Length-Weight Relationships and Potential Biases for Alligator Gar (*Atractosteus spatula*) from Texoma Reservoir, Oklahoma

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Abstract: Alligator Gar (*Atractosteus* spatula) is the largest fish species found in Oklahoma, which makes obtaining field measurements (particularly weight) by fisheries managers or recreational anglers challenging. A method to overcome the logistical hurdles associated with handling and measuring large fish in the field would be beneficial to managers and anglers. Therefore, the objective of this study is to develop length-weight and length-length relationships for Alligator Gar collected from Texoma Reservoir, Oklahoma using total length (TL), standard length (SL), and girth (G) measurements to predict weights and length measurements of Alligator Gar. A total of 339 Alligator Gars averaging 1,666 mm TL (range = 590 to 2,357 mm TL) and weighing 38.2 kg (range = 0.77 to 105.3 kg) were used in this evaluation. No significant differences in weight of Alligator Gar were detected between sex or season (winter-spring and summer-fall), so all fish were pooled for the remaining analyses. All simple linear regression and multiple regression models produced significant relationships ($P \leq 0.05$), were highly correlated ($r^2 = 0.88$ to 0.99), and mean predicted error values were < 13% for all models. However, the simple linear regression model using TL and the multiple regression model using TL and G were the best predictive models to estimate weight in this evaluation. All weight and length estimates predicted with regression analysis were not statistically different than actual Alligator Gar weights and lengths. Visual inspection of weight bias plots suggests little bias between predicted and actual weights for Alligator Gar ≤ 60 kg, but became more variable for fish > 60 kg. However, the simple linear regression model using TL and the multiple regression model using TL and G produced less biased weight estimates for fish up to 80 kg, but appeared to underestimate weights of Alligator Gar ≥ 100 kg. All of the models evaluated in this study provide managers and anglers with a relatively accurate estimate of Alligator Gar weights from Texoma Reservoir and provides fisheries managers with weight-length information to which other Alligator Gar populations can be compared.

Introduction

Alligator Gar (*Atractosteus spatula*) has a limited distribution in Oklahoma due to anthropogenic influences such as dams, dredging, habitat change, unlimited recreational harvest and commercial fishing (Brinkman 2008, Inebnit 2009, Snow et al 2018). The Red River basin remains the stronghold for Alligator Gar in Oklahoma, although anglers occasionally report fish caught from the Arkansas River (Oklahoma Department of Wildlife Conservation [ODWC] unpublished data). Because Alligator Gar have a limited distribution in Oklahoma, ODWC manages them as a species of greatest conservation need and regulates recreational harvest with a one fish daily bag limit (which must be reported to ODWC). Numerous angling methods are permitted to catch Alligator Gar, however bowfishing, rod and reel, and snagging are the most common (ODWC 2019). Alligator Gar anglers rarely have the means to weigh fish due to their large size, even though fish weight is often used as a measure of fishing success by trophy anglers (Meerbeek and Crane 2017). However, anglers often record total length or girth measurements to describe the size of the fish that they catch. Anglers and fisheries managers would benefit by having a method to estimate the weight of an Alligator Gar using the measurements commonly collected in the field.

Length-weight relationships provide fisheries managers with important basic biology information about fish populations, including fish condition, growth rates, morphological differences, and reproductive potential (Santos et al. 2012, Torres et al. 2012, Meerbeek and Crane 2017, Maurya et al. 2018). Further, the mathematical relationship between various fish length measurements and weight allows either measurement to be predicted simply by having the other (Sarkar et al. 2009, Nazir and Khan 2017). Development of length-weight equations for Alligator Gar would provide fisheries managers and anglers with a means to overcome physical and logistical issues associated with weighing large fish in the field, which reduces handling stress or unnecessary harvest just to obtain a weight. Therefore, the objective of this study is to develop predictive equations to estimate Alligator Gar weights using total length, standard length, and girth measurements. Additionally, bias was evaluated between weights predicted from length-weight relationships and actual Alligator Gar weights.

