Effects of Turbidity on Growth of Young-of-Year and Juvenile Spotted Gar (*Lepisosteus oculatus*)

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Abstract: This study examined the impact of turbidity on the growth of young-of-year and juvenile Spotted Gar (*Lepisosteus oculatus*), a key predator in North American freshwater systems facing conservation threats due to habitat degradation. Conducted in controlled outdoor aquaria, the experiment exposed Spotted Gar to high (Secchi depth ≤ 20 cm) and low (Secchi depth > 54 cm) turbidity conditions to assess their growth in total length (TL) and weight. Initial TL and weight measurements did not differ significantly between turbidity treatments within each age group. Our results suggest turbidity affected growth in TL, but there was no effect on growth in weight. Increased turbidity appeared to result in slower growth in TL for young-of-year spotted gar, but higher growth in TL for juvenile spotted gar. Growth in weight was significantly greater in juvenile Spotted Gar compared to young-of-year Spotted Gar. Turbidity may not have influenced growth in weight due to an inability to account for individual variation during statistical analysis or due to Spotted Gar investing more energy in growth in TL at the life stages studied. These findings suggest that increased turbidity may impair young-of-year growth, but potentially benefits older juveniles. Future work should confirm these findings in a field setting. The study highlights the importance of maintaining clear, vegetated habitats for the early life stages of Spotted Gar and suggests that conservation efforts should address habitat quality and turbidity to support Spotted Gar populations, particularly in northern regions where habitat degradation is increasing.

Introduction

Gars (family: Lepisosteidae) are a primitive group of fishes distributed widely in central and eastern North America and throughout Central America (Echelle and Grande, 2014). Gars are large-bodied, top-level piscivores, and are important components of aquatic food webs (David et al. 2015). Gar biology is poorly understood in comparison to other fish species, largely because they are considered nuisance fish across many areas where they are found (Scarnecchia 1992). Populations of several species within Lep-

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isosteidae have declined because of habitat loss and removal efforts which has resulted in conservation challenges (Scarnecchia 1992, Staton et al. 2012, NatureServe 2024). Over the last 15 years, however, there has been a concerted effort to gain a better understanding of the fundamental biology of these species (Smith et al. 2020).

The Spotted Gar (*Lepisosteus oculatus*) is one of four species of gar native to Oklahoma (Miller and Robison 2004, Frenette and Snow 2016). While populations are considered stable in Oklahoma, the Spotted Gar is a species of conservation concern at the northern edge of its range and is critically imperiled in Canada, Kansas, Ohio, and Pennsylvania (Glass et al. 2011, Staton et al. 2012, David et al. 2015, Ontario Ministry of Natural Resources and Forestry 2016, NatureServe 2024). Furthermore, Spotted Gar are presumed to be extirpated in New Mexico (NatureServe 2024). The recovery strategy for Spotted Gar in Canada emphasizes the importance of early life history on population growth rates (Staton et al. 2012, Ontario Ministry of Natural Resources and Forestry 2016). This relatively large ambush predator prefers clear, heavily vegetated near-shore waters, habitats that are especially susceptible to human activities that can negatively impact water quality, such as near-shore development, erosion, and nutrient loading (COSEWIC 2015).

Turbidity is a measure of water cloudiness caused by suspended particles (Wetzel 2001). Turbidity influences both the aquatic ecosystem and the biota within it (Henley 2000, Owens et al. 2005, Prestigiacomo et al. 2007, Rodriguez-Blanco et al. 2013, Merten et al. 2014). Turbidity reduces light penetration into the water, affecting the growth of aquatic plants and algae which can result in bottom-up influences on the food web (Treweek and Morgan 1980, Zingel and Paaver 2010, Jia Du et al. 2023). Reduced visibility due to increased turbidity has been shown to influence foraging behavior and how efficiently fish capture food (Shoup and Wahl 2009, Carter et al. 2010, Higham et al. 2015, Snow et al. 2018), potentially driving changes in growth and condition (Zingel and Paaver 2010, Lowe et al. 2015). Though turbidity effects have been studied on traditional game fishes such as Largemouth Bass (*Micropterus salmoides)*, Shoup and Wahl 2009, Shoup and Lane 2015), little information is available for native nongame species such as Spotted Gar. Turbidity's effects on the hatching success of Spotted Gar has been implicated to explain their population decline at the northern extent of their range (Gray et al. 2012).

