Evaluating the Coarse-Scale Effects of Walleye and Saugeye Stocking on White Crappie Growth in Oklahoma Using Long-Term Data

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Abstract: The white crappie (*Pomoxis annularis*) is an important U.S. game fish but is prone to stunting. In Oklahoma, stocking saugeye (*Sander vitreus* × *S. canadensis*) is a common management strategy for improving white crappie growth. However, recent work has suggested that saugeye stocking may not be a broadly effective management tool for improving crappie growth rates, especially when controlling for among-reservoir variation. Therefore, our objectives were to: (1) determine if stocking of *Sander* spp. (walleye [*S. vitreus*], saugeye, or both) improved white crappie growth trajectories along with predicted and observed length-at-age, and (2) determine if predicted and observed length-at-age yielded similar results to evaluate the potential applicability of using predicted values when observed values are unavailable. We used linear mixed-effects modeling of long-term management data (1984–2020) to determine if metrics associated with stockings of *Sander* spp. influenced white crappie growth parameters and observed or predicted mean total length (TL) at ages 2 and 3. Stocking of saugeye alone or in combination with walleye did not appear to influence white crappie growth across our sample reservoirs. Stocking of walleye was associated with larger asymptotic maximum sizes and annual walleye stocking rate was positively associated with observed and predicted mean TL of white crappie at ages 2 and 3. The same top model was obtained from candidate sets when using observed and predicted mean TLs, suggesting that model-predicted values be used in analyses when missing age classes are present. Despite finding a relationship between crappie growth metrics and walleye stocking variables, our random effect (reservoir) explained at least half the variation for all models. This suggests that though walleye stocking may be a promising management tool for white crappie, further evaluation of reservoir-specific variables that influence its effectiveness is needed.

Key words: mixed-effects models, saugeye, walleye, white crappie

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White crappie (*Pomoxis annularis*) and black crappie (*P. nigromaculatus*) are important game fish across the U.S. (Mitzner 1984). Crappie populations are prone to stunting (Crawley 1954, Boxrucker 1984, Miller 2012), with stunted crappie populations characterized by slower growth and earlier maturation (Michaletz 2012). Past management strategies to improve crappie size structure have included prey manipulation, predator stocking, and harvest regulations (Boxrucker and Irwin 2002, Bonvechio et al. 2015). However, these management strategies have not always been effective (e.g., DeVries et al. 1991, Carlson et al. 2004, Shoup and Carl 2023). Variation in success is potentially because of system-specific or temporal abiotic and biotic influences also affecting crappie size structure (e.g., Guy and Willis 1994, Hale 1999). Determining broad-scale (e.g., statewide, regionwide) applicability of these management strategies is important to understanding their utility and improving their effectiveness.

In Oklahoma reservoirs, stocking of saugeye (*Sander vitreus* × *S. canadensis*) is a common management technique for improving stunted crappie populations (Boxrucker 2002). However, a recent large-scale before-after control-impact (BACI) study suggested that saugeye stocking did little to improve white crappie proportional size distribution (PSD), proportional size distribution of preferred-size fish (PSD-P), relative weight (W_r), catch per unit effort (CPUE), or mean lengths at ages 1 and 2 (Shoup and Carl 2023). Shoup and Carl (2023) suggested temporal and regional climatic factors (e.g., flood/drought, temperature) exhibited the strongest influence on white crappie population metrics. Walleye have also been stocked in Oklahoma; however, the responses of white crappie populations to walleye stocking have not been evaluated.

Many previous studies regarding the use of predator stocking for improving crappie size structure have lacked replication (e.g., Boxrucker 2002, Galinat et al. 2002) and failed to control for reservoir-specific effects (*sensu* Shoup and Carl 2023). The goal of our study was to investigate the effects of predator stocking on white crappie growth metrics using long-term management data from across Oklahoma. Our first objective was to determine if stockings of *Sander* spp. improved white crappie growth trajectories and observed and predicted length-at-age while controlling