Methods

Alligator Gar were sampled in Texoma Reservoir using experimental gillnets (net dimensions described by Binion et al. 2015 and Schlechte et al. 2016). Nets were set in coves or on main-lake flats in depths ranging 2 - 9 m. Site selection was aided by the use of visual observation of Alligator Gar surfacing (aerial breathing) and side scan sonar. In deeper water or when fish were observed with side scan sonar near the lake bottom, weights (9.1 kg keg- style anchors) were attached to the lead line in the middle of the net to ensure the net maintained contact with the lake bottom. Nets were monitored every 15 to 30 min to ensure quick release of Alligator Gar and reduce mortalities. Besides gillnetting, several angling methods (jug fishing, rod and reel, and snagging) were used to collect Alligator Gar and harvested fish were donated by recreational anglers.

Upon capture, each Alligator Gar was measured using a fabric measuring tape for snout length (snout tip to anterior start of eye orbit), anal fin base length, girth (G; taken anterior of the pelvic fins), standard length (SL; snout tip to insertion of epichordal lobe of caudal fin) and total length (TL). These measurements were used to identify sex of each gar using methods outlined by McDonald et al. (2013). Due to their large size, individual Alligator Gar were placed into a fish sock (25.4 mm #60 green-twine mesh x 3.05 m long x 457.2 mm diameter), which were then hooked to a hanging scale (Intercomp CS200; Intercomp CO., Medina, Minnesota) attached to a winch (Badland 2500 ATV/Utility Winch; Badland Winches, Camarillo, California) and lifted to attain the weight (W; kg) of each fish (Figure 1).

To meet the assumptions of normality, length and weight data were log transformed prior to regression analyses. Differences in weight between seasons (winter/spring versus summer/fall) and sex of Alligator Gar were tested using ANCOVA. Simple linear regression models were used to describe the relationships between girth, length, and weight (TL:W, SL:W, G:W, TL:SL, TL:G, and SL:G) of Alligator Gar. Multiple regression analysis was used to determine the relationships between girth, length, and weight (TL/G:W and SL/G:W) for

Figure 1. Photographs depicting the winching apparatus used to weigh Alligator Gar and the fish sock (25.4 mm #60 green-twine mesh x 3.05 m long x 457.2 mm diameter) used to support Alligator Gar.

Alligator Gar. Differences between individual weights and lengths predicted from the simple linear and multiple regression equations were tested against actual fish weights and lengths using paired t-tests. Strength of each model was evaluated by comparing percent error [(Observed - Predicted)/Predicted*100] by averaging the percent predicted error across all observations for each model (Wood 2005, Scharf et al. 1998, Snow et al. 2017, Jeter et al. 2019). Additionally, bias plot were constructed to compare bias between actual and predicted girths, lengths, and weights of Alligator Gar. A bias plot was not constructed for TL:SL, as this relationship was highly correlated (r^2 = 0.99). All statistical analyses were conducted at a significance level of $P \leq 0.05$.

Results

A total of 339 Alligator Gar averaging 1,666 mm TL (range = 590 to 2,357 mm TL) and weighing 38.2 kg (range = 0.77 to 105.3 kg) were collected from Texoma Reservoir. The sex ratio of Alligator Gar was 52.5% male and 47.5% female. More Alligator Gar were collected during winter and spring (n=203) than during summer and fall (n=136). No significant difference in weight was detected between sex ($F_{1, 337}$ = 0.619, P = 0.57) or season ($F_{1, 337}$ = 0.116, P = 0.26), therefore all fish were pooled for the remaining analyses.

Simple linear regression models indicated significant relationships between all length and weight measurement combinations ($P \leq 0.01$;

Table 1. Simple linear and multiple regression equations for predicting length and weight measurements of Alligator Gar using total length (TL), standard length (SL), and girth (G) measurements, with associated r^2 and *P*-values.