Turbidity has been shown to negatively affect hatching success by approximately 24% for Spotted Gar eggs held in turbid conditions compared clear water conditions (Gray et al. 2012). Turbidity does not appear to effect growth of young-of-year Spotted Gar (Frenette 2014). However, mortality of young-of-year Gar was high (Frenette 2014), particularly in smaller individuals (measured as initial TL), which resulted in limited replication. These results suggested the study should be repeated to better understand turbidity's influence on early life survival of Spotted Gar. Therefore, the goal of this study is to test the effects of high (Secchi depth $\leq$ 20 cm) and low (Secchi depth $\geq$ 53 cm) turbidity on growth of young-of-year (Age 0) and juvenile (Ages 1 to 3) Spotted Gar. The specific objectives of our study were to determine if high and low turbidity changed growth based on (1) length or (2) weight for young-of-year and juvenile Spotted Gar.

Methods

Young-of-year Spotted Gar were captured in the river-reservoir confluence of Texoma Reservoir, Oklahoma, using mini-fyke nets (0.6 m x 6.35 m with 3.18 mm mesh, 0.6 m x 1.92 m rectangular cab, and 510 mm metal throat) with 9.14 m leads. Mini-fyke nets were set perpendicular towards the shoreline where herbaceous vegetation and woody debris were abundant (Brinkman 2008, Snow et al 2016). Juvenile Spotted Gar were collected from Sparks Reservoir, Oklahoma, using boat electrofishing (pulsed DC, high voltage, Smith Root GPP). Electrofishing was used to sample the entire shoreline, and all Spotted Gar were captured; however, only individuals <450 mm total length (TL) were retained. Both reservoirs experience a wide range of turbidity levels that overlap and range from 30 to 130 cm (Sager et al. 2011, ODWC unpublished data), All Spotted Gar collected were placed in a livewell on each boat and transferred to a hauling box where dissolved oxygen (DO) was maintained at or above 7 mg/L and water temperature mirrored that of the body of water where collection occurred. Spotted Gar were then transported to the Oklahoma Fisheries Research Laboratory, where they were acclimated to the temperature of one of four 946-L round fiberglass tanks. All four tanks shared the same water supply which resulted in consistently similar temperatures for all tanks during the duration of the study.

Fathead Minnows (*Pimephales promelas*) that had been raised in outdoor ponds were used as forage for Spotted Gar. All Fathead Minnows were donated by the Matt McBride fish farm (Wetumka, Oklahoma). Fathead Minnow TL were selected based on the TL of sampled Spotted Gar to provide forage of optimal size (optimum point of handling time divided by prey weight; Hoyle and Keast 1987), resulting in forage being 10 to 25% of predator TL. All Fathead Minnows were transported to the Oklahoma Fisheries Research Laboratory, where they were placed into a 946-L round tank with slow water exchange and aeration. Fathead Minnows were allowed to acclimate for at least 10 days prior to use in the experiment.

Growth trials were conducted outdoors in oval 378.5-L aquaria. At the start of the trial, each aquarium was randomly assigned a turbidity level based on Secchi depth of either ≤ 20 or > 54 cm. Turbidity in each tank was produced using bentonite clay. Clay and water were first stirred together in a separate container until thoroughly mixed. The clay mixture was then added to aquaria until the desired turbidity was achieved. Turbidity in each tank was measured using a Secchi tube (Myre and Shaw 2006). To maximize precision, the same observer always measured Secchi depth. All aquaria were equipped with aeration to keep the clay suspended (Shoup and Wahl 2009). The turbidity measurement of ≥ 54 cm were chosen based on the maximum water depth in the aquarium. With the ≤ 20 cm turbidity measurement being chosen to ensure consistent turbidity levels throughout the trial, following the approach used by Snow et al. (2018).

