – | – | – |
| 1961 | 1 | 0.3 | – | – | – | – |
| 1958 | 1 | 0.3 | – | – | – | – |

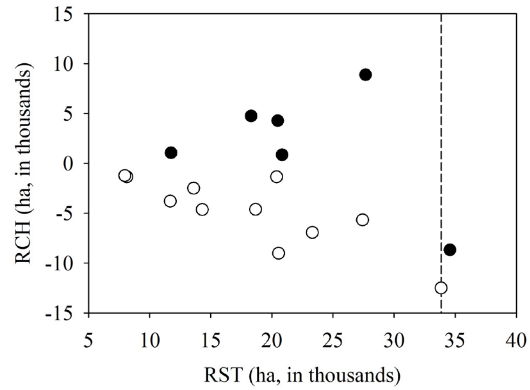


**Figure 5.** Relationship of strong (solid circles) and weak (open circles) alligator gar year-classes to reservoir size at the start of spawning season (April, RST) and change in reservoir size during the spawning season (April–August, RCH) in Falcon Reservoir. The dashed vertical line demarks reservoir size at conservation pool elevation.

22% greater for females than males at age 10 according to the von Bertalanffy models. Females attained 152 cm TL at age 4.5, whereas males attained this same TL at age 9.1. Females reached trophy size (≥180 cm TL) at age 8.3. Asymptotic average TL was 20% greater for females (225 cm TL) than males (186 cm TL).

Female alligator gar matured at a larger size and older age than males (Table 1). Onset of sexual maturity (50% of individuals mature) for females was 166 cm TL corresponding to 5.6 years, and for males was 103 cm TL corresponding to 1.2 years. All age-7 females and all age-5 males were mature. Overall, fewer females were mature than males. In 2014, 38% of females and 88% of males collected were mature, and in 2018, 71% of females and 99% males collected were mature.

Alligator gar recruitment success was sporadic and wide ranging among years. In 2014, fish from 19 year-classes were collected ranging from age 1 to 56. In 2018, fish from eight year-classes were collected ranging from age 3 to 19. The population was dominated by two year-classes in both sample years (Table 2). Fish hatched in 2007 and 2010 represented 82% of all fish collected in 2014, and fish hatched in 2010 and 2015 accounted for 85% of sampled fish in 2018. Analyses of weighted-catch curve residuals revealed six strong year-classes occurred from 1999 to 2015. These had DEV values indicative of a strong year-class (>0.5) in at least one of the sample years (Table 2). Of the year-classes available in both sample years, three had DEV values >0.5 in both sample years (2010, 2004, and 1999) while the 2007 and 2009 year-classes had strong year-class DEV values in one sample year. The most recent strong year-class was formed in 2015 (DEV = 0.95).

During strong year-class years, RST averaged 22,309 ha (range = 11,794–34,604 ha) and in other years averaged 18,214 ha (range = 8014–33,883 ha). Average RCH was 1804 ha in strong year-class years and -4922 ha in other years. Five of the six strong year-classes had positive corresponding RCH values and were produced when reservoir water-level was below conservation-pool elevation (Figure 5). The overall fit of the logistic regression model using RST and RCH as predictors of strong year-class occurrence (logit(p) = -6.38 + (0.00041*RST) + (0.00093*RCH) was significant (HL $X^2$ = 2.58; df = 1; $P$ = 0.921). Rank correlation of the model was high (c = 0.96). In the presence of one another, RST and RCH were

**Table 3.** Predicted probability of alligator gar strong year-class occurrence at combinations of RST and RCH according to the logistic model logit(p) = –6.3786 + (0.00041*RST) + 0.00093*RCH); RST is reservoir size (ha, in thousands) at the beginning of the spawning season (1 April) and RCH is the change in reservoir size (ha, in thousands) during the spawning season (1 April–31 August). Cells without values represent unrealistic reservoir size given historic minimum and maximum sizes.