Regression type	*n*	*P*-value	r^2	Regression equation
Simple Linear	338	≤ 0.01	0.91	logW = 3.074(logTL)-8.364
	331	≤ 0.01	0.88	logW = 2.839(logSL)-7.451
	227	≤ 0.01	0.91	logW = 2.501(logG)-5.536
	331	≤ 0.01	0.99	logSL = 1.011(logTL)-0.0878
	235	≤ 0.01	0.93	logG = 1.111(logTL)-0.7514
	234	≤ 0.01	0.93	logG = 1.095(logSL)-0.6431
Multiple	227	≤ 0.01	0.92	logW = 3.0806(logTL)-0.0037(logG)-8.3806
	227	≤ 0.01	0.90	logW = 2.8521(logSL)-0.0021(logG)-7.4931

Table 2. Percent error of length and weight measurements predicted from simple linear regression and multiple linear regression using total length (TL), standard length (SL), and girth (G) measurements taken from Alligator Gar, including outcomes of paired t-tests.

Regression type	Predicting variables	% error	t-statistic	df	*P*-value
Simple Linear	TL:W	8.1	0.596	337	0.28
	SL:W	12.4	1.54	330	0.06
	G:W	9.3	0.607	226	0.27
	TL:SL	1.1	0.108	330	0.46
	TL:G	-3.9	0.443	234	0.33
	SL:G	-8.8	0.436	233	0.33
Multiple	TL/G:W	2.86	-0.829	226	0.20
	SL/G:W	2.14	-0.191	226	0.42

Table 1), and these relationships were highly correlated (r^2 = 0.88 to 0.99). The simple linear regression model using TL was the best predictor of Alligator Gar weight ($P < 0.01$, $r^2 = 0.91$, mean % error = 8.1%; Table 2). Regardless of model, all predicted length and weight measurements were not significant different than actual values ($P > 0.05$; Table 2).

The multiple regression models using TL and G and SL and G to predict weight were significant ($P \leq 0.01$) and highly correlated (r^2 = 0.90-0.92; Table 1). The mean percent error was low for both multiple regression models (< 3%; Table 2). The weights predicted using the TL/G and SL/G models were not different than actual fish weights ($P > 0.05$; Table 2), suggesting both models predicted fish weights similarly.

Bias plots suggest predicted weights were relatively unbiased compared to actual fish weights for all models, particularly for Alligator Gar < 60 kg (Figure 2). As Alligator Gar weights exceeded 60 kg, increased variability was observed between predicted and actual weights for all linear regression and multiple regression models (Figure 2). The linear and multiple regression models using TL were the best predictors of fish weight compared to actual fish weights for large fish (80-100 kg). Visual inspection of bias plots suggests that predicted weights from all models underestimate the actual weights of the largest Alligator Gar (> 100 kg; Figure 2). Little bias was observed between girth measurements predicted using TL and SL and actual girth measurements for smaller fish, however the variability of predicted girth measurements increased with increasing Alligator Gar length (Figure 3).

Discussion

This study provides length-weight equations for Alligator Gar from Texoma Reservoir, Oklahoma. Both models (simple linear regression and multiple linear regression) that best predicted Alligator Gar weights used TL to predict weight, which had the highest correlation coefficients (r^2 = 0.91-0.92). Although all predictive models produced reliable estimates of Alligator Gar weight for smaller fish (≤ 60 kg), the weights predicted using simple linear (TL) and multiple regression (TL and G) models were less variable than weights predicted using other length measurements (SL or G), particularly for larger fish (≥ 80 kg). The simple linear regression model relating TL to weight was the best predictor of Alligator Gar weights for fish up to 100 kg. The variability in predicted weights of larger fish was likely due to low sample size of large fish, which comprised <1% of sample. Additionally, variability in predicted weights may have also been caused by intrinsic (gonadal development, age, sex and genetic makeup) and