Once the desired turbidity level was achieved in aquaria, 25 Fathead Minnows were added to each tank. After forage was added a single Spotted Gar was netted out of the holding tank and TL (mm) and weight (g) were recorded. Spotted Gar were then randomly assigned to aquaria. During trials turbidity was measured daily along with temperature (^{o}C) and DO (mg/L). If the Secchi depth was not within 10% of the assigned level within a 48-hour period, the turbidity level was adjusted to within 10%. A total of 38 young-of-year and 16 juvenile Spotted Gar were available for trials, allowing for 19 and 8 individuals to be assigned to each turbidity treatment, respectively. Since there were not enough aquaria to run all trials simultaneously, two separate trials were conducted resulting in isolative segregation between age groups (Hurlbert 1987). Trials for young-of-year Spotted Gar were conducted between 6/16/2017 and 7/11/2017, whereas trials for juvenile Spotted Gar were conducted between 7/20/2017 and 8/28/2017. Spotted Gar TL was measured during trials once every half to full fortnight, and additional Fathead Minnows were added so that 25 individuals were available in each aquarium. This occurred at 8, 14, 19, and 25 days after the start of trials for young-of-year Spotted Gar and at 7, 20, 29, and 39 days for juvenile Spotted Gar. After trials, tanks were drained, and TL and weight were recorded for each Spotted Gar.

To determine if initial TLs or weights were different between Spotted Gar that received each turbidity treatment, we used two-sample Kolmogorov-Smirnov tests (KS-tests; Kolmogorov 1933, Smirnov 1939) to compare initial measurements of each individual separately for each age group (i.e., young-of-year, juvenile). Kolmogorov-Smirnov tests were confirmed via distributional overlap ($\hat{\eta}$; Pastore and Calcagnì 2019) estimated using the overlapping package (Pastore 2020). Thresholds for low, moderate, and high distributional overlap were equivalent to estimates of $\hat{\eta}$ = 0.20, 0.50, and 0.80, respectively (see Pastore 2020). To determine if turbidity level influenced Spotted Gar growth based on TL or weight, we estimated growth rates for each fish. Growth in TL was estimated as the difference in TL at each sample period relative to the initial TL of each Spotted Gar. Weight was estimated as the difference in weight at the end of the study relative to the initial weight of each Spotted Gar. We then used a generalized linear mixed model (GLMM) or generalized linear model (GLM) to determine if turbidity significantly influenced the change in TL or weight of Spotted Gar, respectively. All analyses were conducted in program R version 4.4.1 (R Core Team 2024) and significance was always assessed at $\alpha = 0.05$.

A Poisson distributed GLMM with a log link function was used to model growth based on TL via the lmerTest package (Kuznesova et al. 2017). Individual Spotted Gar were used as the random effect to account for each fish receiving multiple TL measurements over the course of the study. Fixed effect predictors were turbidity, time since start of trial (days), and age group (i.e., young-of-year or juvenile). Time since start of trial was centered and scaled prior to analysis (R Core Team 2024). A backwards selection approach was used to determine if any of our predictors or their interactions exhibited a significant relationship with growth based on TL (James et al. 2013). Insignificant predictors ($p > 0.05$) were removed starting with the three-way interaction, then second-order interactions, and then main effects, if necessary (Jeter et al. 2023). Appropriateness of the final GLMM from the backwards selection process was assessed via a nonparametric dispersion test using the DHARMa package (Hartig 2022) along with diagnostic plots displaying a posterior predictive check, variance inflation factors, scale-location relationships, leverage, and normality within our random effects using the performance package (Lüdeke et al. 2021). Coefficients of determination for fixed (R^2_F) and random (R^2_R) effects for the final GLMM were estimated via the rsq package (Zhang 2020, Zhang 2023). Predictions from the final GLMM from the backwards selection process were then used with coefficient estimates to determine how significant predictors or interactions influenced growth based on TL.