| | RCH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **RST** | **–8** | **–4** | **–2** | **–1** | **0** | **1** | **2** | **4** | **8** |
| 8 | – | – | 0.01 | 0.02 | 0.04 | 0.1 | 0.23 | 0.65 | 0.99 |
| 10 | – | 0 | 0.02 | 0.04 | 0.09 | 0.21 | 0.4 | 0.81 | 0.99 |
| 12 | – | 0.01 | 0.04 | 0.09 | 0.19 | 0.37 | 0.6 | 0.91 | 1 |
| 14 | 0 | 0.01 | 0.08 | 0.18 | 0.35 | 0.58 | 0.78 | 0.96 | 1 |
| 16 | 0.01 | 0.03 | 0.16 | 0.33 | 0.55 | 0.76 | 0.89 | 0.98 | 1 |
| 18 | 0.02 | 0.06 | 0.3 | 0.53 | 0.74 | 0.88 | 0.95 | 0.99 | 1 |
| 20 | 0.04 | 0.13 | 0.5 | 0.72 | 0.86 | 0.94 | 0.98 | 1 | 1 |
| 22 | 0.09 | 0.26 | 0.69 | 0.85 | 0.94 | 0.97 | 0.99 | 1 | 1 |
| 24 | 0.02 | 0.45 | 0.84 | 0.93 | 0.97 | 0.99 | 1 | 1 | 1 |
| 26 | 0.04 | 0.65 | 0.92 | 0.97 | 0.99 | 0.99 | 1 | 1 | 1 |
| 28 | 0.09 | 0.81 | 0.96 | 0.99 | 0.99 | 1 | 1 | 1 | 1 |
| 30 | 0.19 | 0.9 | 0.98 | 0.99 | 1 | 1 | 1 | 1 | 1 |
| 32 | 0.35 | 0.96 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 |
| 34 | 0.55 | 0.98 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

significant predictors (Wald $X^2 = 2.49 – 2.71$; $P < 0.10$). Probability of a strong year-class increased as RST and RCH increased. When RST and RCH exceeded 20,000 ha and 1000 ha, respectively, probability of a strong year-class exceeded 0.90 (Table 3). Probability of a strong year-class exceeded 0.65 when RCH was larger than 4000 ha regardless of RST. Alternately, when RCH was less than –4000 ha, RST needed to exceed 26,000 ha to achieve 0.65 probability of a strong year-class.

## Discussion

Falcon Reservoir alligator gar exhibited 51% greater fecundity (6.2 eggs per g of body weight; SE = 0.27) than reported for Gulf coastal estuaries (4.1 eggs per g of body weight; Ferrara 2001). However, fecundity is not a fixed proportion of fish size, as larger females can produce disproportionately more eggs than smaller females (Hixon et al. 2014, Barneche et al. 2018). We estimated fecundity at Falcon Reservoir for females that averaged 175 cm TL; Ferrara (2001) estimated fecundity in Gulf of Mexico coastal estuaries for females that averaged 135 cm TL. Thus, the difference in fecundity estimates between these studies may be attributable to female size. Fecundity is an important parameter in determining the reproductive potential of a fish stock (Rickman et al. 2000) and small differences in fecundity can influence estimates of fish production (Welch and Foucher 1988). Our fecundity estimate should be useful in conjunction with alligator gar stock-assessment models, particularly for populations exhibiting dynamic rates similar to the Falcon Reservoir population.

Minimal alligator gar spawning occurred during our study years, and female mean GSI remained high in September and October, suggesting females retained spawning capability into the fall season. Information in the literature indicates that alligator gar spawning occurs mostly from April to June (Buckmeier et al. 2016) but can be as early as March (DiBenedetto 2009) or as late as August (García de León et al. 2001). Anecdotal observations of spawning in September and October have been reported in south Texas waterbodies by Texas bowfishing guides, lending further evidence that spawning may be plausible in later months.