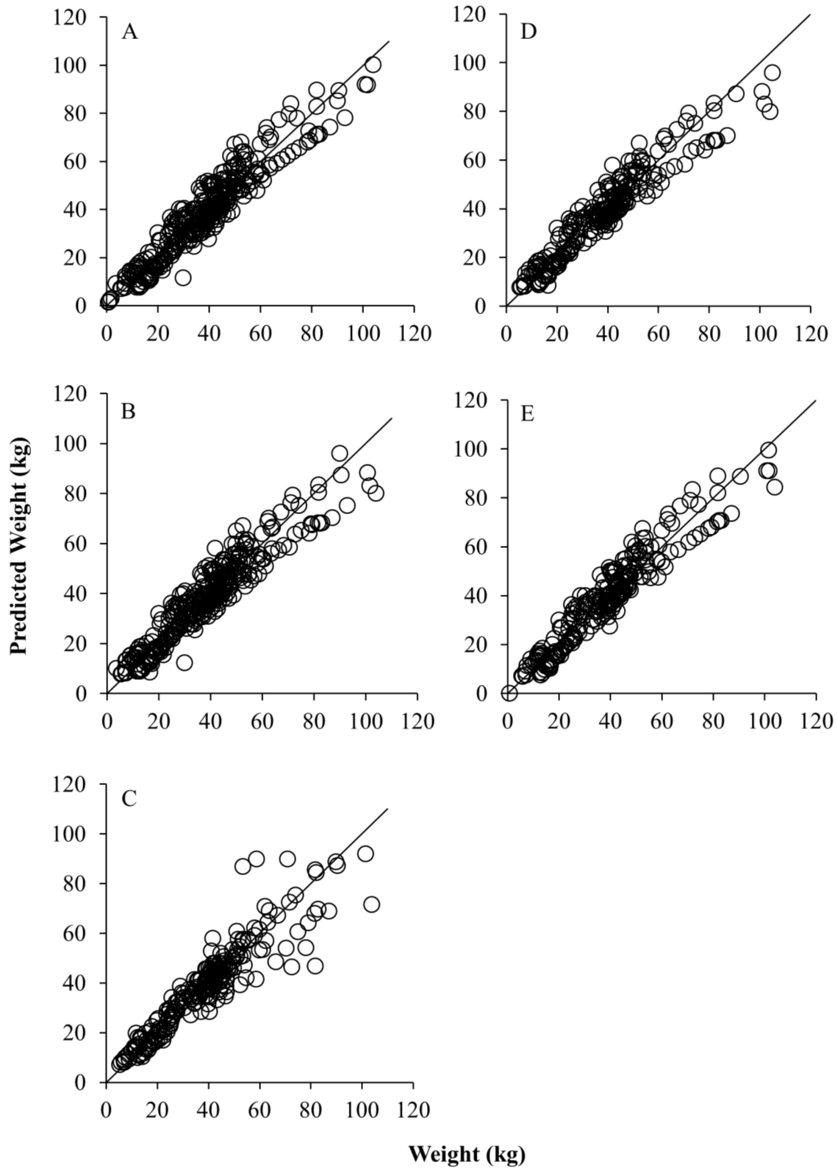

Figure 2. Bias plots comparing actual Alligator Gar weights to those predicted using regression anaysis: A) TL:W, B) SL:W, C) G:W, D) SL and G:W, and E)TL and G:W) of Alligator Gars. The diagonal line represents a 1:1 relationship between predicted and actual weights.

extrinsic factors (gut content, habitat, season; Neumann et al. 2012). Despite this variability, the best predictive models estimated the weight of the current Oklahoma state record Alligator Gar (not used in this study) to within 1.9 to 2.4% (TL:W = 118.05, TL and G:W = 117.49 kg) of the actual weight (115.27 kg).

Although Alligator Gars exhibit sexual dimorphism (McDonald et al. 2013), we found no significant differences in weights by sex or season. Similarly, García de León et al. (2001) found no difference in the weight-length relationships of Alligator Gar collected from Vincente Guerrero Reservoir, Mexico. Previous research produced similar results for other large-bodied fishes. Meerbeek and Crane (2017) found inclusion of sex and reproductive