A Gamma distributed GLM with a log link function was used to model growth based on weight over the course of the study via the lmerTest package (Kuznesova et al. 2017). Random effects were not included as each Spotted Gar only had only one measurement (i.e., the final measurement) taken to estimate growth in weight. Likewise, the effect of time since start of trial was not included as it was confounded with age group, and age group was of more interest. Therefore, predictors used for this model were turbidity and age group. The same backward selection approach was taken as described prior for GLMMs investigating growth in TL. However, removal of insignificant predictors included the two-way interaction (i.e., turbidity level × age group) and main effects until only significant predictors remained. Appropriateness of the final GLM from the backwards selection approach was determined via a nonparametric dispersion test using the DHARMa package (Hartig 2022) along with diagnostic plots displaying a posterior predictive check, scale-location relationships, and leverage using the performance package (Lüdeke et al. 2021). McFadden's pseudo-r^2 (ρ^2) was used as the coefficient of determination for the top model, with a $\rho^2 = 0.20$ indicating an 'excellent' model fit (McFadden 1974, 1979). Predictions from the final GLM from the backward selection process were then used with coefficient estimates to determine how significant predictors or interactions influenced growth based on weight.

Results

Across all trials tank temperatures ranged from 21°C to 27°C daily and DO ranged between 6.8 – 8.7 mg/L. Forage densities appeared to be appropriate as all fish grew during the trials (Table 1). Young-of-year Spotted Gar TLs increased 1 to 95 mm over the course of the study, and weights increased by 4 to 13 g. Likewise, juvenile Spotted Gar TLs increased 1 to 29 mm over the course of the study and weights increased by 9 to 43 g. No Spotted Gar mortalities were observed during trials.

Initial TLs and weights were similar between turbidity treatments for young-of-year and juvenile Spotted Gar (Table 1). Our KS-tests did not detect a significant difference in starting TLs (D = 0.21, p = 0.74) or weights (D = 0.37, p = 0.07) between turbidity treatments for young-of-year Spotted Gar. Overlap tests suggested there was high overlap between initial TLs ($\hat{\eta}$ = 0.82) and moderately high overlap between initial weights ($\hat{\eta}$ = 0.76) for young-of-year Spotted Gar. Similarly, KS-tests detected no significant differences in starting TLs (D = 0.38, p = 0.66) or weights (D = 0.38, p = 0.57) between turbidity treatments for juvenile Spotted Gar. Overlap tests suggested high overlap between initial TLs ($\hat{\eta}$ = 0.80) and moderately high overlap between initial weights ($\hat{\eta}$ = 0.79) for juvenile Spotted Gar.

Table 1. Mean, 95% quantiles (95%Q), and ranges of total lengths and weights for each age group (i.e., young-of-year [YOY] and juvenile) of Spotted Gar in each turbidity treatment (based on Secchi Depth) at the beginning (Time = 0) and end (YOY Time = 25, Juvenile Time = 39) of each trial.

Age Group	Secchi Depth	Time (days)	Total Length (mm)			Weight (g)		
			Mean	95%Q	Range	Mean	95%Q	Range
YOY	≤ 20 cm	0	131	115 - 147	112 - 147	5	3 - 8	3 - 8
YOY	≤ 20 cm	25	184	172 - 205	164 - 206	14	11 - 19	10 - 19
YOY	> 54 cm	0	131	111 - 158	108 - 163	4	2 - 8	2 - 8
YOY	> 54 cm	25	179	167 - 204	157 - 205	13	8 - 19	7 - 19
Juvenile	≤ 20 cm	0	402	353 - 449	347 - 450	192	127 - 275	123 - 284
Juvenile	≤ 20 cm	39	417	375 - 458	373 - 458	220	159 - 301	154 - 308
Juvenile	> 54 cm	0	383	355 - 422	352 - 424	160	127 - 219	123 - 223
Juvenile	> 54 cm	39	401	377 - 442	374 - 446	187	160 - 240	155 - 245