In Falcon Reservoir, 50% of female alligator gar matured at 5.6 years, which was similar to the earliest age reported for other populations (range = 5 to 14 years), but males matured at an earlier age (50% mature = 1.2 years) than reported for other populations (range = 3 to 6 years; Ferrara 2001, DiBenedetto 2009, Felterman 2015). However, only DiBenedetto (2009) collected sufficient number of males younger than age 3 to reliably assess maturity of young males. Felterman (2015) determined that 98% of males (age range = 1–23 years, including two age-1 fish) collected from Louisiana estuaries were spawning capable. Length at first maturity of male alligator gar in Falcon Reservoir (103 cm TL) was similar to that reported by García de León (2001) for Vicente Guerrero Reservoir, Mexico (95 cm TL). Conversely, Falcon Reservoir females exhibited first maturity at a larger size (161 cm TL) compared to females in Vicente Guerrero Reservoir, Mexico (125 – 130 cm TL). Alligator gar attain maturity at a similar or earlier stage of life as other large, long-lived fishes occurring in the southern United States. For instance, blue catfish (*Ictalurus furcatus*) mature at age 4–7 years (summarized in Graham 1999), female American paddlefish (*Polyodon spathula*) mature at age 9–10 years (Reed et al. 1992), and female gulf sturgeon (*Acipenser oxyrhynchus desotoi*) mature at age 8–12 (Huff 1975).

Falcon Reservoir alligator gar exhibited considerable sexual dimorphism and greater maximum size for females similar to that reported for Louisiana estuaries (Felterman 2015) and Texas rivers (Daugherty et al. 2019). Further, Felterman (2015) found that growth differed between two estuary populations; females averaged 152 cm TL in 7.1 and 13.0 years and males averaged 122 cm TL in 8.9 and 12.9 years. Falcon Reservoir fish grew faster than other populations, with females averaging 152 cm in 4.5 years and males averaging 122 cm in 3.3 years. In the Guadalupe and Trinity Rivers, Texas (pooled), females attained 152 cm TL in 7.3 years and males reached 122 cm in 4.9 years (Daugherty et al. 2019). Falcon Reservoir females reached trophy size (≥180 cm TL) in 8.3 years on average. Alligator gar growth differs between sexes (Felterman

2015, Daugherty et al. 2019), among systems having similar habitat (Felterman 2015), and across habitats. Therefore, system-and sex-specific growth estimates are necessary for management of individual populations (Daugherty et al. 2019).

Gill net catch of female and male alligator gar in Falcon reservoir was disparate (2.2 females to 1 male). Faster growth and larger size of females may favor gill net collection of females over males (Daugherty et al. 2019). The array of gill net mesh-sizes we used in combination with growth and size differences between sexes likely led to the higher catch of females. Females composed 74%–100% of the catch in gill nets having a mesh size ≥114 mm, 49% of the catch in 102-mm mesh-size gill nets, and 25% of the catch in the smallest mesh-size gill nets (89 mm). Faster growth by females may necessitate more active foraging relative to males, and in turn, lead to greater vulnerability to gill net capture. Females composed 97% of individuals measuring at least 160 cm TL, but males composed 90% of individuals under 120 cm TL collected from Falcon Reservoir. In the Guadalupe and Trinity Rivers, Texas, females similarly dominated the catch of alligator gar 160 cm TL or larger (Daugherty et al. 2019). Other circumstances could possibly influence alligator gar sex ratios, including higher mortality for male alligator gar and unequal sex determination (Daugherty et al. 2019).

We found that annual recruitment of alligator gar in Falcon Reservoir was highly irregular, similar to that reported for other freshwater systems. Six strong year-classes occurred over a 17-year period (35% of years). A similar frequency of strong year-classes was reported for the Trinity River (28%) and Choke Canyon Reservoir (32%), Texas (Buckmeier et al. 2016). In our study, no fish from 3 of 15 possible year-classes (20%) were collected in 2014 ($n = 362$) and from 9 of 17 possible year-classes (53%) in 2018 ($n = 200$). Our results indicate that alligator gar spawning was minimal in 2014 and 2018 in Falcon Reservoir. Spawning habitat availability was low during our sample years (RST ≤ 19,863 ha and RCH ≤ -4703 ha), and our model predicted less than 0.05 probability of a strong year-class occurring those years. Missing year-classes is not uncommon for river and reservoir populations. In the Trinity River and Choke Canyon Reservoir, Texas, no fish were collected corresponding to 24% and 40% of 25 possible year-classes, respectively (Buckmeier et al. 2016). Sample size undoubtedly influences the number of year alligator gar classes detected, but missing year-classes combined with observation of very few spawned females during our study years suggests that alligator gar reproductive success can be nil in some years. Inconsistent annual recruitment in rivers and reservoirs could cause alligator gar abundance to fluctuate. Formation of multiple strong year-classes over a short period of time (e.g. ≥3 strong year-classes in 10 years) could increase abundance: however, lack of strong year-class formation for an extended period (>10 years) could lead to decreased alligator gar abundance.