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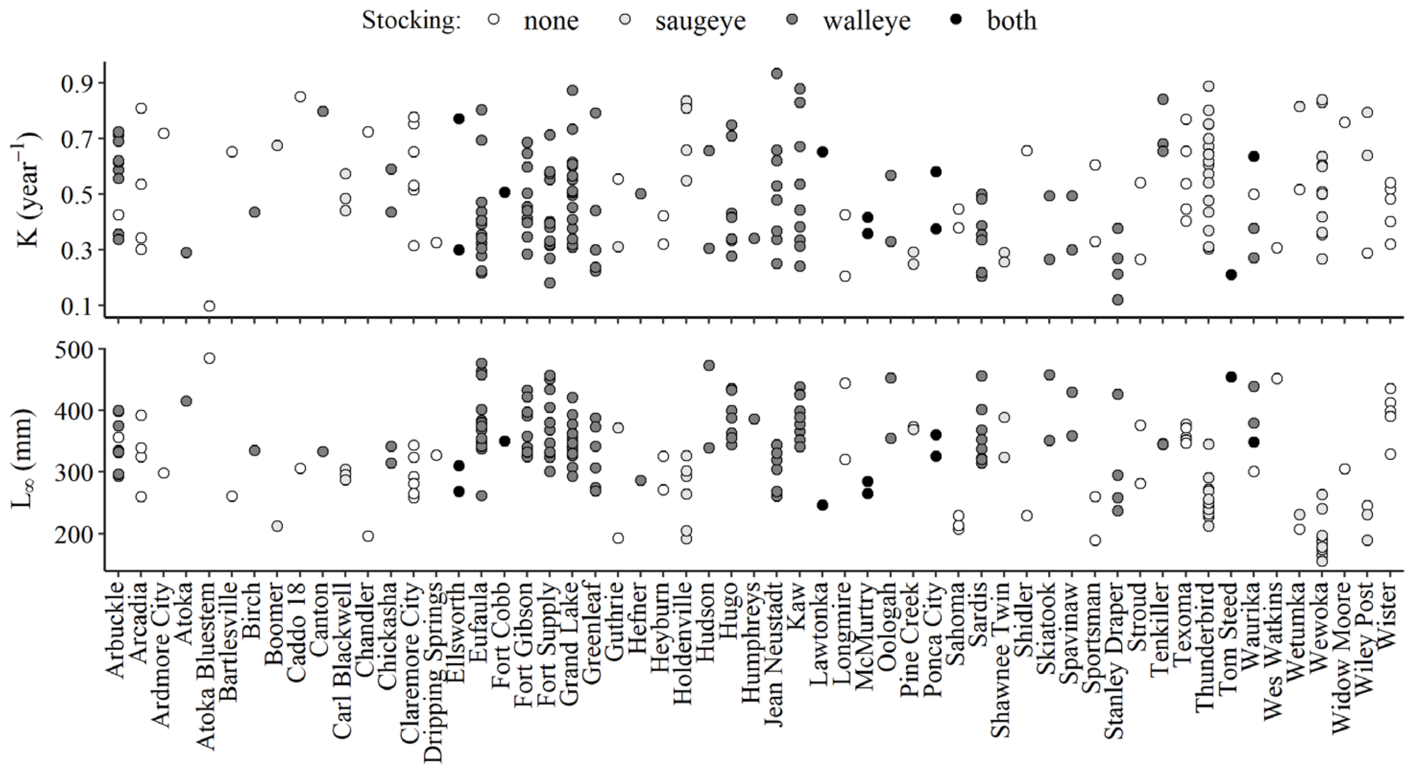

Figure 1. Mean estimated asymptotic maximum sizes (L_∞) and Brody growth coefficients (K) from von Bertalanffy growth curves for white crappie across Oklahoma sample reservoirs. Symbols denote whether each reservoir was stocked with walleye, saugeye, both walleye and saugeye (both), or neither *Sander* (none) prior to each sample year.

for within-reservoir variation. Our second objective was to determine if predicted and observed white crappie length-at-age yielded similar analytical results. This allowed us to evaluate the potential applicability of using predicted length-at-age for inference when observations of length-at-age are unavailable (e.g., Bonvechio et al. 2015).