The final model from the backwards selection process investigating growth in TL for Spotted Gar included a two-way interaction between age group and time since start of trial, a two-way interaction between turbidity and age group, and their associated main effects (Table 2). The dispersion test suggested that the Poisson distribution was appropriate for the data (p = 0.80) and diagnostic plots suggested good fit of fixed and random effects, low multicollinearity between predictors, and no influential points or leverage. Coefficients of determination suggested fixed effects ($R^2_F = 0.71$) explained more variation than the random effect ($R^2_R = 0.19$) in our final model, resulting in a relatively good overall fit to the data ($R^2_F + R^2_R = 0.90$). Coefficient estimates for the two-way interaction between age group and time since start of trial suggested that juvenile Spotted Gar growth in TL increased slower than young-of-year (Table 2). Interestingly, the two-way interaction between turbidity and age group suggested that turbidity had a positive overall effect on growth in TL of juveniles relative to young-of-year Spotted Gar (Table 2). Predicted output from the final GLMM from backward selection showed that young-of-year Spotted Gar growth in TL was faster than that of juvenile Spotted Gar (Figure 1). Likewise higher turbidity (Secchi depth ≤ 20 cm) resulted in slower growth of young-of-year Spotted Gar and faster growth in TL of juvenile Spotted Gar (Figure 1). However, it is important to note that the growth in TL was not statistically different within each age group due to turbidity. Instead, the effect of turbidity on growth in TL varied between the age groups.

Table 2. Mean and standard error (SE) estimates along with resulting z- and p-values for each fixed parameter from the final Poisson distributed GLMM obtained via backward selection predicting growth in TL. Parameters include the intercept, turbidity (i.e., Secchi depth ≤ 20 or > 54 cm), age group (i.e., young of year, juvenile) and time since start of trial (Time).

Predictor	Mean	SE	z-value	p-value
Intercept	2.43	0.06	43.21	$< 2.00\times10^{-16}$
Turbidity	0.03	0.05	0.62	0.54
Age Group	-0.62	0.06	-11.02	$< 2.00\times10^{-16}$
Time	0.74	0.02	29.88	$< 2.00\times10^{-16}$
Turbidity × Age Group	0.11	0.05	2.13	0.03
Age Group × Time	-0.28	0.02	-11.41	$< 2.00\times10^{-16}$

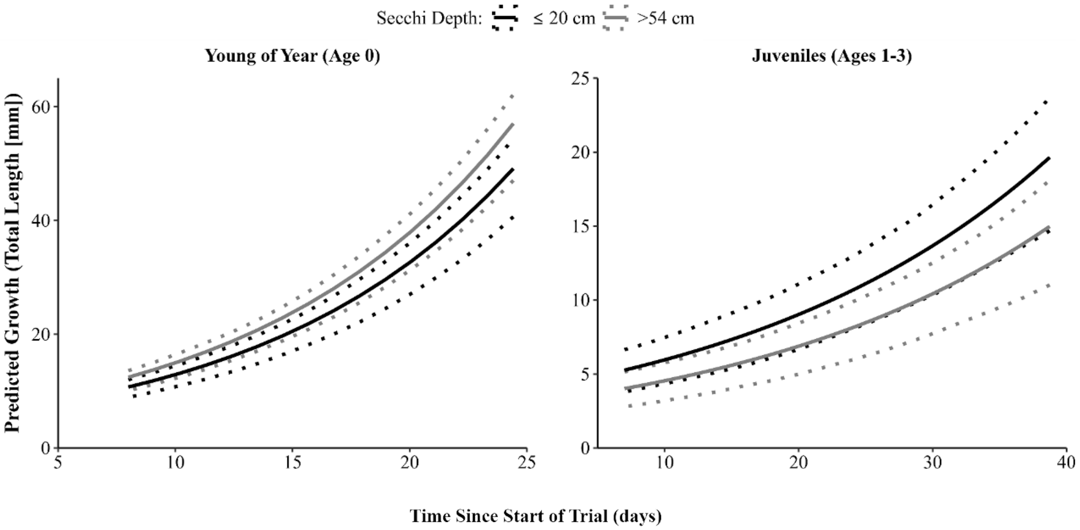

Figure 1. Predicted growth based on total length plotted against time since start of trial for age groups in each turbidity treatment (based on Secchi Depth) from the final Poisson distributed GLMM obtained via backward selection. Solid lines represent means and dotted lines represent 95% confidence intervals. Note that different scales have been used for each age group to better display trends.