In our study, alligator gar from the 2007 year-class composed 38% of the catch in 2014; however, no fish from this cohort were collected in 2018. Additionally, few fish >age 10 were caught during 2014 ($n = 40$; 11%) and 2018 ($n = 8$; 4%). In smaller systems, Guadalupe and Trinity Rivers, Texas, fish >age 10 composed larger fractions of the population samples (61% and 22%, respectively; Daugherty et al. 2019). The relative scarcity of older fish in our sample could be a function of sampling location, water body type, or both. We sampled in reservoir tributary arms exclusively to maximize catch; however, older, larger fish may have primarily resided in the deeper, main-stem, areas of the reservoir where gill net sampling was not conducted. Compared to reservoirs, rivers are more confined environments and more easily sampled with gill nets. Alternatively, high natural mortality, fishing mortality, or both could cause a truncated age-distribution (Hixon et al. 2014). However, low annual alligator gar harvest (<400 fish) and angling effort (<4000 h; unpublished data, Texas Parks and Wildlife Department) suggest fishing mortality has been low at Falcon Reservoir. Size-and age-specific mortality and habitat use has not been determined for the species. Collection of two very old alligator gar (>age 50) indicate that the species can be long-lived in Falcon Reservoir, similar to in other Texas waterbodies (Buckmeier et al. 2015, Daugherty et al. 2019).

Our logistic model correctly predicted strong year-class occurrence when RST was neither extremely high nor low. Predicted probability values exceeded 0.95 for four of the six strong year-class years but were 0.35 and 0.44 for the other two years. In 1999, reservoir size was very low at the start of the spawning season (RST = 11,794 ha) and increased slightly over the course of the spawning season (RCH = 1006 ha). In 2009, reservoir size was very high at start of the spawning season (34,604 ha) and decreased substantially during the spawning season (RCH = -8723 ha). Both scenarios yielded a moderate probability of strong year-class occurrence, yet strong year-classes were produced in those years. Conversely, all but one of the 11 years that were not designated as having strong year-classes had strong year-class probability values below 0.40. Thus, while not perfect, our model allows for annual and reliable assessments of alligator gar recruitment in Falcon Reservoir without having to conduct intensive field sampling efforts involving sacrifice of fish for age determination.

Harvest regulation of alligator gar in Falcon Reservoir was liberalized during this study, changing from a one-fish to a five-fish daily bag limit in 2015 to increase harvest opportunity for anglers. We did not detect negative population impacts subsequent to the daily bag limit increase; population size-structure and gill net

CPUE were improved in 2018 compared 2014. Further, creel survey sampling conducted on the Texas side of the reservoir following the daily-bag limit increase in 2016 estimated low alligator gar harvest (<400 fish) and angling effort (<4000 h; unpublished creel survey data, Texas Parks and Wildlife Department). However, recruitment variability may mask detection of harvest regulation impacts and may necessitate an extended evaluation period (Allen and Pine 2000). We recommend creel survey sampling be conducted periodically (every three-four years) to evaluate for large-scale changes in alligator gar harvest, as relatively low exploitation (5%–6.5%) may be detrimental to alligator gar populations (Buckmeier et. 2015, Smith et al. 2017). Falcon Reservoir alligator gar exhibited rapid growth, early sexual maturity, high fecundity, and frequent strong year-classes compared to other studied populations suggesting that the population could potentially withstand and recover quickly from periods of higher exploitation.

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