Methods

Crappie age and total length (TL; mm) information was obtained from the Oklahoma Fishery Analysis Application (OFAA 2022). This represented 51,269 paired observations of age and TL from 93 reservoirs across the state from 1983 to 2020. From these data, we constructed von Bertalanffy growth curves for each unique reservoir-year combination. All growth curves were estimated via nonlinear least-squares estimation with the minpack.lm package (Elzhov et al. 2023) in R (R Core Team 2022) and starting values for each curve were estimated with the Fisheries Stock Assessment (FSA) package (Ogle et al. 2023). Year-reservoir combinations for which the growth curve could not be estimated via nonlinear least-squares estimation or which produced unrealistic growth curves (e.g., negative parameter estimates) were removed. This resulted in 241 usable white crappie growth curves from 57 reservoirs sampled from 1984 to 2020 (Figures 1–3). Asymptotic maximum size (L_∞) and the Brody growth coefficient (K) were obtained from these growth curves, along with predicted TL at ages 2 and 3. Observed mean TL at ages 2 and 3 were also obtained from the age estimates available for reservoir-year combinations where growth curves could be estimated. Mean TL at ages 2 and 3 were selected as we had relatively few observed age-1 samples from reservoir-year combinations with usable growth curves.

We selected ten reservoirs to examine predictors potentially explaining variation in white crappie L_∞, K, along with predicted and observed TL at ages 2 and 3. Sample year was included as a predictor as it may influence white crappie population dynamics (Shoup and Carl 2023). The other nine predictors were obtained using the Oklahoma Department of Wildlife Conservation's stocking database. The first three predictors were binary indicator variables categorizing whether the reservoir had been stocked (i.e., 0 = unstocked, 1 = stocked) with walleye, sauger, or either *Sander* (i.e., either walleye or sauger). This approach allowed for more detailed comparison of walleye, saugeye, and *Sander* stocking as some reservoirs were never stocked with either species, some were stocked with one or both species, and some were only stocked during later sample years. Reservoirs were classified as stocked with the above species from the prior year after initial stocking (i.e., a reservoir stocked in 1985 was deemed "stocked" in 1986) for all subsequent