The final model from the backwards selection process investigating growth in weight for Spotted Gar only included the main effect age group (Table 3). The dispersion test suggested that the Gamma distribution was appropriate for the data (p = 0.70) and diagnostic plots suggested good fit and no influential points or leverage. The coefficient of determination suggested this model had "excellent" fit to our data (ρ^2 = 0.23). Coefficient estimates for the effect of age group suggested that juvenile Spotted Gar growth in weight was higher relative to young-of-year (Table 3). Predicted output from the final GLM from backwards selection confirmed this trend with juvenile Spotted Gar growth in weight being roughly three times higher than young-of-year (Figure 2). Though there was a 14-day difference in trial length, the large difference in growth in weight between age groups suggests that this difference was primarily due to age group. For example, when predated growth in weight for each age group was divided by the duration of each study there was still a substantially higher daily growth rate for juvenile Spotted Gar (mean = 0.71 g/day [95%CI = 0.59 – 0.81 g/day]) compared to young-of-year Spotted Gar (mean = 0.34 g/day [95%CI = 0.31 – 0.37 g/day]). However, this hypothesis cannot be confirmed due to the confounding effects of trial length and age group.

Table 3. Mean and standard error (SE) estimates along with resulting z- and p-values for each parameter from the final Gamma distributed GLM obtained via backward selection predicting growth in weight. Parameters include the intercept and age group (i.e., young of year, juvenile).

Predictor	Mean	SE	z-value	p-value
Intercept	2.73	0.04	62.71	$< 2.00\times10^{-16}$
Age Group	0.59	0.04	13.61	$< 2.00\times10^{-16}$

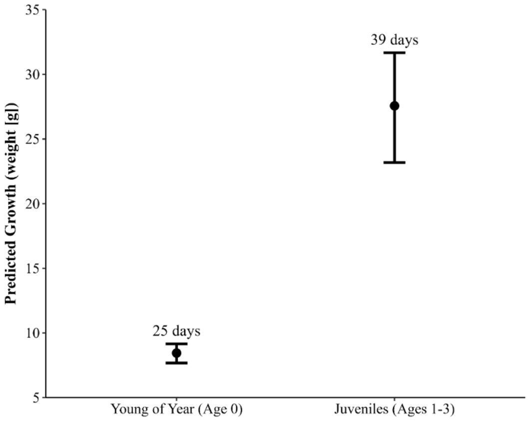

Figure 2. Predicted growth based on weight plotted against age groups from on the final Gamma distributed GLM obtained via backward selection. Black circles represent means and error bars represent confidence intervals. Included above each estimate is the total duration of the trial for each age group.

Discussion

Our results suggest that turbidity levels have varying effects on different age groups of Spotted Gar. Growth in TL was less for young-of-year Spotted Gar and more for juvenile Spotted Gar under increased turbidity. However, growth in TL was not statistically different between turbidity treatments within age groups (i.e., young-of-year, juvenile) even though data showed trends. Though no studies comparing the effects of turbidity on different age groups of Spotted Gar were available, Wellington et al. (2010) determined that young-of-year and juvenile Yellow Perch (Perca flavescens) exhibited differences in foraging success due to different levels and types of turbidity likely influencing growth. Prior work found no statistical difference in growth for young-of-year Spotted Gars under turbid and clear conditions (Frenette 2014). Frenette (2014) noted higher growth under clear conditions and attributed the lack of statistical difference to insufficient statistical power caused by a low sample size due to high mortality during the study. Predicted output from our GLMM also suggested higher but insignificant growth of young-of-year Spotted Gar in our lower turbidity treatment. Our results suggest that turbidity improves growth in TL of juvenile Spotted Gar, though this improvement was not statistically significant. Further study into the effects of turbidity on growth in TL for young-of-year and juvenile Spotted Gar and other gar species (e.g., Longnose Gar [*Lepisosteus osseus*], Alligator Gar [*Atractosteus spatula*]) is warranted given the lack of literature available on this topic.