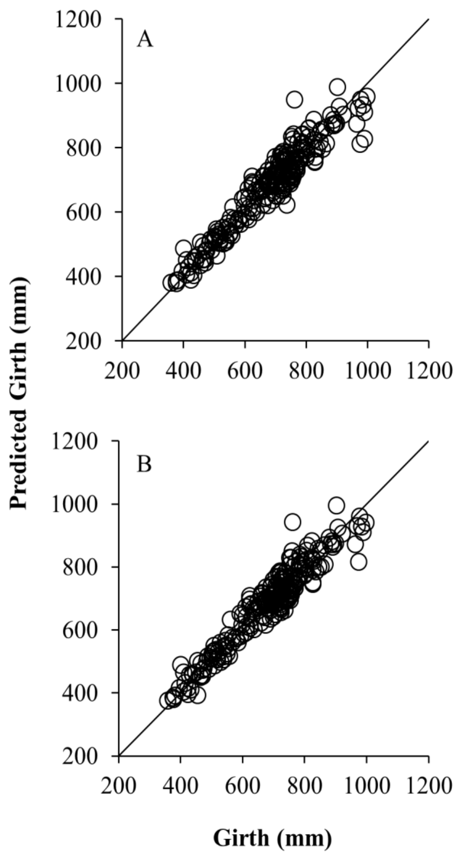

Figure 3. Bias plots comparing actual Alligator Gar girth measurements to those predicted using regression analysis: A) TL:G, B=SL:G) of Alligator Gars. The diagonal line represents a 1:1 relationship between predicted and actual girth measurements.

status did not significantly improve regression models for estimating weights of Muskellunge (*Esox masquinongy*). Similarly, Craig et al. (2005) found no differences in length-weight relationships between sexes of Lake Sturgeon (*Acipenser fulvescens*) from the St. Clair River, Michigan. However, they attributed this to a small sample size of old, large females in their study, which tend to not become larger than males until they have spawned several times (Bruch 1999). It is possible that our results are affected by a limited sample of old, large females, as Alligator Gars exhibit a periodic life history (Buckmeier et al. 2017), which may affect the ultimate size of female gar, similar to species of Acipenseridae (Bruch 1999). Past commercial harvest and unregulated harvest by anglers may have also reduced the number of old, large female Alligator Gar in Texoma Reservoir (Taylor et al. 2019).

The equations presented in this study to predict weight of Alligator Gar provide anglers and fisheries managers with an important tool that allows them to overcome physical and logistical issues associated with obtaining weights of large fishes. Obtaining weights of large-bodied fishes, like Alligator Gars, in the field requires specialized equipment (large capacity scales), and can increase handling time leading to additional physiological stress to a fish (Neumann et al 2012). For these reasons, numerous studies have provided length-weight relationships or predictive equations for large-bodied fishes including, Atlantic Tarpon (*Megalops atlanticus*; Ault and Luo 2013), Lake Sturgeon (Commanda 2018), Muskellunge (Meerbeek and Crane 2017), Pacific Goliath Grouper (*Epinephelus quinquefasciatus*; Boas et al. 2016), and White Sturgeon (*Acipenser transmontanus*; DeVore et al. 1995). Alligator Gar anglers are often not equipped to measure fish weights in the field, even though fishing success is measured by the number of fish caught, and the lengths and weights of those fish (Ault and Luo 2013, Meerbeek and Crane 2017). Our results promote Alligator Gar conservation by providing a method to assign weight to Alligator Gar, reducing the need to over-handle or harvest fish simply to obtain a weight.

The models presented in this study provide fisheries managers and anglers with a method to estimate measurements or weights of Alligator Gar that are typically captured in the field (G, SL, TL, and). However, readers should keep in mind that these models include only Alligator Gar from Texoma Reservoir and application of these equations to other Alligator Gar populations should be done with caution, due to population specific morphological differences. Further, use of these equations to predict measurements of Alligator Gar outside of the size distribution included in this study should be done cautiously. As future Alligator Gar conservation efforts increase in Oklahoma and across the range of the species, models in this study provide managers with a method to compare body condition and growth potential across populations.

Acknowledgments

The authors thank Micah Waters, Jory Bartnicki, Shelby Jeter, Matthew Lyons, ODWC Southcentral Regional Management Staff, and the Tishomingo National Fish Hatchery personnel for assisting with field sampling. We thank Kurt Kuklinski (ODWC) and Jim Long (OSU) for reviewing an earlier draft of this manuscript. Additionally, comments provided by Dr. Mostafa Elshahed and anonymous reviewers greatly improved this manuscript. Financial support for this publication was provided by Sport Fish Restoration Program grants [F-50-R-25] and [F-86-D-1] to the Oklahoma Department of Wildlife Conservation.

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Submitted August 7, 2020 Accepted November 22, 2020