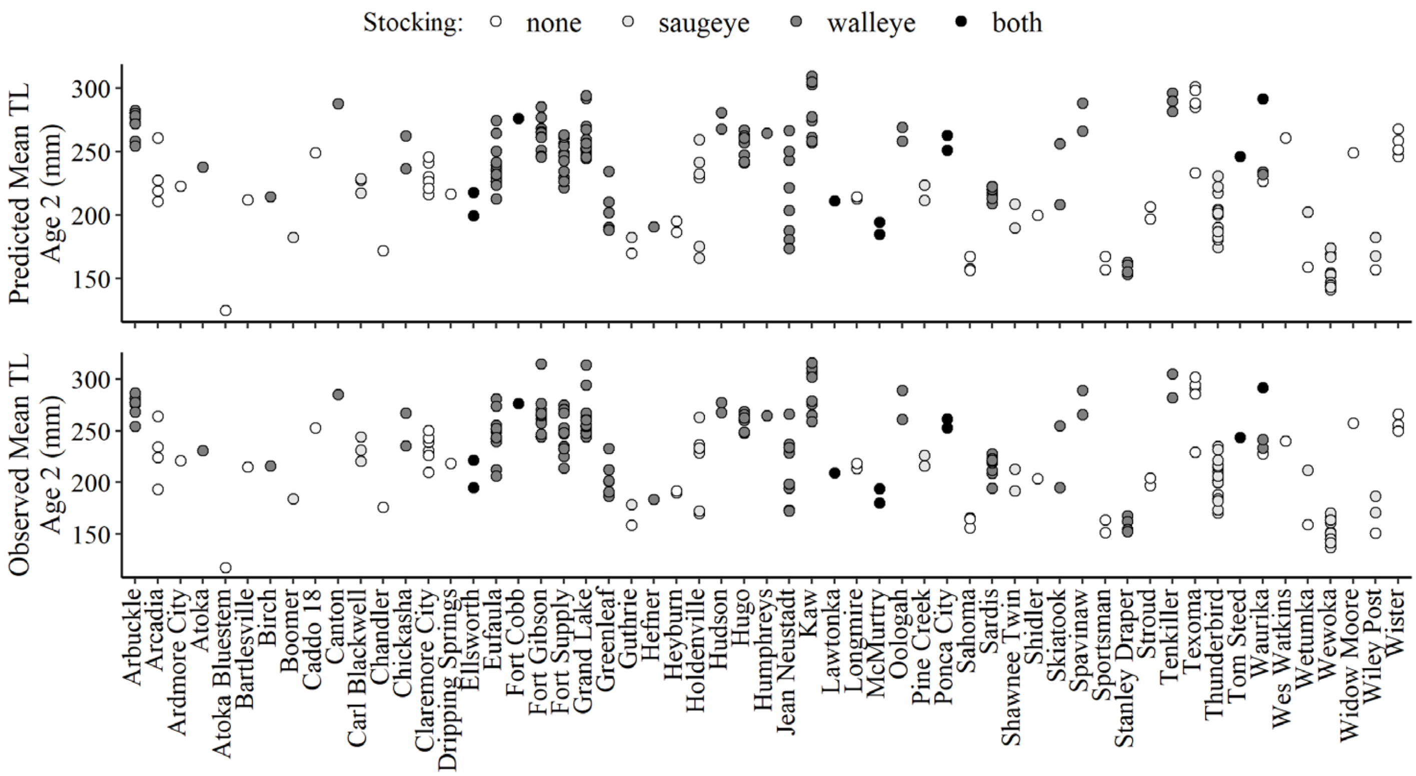

Figure 2. Observed and predicted mean total length (TL) at age 2 for white crappie across Oklahoma sample reservoirs. Symbols denote whether each reservoir was stocked with walleye, saugeye, both walleye and saugeye (both), or neither *Sander* (none) prior to each sample year.

years. This allowed us to determine if stocking predators at any point in time influenced white crappie growth. Three integer-coded variables captured the number of walleye, sauger, or *Sander* stockings that occurred prior to the year the growth curve was constructed. These predictors allowed us to determine if repeated exposure to walleye, saugeye, or *Sander* predator stockings improved white crappie growth. The final three predictive variables explored variable stocking rates and were derived by taking the number of walleye, sauger, or *Sander* stockings prior to the year the growth curve was constructed and dividing it by the number of years between the initial stocking year and the year the growth curve was constructed. For example, if a reservoir was stocked ten times with walleye starting in 1985 and the growth curve was estimated using data from 1995 the annual walleye stocking rate would be 1 stocking per year (i.e., 10 stockings ÷ 10 yr). Estimates of annual stocking were obtained separately for walleye, saugeye, and *Sander* predator stockings. This allowed us to coarsely estimate annual stocking rate for each system as a true stocking rate could not be defined given the inconsistency with early stocking records (e.g., pre-1980), the variability in stocking size (e.g., fry, fingerling, adult, 38.1 mm), and inconsistent information regarding early stocking numbers. This variable allowed us to determine if annual stocking rate of walleye, saugeye, or *Sander* predators improved white crappie growth. All predictors were centered and scaled prior to analysis.

Prior to candidate model construction, Spearman's correlation coefficient (Spearman 1904) was used to determine if any predictors were highly correlated ($|r| \geq 0.7$; Akoglu 2018) to reduce multicollinearity within our regression models. Walleye stocking was highly correlated with the number of walleye stockings ($r = 0.88$) and walleye stocking rate ($r = 0.88$). Likewise, saugeye stocking was highly correlated with the number of saugeye stockings ($r = 0.99$) and saugeye stocking rate ($r = 0.99$). The number of walleye and saugeye stockings were also correlated with walleye ($r = 0.96$) and saugeye ($r = 0.98$) stocking rates, respectively. *Sander* stocking was only correlated with number of *Sander* stockings ($r = 0.71$). However, number of *Sander* stockings was correlated with *Sander* stocking rate ($r = 0.82$). Based on these correlations we hypothesized seven candidate models that were unlikely to produce multicollinearity (see Results).

Candidate models were fit using Gaussian linear mixed-effects models using a maximum likelihood approach in the lmerTest package (Kuznetsova et al. 2017) with program R (R Core Team 2022). Reservoir was included as a random effect in all models to control for confounding abiotic variables across reservoirs (see Shoup and Carl 2023). An information-theoretic approach