The differential influence of turbidity on growth in TL for young-of-year and juvenile Spotted Gar may be the result of juvenile Spotted Gar being better adapted to foraging in turbid conditions. Though we were unable to locate other published study results for Spotted Gar, higher turbidities are thought to generally result in reduced foraging success for fishes (Ginetz and Larkin 1976, Gardner 1981, Huenemann et al. 2012, Snow et al. 2018). However, size-specific variation in foraging success has been observed for Walleye (Sander vitreus, Vandenbyllaardt et al. 1991), Yellow Perch (Perca flavescens, Wellington et al. 2010), and Pikeperch (Zingel and Player 2010). Interestingly, during this study, we observed both young-of-year and juvenile Spotted Gar which exhibited discoloration in the high turbidity treatment (Figure 3). Given we did not observe differences in growth rates within the age group, this discoloration may have allowed study subjects to better blend in with the turbid water, potentially resulting in higher capture efficiency; however, this was beyond the scope of our study. Color variation such as this should be studied further to understand the mechanisms behind depigmentation and any potential effects it may have on foraging success. Likewise, turbidity's effects on foraging success in Spotted Gar should be studied to determine if this caused the observed differences in growth in TL between young-of-year and juveniles.

Turbidity appeared to have no effect on growth in weight for young-of-year or juvenile Spotted Gar in our study. We were unable to locate studies comparing growth in weight and turbidity for young-of-year or juvenile Spotted Gar, though findings were available for other species. Weight gain in larval Northern Pike (*Esox Lucius*) and juvenile Silver Seabream (*Pagrus auratus*) was reduced at higher turbidity levels (Salonen and Engström-Öst 2013; Lowe et al. 2015). Zingel and Paaver (2010) noted that turbidity had no relationship with Fulton's condition factor (i.e., 100,000 × weight/TL^3) for Pikeperch (*Sander Lucioperca*) ranging from 31 – 75 mm TL and a negative relationship with Fulton's condition factor for Pikeperch 76 – 90 mm TL, suggesting the effect of turbidity on condition varied with size. Our findings that turbidity has little to some effect on growth in weight for young-of-year and juvenile Spotted Gar contradicts most other available literature for other species (e.g., Pikeperch [*Sander Lucioperca*]: Zingel and Paaver 2010, Rainbow Trout [*Oncorhynchus mykiss*]: Ginetz and Larkin 1976; salmonids: Berg 1982; juvenile Walleyes [*Sander vitreus*]: Vandenbyllaardt et al. 1991; Bluegill [*Lepomis macrochi*], Gardner 1981, Largemouth Bass [*Micropterus salmoides*]: Huenemann et al. 2012; juvenile Yellow Perch [*Perca flavescens*]: Wellington et al. 2010). This may be due to Spotted Gar exhibiting different relationships with turbidity than other species of fish. Though this may be the result of species-specific differences, further study into the effects of turbidity on growth in weight for young-of-year and juvenile Spotted Gar is warranted. This is especially true as, to the best of our knowledge, this study constitutes the only investigation into the effects of turbidity on growth in weight available for the gar family.

Contrasting results for turbidity's effect on growth in TL and weight for young-of-year and juvenile Spotted Gar may be due to differences in the statistical analysis or differences between indexes of growth. Individual variation in growth was accounted for when comparing turbidity's effect on growth in TL. However, we were unable to account for induvial variation when comparing turbidity's effect on growth in weight due to having only one observation per individual. Conversely, turbidity may have had little effect on growth in weight due to more energy being invested in growth in TL at the early life stages studied (Moyle and Cech 2004, Won and Borski 2013). The effects of turbidity on growth in weight should be studied further and compared while accounting for individual variation to determine if the lack of effect observed in this study is an artifact of the statistical process used.