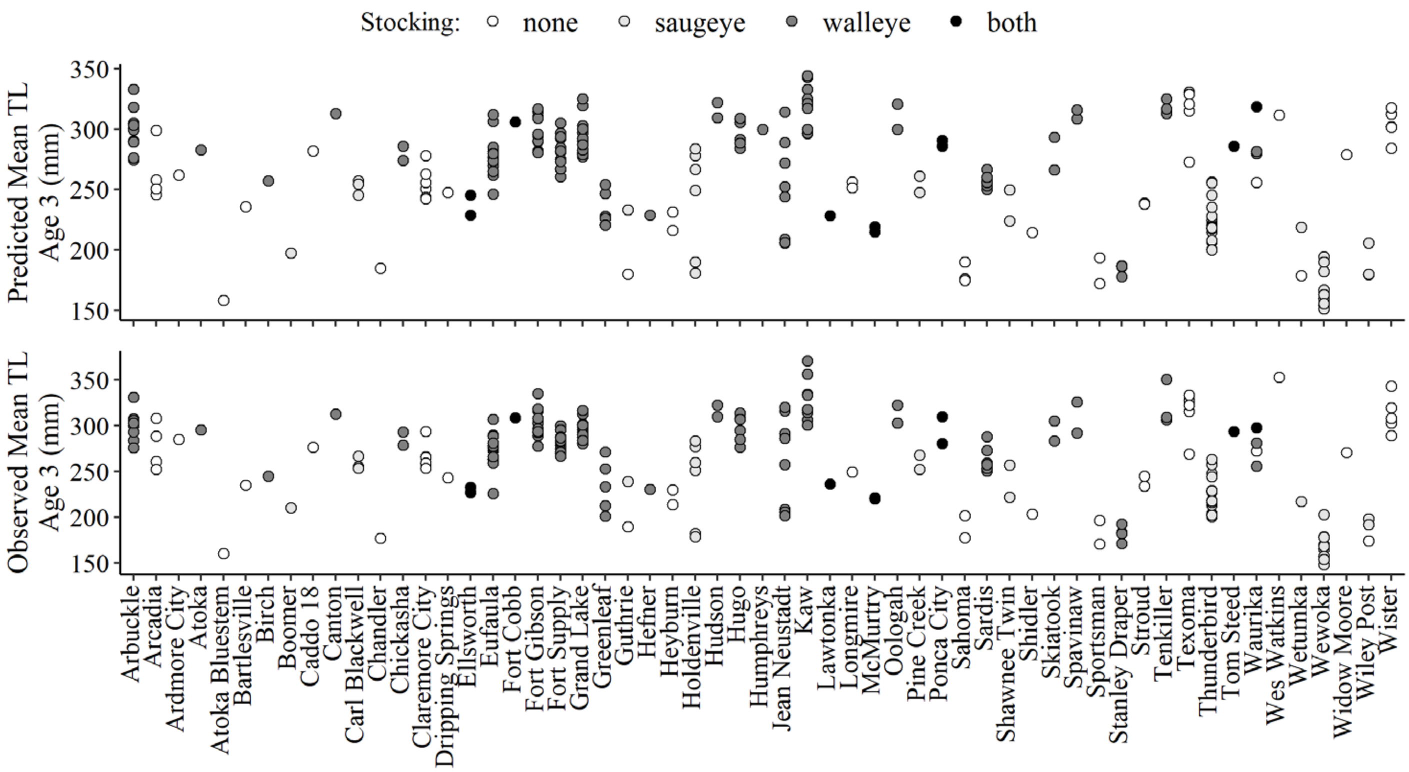

Figure 3. Observed and predicted mean total length (TL) at age 3 for white crappie across Oklahoma sample reservoirs. Symbols denote whether each reservoir was stocked with walleye, saugeye, both walleye and saugeye (both), or neither *Sander* (none) prior to each sample year.

(Burnham and Anderson 2002) was used to independently rank models for each white crappie growth response variable. Models were compared using Akaike information criterion corrected for small sample size (AICc, Hurvich and Tsai 1989) and a cutoff of ΔAICc ≤ 2.00 was used to determine if other candidate models had a similar likelihood to the top ranked model (Burnham and Anderson 2002). We also derived AICc weights (w_i) and evidence ratios for each model (Royall 1997, Burnham and Anderson 2002). We examined diagnostic plots via the performance package (Lüdecke et al. 2021) to assess heteroskedasticity, multicollinearity, leverage, influential points, and normality. Based on diagnostic plots, L_∞ was $\log_{10}$ transformed, K was $\log_e$ transformed, and both predicted and observed TL for age 2 and 3 were square-root transformed (Zar 1999).

We estimated coefficients of determination for fixed (R^2_F) and random (R^2_R) effects in each top ranked model along with competing models using the rsq package in R (Zhang 2020, Zhang 2023). This allowed us to assess the variance explained by fixed and random effects independently. We developed 95% confidence intervals (95% CIs) for fixed effects coefficients from the top ranked, or equally likely, models using profile estimation. We report coefficients from the top ranked model that were deemed to be significant (i.e., different from zero) based on their 95% CIs. To determine their average effect, significant predictors were plotted with all other predictors from the top ranked model held to their mean. The average effect was then compared to the average of each specific response variable (e.g., L_∞, observed TL at age 2) corrected for reservoir specific effects (see Shoup and Carl 2023). The order of candidate model rankings for observed mean TL at ages 2 and 3 were compared qualitatively to the order of candidate model rankings for predicted mean TL at ages 2 and 3, respectively. This allowed us to determine if there were differences in ranking order when using predicted mean TL for each age. We also compared 95% CIs obtained for coefficients from the top ranked models for predicted and observed TL at ages 2 and 3, respectively, to assess potential differences in coefficient estimates when using observed or predicted mean TL for each age.

Results

Sander stockings were variable across our sample reservoirs and within reservoirs across years. Eighteen reservoirs were not stocked with *Sander* spp. during any sample years, while six reservoirs were stocked only in some sample years (Figures 1–3). This yielded 46 unstocked reservoir-year observations from 1984 to 2020. Twenty-nine reservoirs were stocked with walleye, resulting in 134 samples from 1984 to 2020. In stocked reservoirs, the number of walleye stockings ranged from 1 to 64 and annual walleye stocking rate ranged from 0.03 to 2.10 stockings per year. Seventeen reservoirs were stocked with saugeye, resulting in 56 samples from 1987 to 2020 (Figures 1–3). In stocked reservoirs, number of prior saugeye stockings ranged from 1 to 49 and annual saugeye stocking rate ranged from 0.12 to 2.00 stockings per year.

The top ranked model for predicting white crappie L_∞ consisted of sample year, walleye stocked, and saugeye stocked (Table 1). Fixed (R^2_F = 0.37) and random effects (R^2_R = 0.37) explained similar amounts of variance in L_∞. Only walleye stocking had a significant effect on white crappie L_∞ (95% CI: 0.02–0.06). White crappie had a lower predicted L_∞ in the absence of walleye stocking ($\bar{x}$ = 288.61; 95% CI: 235.84–363.08) relative to if they were stocked with walleye ($\bar{x}$ = 346.29; 281.86–427.43) when accounting for the variation between reservoirs (Figure 4). However, L_∞ was highly variable within both stocked and unstocked reservoirs. The null model was the top ranked model for predicting the white crappie growth coefficient (K), with no other competing models based on AICc (Table 1). On average, K for white crappie populations was 0.45 (95% CI: 0.27–0.74; Figure 4), but similar to observations for L_∞, there was a large amount of variability within K estimates across reservoirs (R^2_R = 0.29).

The top two models for observed and predicted white crappie mean TL at age 2 were similar based on candidate set rankings (Table 2). However, there was disagreement between the third and

Table 1. Candidate model rankings for predicting mean estimated asymptotic maximum sizes (L_∞) and Brody growth coefficients (K) for white crappie across Oklahoma reservoirs. Predictors are sampling year (year); binary indicators of whether stocking occurred (walleye, saugeye, or either *Sander*); number of walleye, saugeye, or overall *Sander* stockings prior to the white crappie sample year (s.); and annual stocking rate (number walleye, saugeye, or overall *Sander* stockings divided by number of years) prior to each white crappie sample year (s.r.).

Response	Model	AICc	ΔAICc	w_i	Evidence Ratio
L_∞	year + walleye + saugeye	−534.5	0.0	0.90	1.0
	year + *Sander*	−528.0	6.5	0.03	30.0
	year + *Sander* s.	−527.1	7.4	0.02	45.0
	null	−526.3	8.3	0.01	90.0
	year + *Sander* + *Sander* s.r.	−526.0	8.6	0.01	90.0
	year + walleye s. + saugeye s.	−525.9	8.6	0.01	90.0
	year	−524.2	10.3	0.01	90.0
	year + walleye s.r. + saugeye s.r.	−522.7	11.8	<0.01	>100.0
K	null	222.3	0.0	0.45	1.0
	year	224.3	2.1	0.16	2.8
	year + *Sander* + *Sander* s.r.	225.4	3.1	0.10	4.5
	year + walleye + saugeye	225.7	3.4	0.08	5.6
	year + walleye s.r. + saugeye s.r.	226.2	3.9	0.06	7.5
	year + *Sander*	226.3	4.0	0.06	7.5
	year + *Sander* s.	226.4	4.1	0.06	7.5
	year + walleye s. + saugeye s.	227.3	5.0	0.04	11.3