Reduced growth in TL due to increased turbidity in young-of-year Spotted Gar may have significant population-level consequences. The first season of growth is likely when Spotted Gar are most vulnerable (Staton et al. 2012). Early life survival in fishes is often influenced by their ability to grow large enough before facing their first period of resource scarcity, typically occurring during their first winter (Gray et al. 2012, Frenette 2014). This could explain why Spotted Gar populations appear most vulnerable at the northern extent of their range, where winter resource scarcity generally persists for longer durations (Hurst 2007). Differences in winter resource scarcity between northern and southern latitudes may also explain why Spotted Gar in Oklahoma appears to exhibit stable recruitment in reservoirs that are turbid (ODWC unpublished data, Frenette and Snow 2016). This study does suggest that if Spotted Gar can survive through their first year they may acclimate to turbid conditions and such conditions may improve growth, which

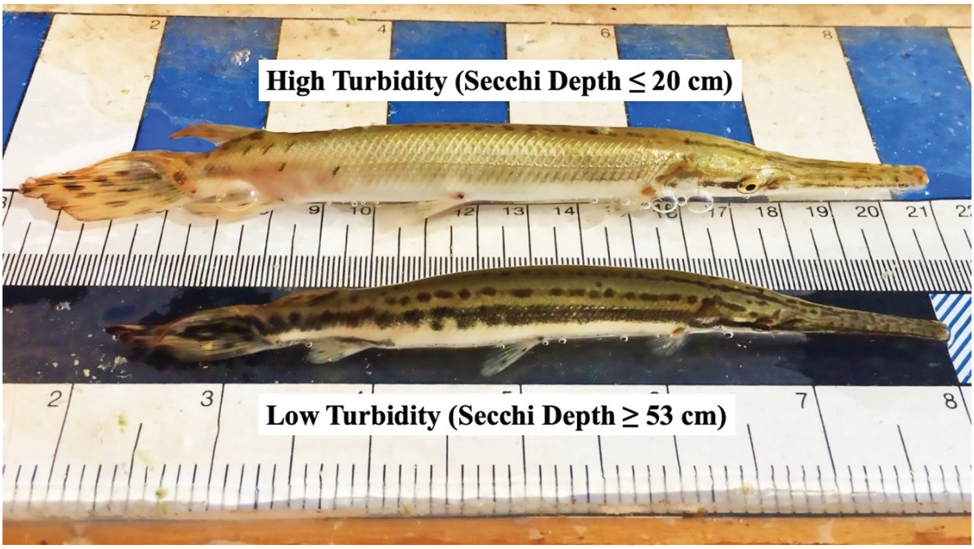

Figure 3. Example of discoloration observed in Spotted Gar due to high turbidity (top) relative to those in low turbidity treatments (bottom).

may be influenced by transitioning from clear, near-shore refugia at early life history stages to more open, turbid environments as they grow. However, these results should be confirmed in a field setting as prior investigations into turbidity's influences on foraging success and growth have varied between laboratory and field studies in other species (Spier and Hidinger 2002, Shoup and Lane 2015). Increased turbidity may also indirectly affect Spotted Gar through the reduction of vegetated habitats upon which these fish are thought to be reliant (Bouvier and Mandrak 2010, Gray et al. 2012). Early in life Spotted Gar are thought to use aquatic vegetation to forage and as refuge from predators (Snedden et al. 1999). However, there is still a need to identify critical habitats as young-of-year Spotted Gar transition into juveniles (Glass et al. 2012). Future studies should focus on a better understanding of direct and indirect effects of turbidity on gar populations at broader spatial scales along with a better understanding on turbidity's effects on foraging and predation, especially at early life stages.

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