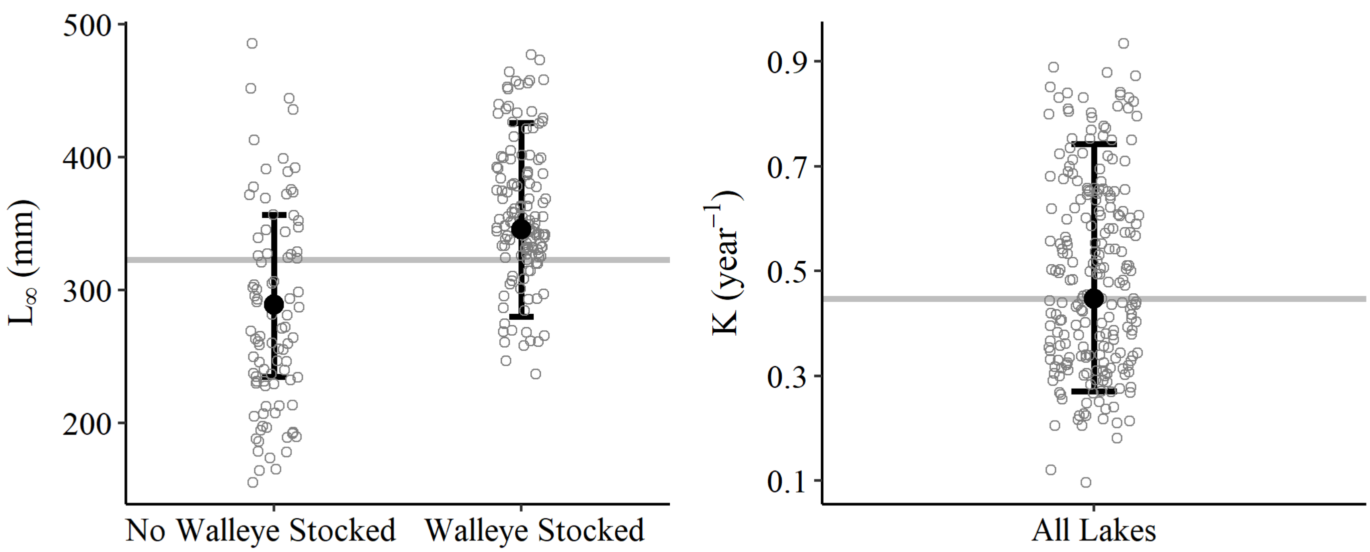

Figure 4. Predicted mean (black circles) and 95% confidence intervals (error bars) for significant predictors (i.e., different from zero) from top ranked linear mixed-effects models (Table 1) for predicting mean estimated asymptotic maximum sizes (L_∞) and Brody growth coefficients (K) for white crappie across Oklahoma sample reservoirs. Included are individual observations (gray circles) and mean across all observations (gray line) of L_∞ and K.

fourth most likely models between predictor candidate sets. Following this, all other models were ranked similarly between observed and predicted white crappie mean TL at age 2. The reservoir random effect explained the majority of variation relative to fixed effects for both predicted (R^2_R = 0.61; R^2_F = 0.27) and observed (R^2_R = 0.60; R^2_F = 0.25) white crappie mean TL at age 2. Parameter confidence intervals from the top ranked models for both observed and predicted white crappie mean TL at age 2 suggested year (observed 95% CI: 0.05–0.30; predicted: 0.07–0.27) and annual stocking rate (observed: 0.23–0.73; predicted: 0.30–0.73) were significant predictors. Over sample years, observed and predicted mean TL at age 2 barely deviated from the corresponding mean estimated TL across reservoirs (observed = 224.27 mm; predicted = 224.24 mm; Figure 5). Furthermore, the difference in average minimum and maximum observed and predicted mean TLs at age 2 for our models were likely not different enough to be noticed by anglers (observed = 19.86 mm; predicted = 19.39 mm). Annual walleye stocking rate had a strong positive influence that deviated from the mean across reservoirs at a stocking rate of ~1.3 walleye stockings per year for both observed and predicted mean TL at age 2 (Figure 5). The difference in average minimum and maximum observed and predicted mean TLs at age 2 was likely high enough to be noticed by anglers (observed = 75.88 mm; predicted = 81.96 mm).

Only the top ranked model, third ranked model, and lowest two ranked models were similar based on candidate set rankings for observed and predicted mean TL at age 3 (Table 2). All other models were ranked dissimilarly between candidate sets. The reservoir random effect explained the majority of variation relative to fixed effects for both predicted (R^2_R = 0.59; R^2_F = 0.30) and observed (R^2_R = 0.58; R^2_F = 0.28) white crappie mean TL at age 3. Annual stocking rate (95% CI: 0.23–0.75) was the only significant predictor based on confidence intervals from the top ranked model for observed white crappie mean TL at age 3 (Figure 6). However, for predicted white crappie mean TL at age 3, both annual stocking rate (95% CI: 0.28–0.73) and year (0.03–0.24) were significant, although the effect of year appeared weak (Figure 6). Annual walleye stocking rate had a strong positive influence that deviated from the mean across reservoirs at stocking rates of ~1.3–1.4 walleye stockings per year for both observed (258.26 mm) and predicted (255.59 mm) mean TL at age 3 (Figure 6). The difference in average minimum and maximum observed and predicted mean TLs at age 3 (observed = 84.41 mm; predicted = 86.47 mm) was likely high enough to be noticed by anglers.

Table 2. Candidate model rankings for predicted and observed total length at ages 2 and 3 for white crappie across Oklahoma reservoirs. Predictors are sampling year (year); binary indicators of whether stocking occurred (walleye, saugeye, or either *Sander*); number of walleye, saugeye, or overall *Sander* stockings prior to the white crappie sample year (s.); and annual stocking rate (number walleye, saugeye, or overall *Sander* stockings divided by number of years) prior to each white crappie sample year (s.r.).

Age	Response	Candidate Model	AICc	ΔAICc	w_i	Evidence Ratio
Age 2	Predicted	year + walleye s.r. + saugeye s.r.	532.7	0.0	0.95	1.0
		year + walleye + saugeye	539.1	6.4	0.04	23.8
		year + *Sander* + *Sander* s.r.	543.5	10.8	<0.01	>100.0
		year + *Sander*	544.6	11.9	<0.01	>100.0
		year + *Sander* s.	545.3	12.6	<0.01	>100.0
		year + walleye s. + saugeye s.	547.4	14.7	<0.01	>100.0
		year	549.6	16.9	<0.01	>100.0
		null	550.3	17.6	<0.01	>100.0
	Observed	year + walleye s.r. + saugeye s.r.	571.9	0.0	0.74	1.0
		year + walleye + saugeye	574.9	3.0	0.16	4.6
		year + *Sander*	577.8	5.8	0.04	18.5
		year + *Sander* + *Sander* s.r.	578.3	6.4	0.03	24.7
		year + *Sander* s.	579.8	7.9	0.01	74.0
		year + walleye s. + saugeye s.	581.9	10.0	0.01	74.0
		year	582.3	10.4	<0.01	>100.0
		null	583.1	11.1	<0.01	>100.0
Age 3	Predicted	year + walleye s.r. + saugeye s.r.	549.0	0.0	0.79	1.0
		year + walleye + saugeye	552.8	3.8	0.12	6.6
		year + *Sander* + *Sander* s.r.	554.4	5.4	0.05	15.8
		year + *Sander*	556.4	7.4	0.02	39.5
		year + *Sander* s.	557.7	8.7	0.01	79.0
		year + walleye s. + saugeye s.	559.0	10.0	0.01	79.0
		null	563.6	14.6	<0.01	>100.0
		year	564.6	15.6	<0.01	>100.0
	Observed	year + walleye s.r. + saugeye s.r.	585.8	0.0	0.62	1.0
		year + *Sander* s.	588.5	2.8	0.15	4.1
		year + *Sander* + *Sander* s.r.	590.0	4.3	0.07	8.9
		year + walleye s. + saugeye s.	590.1	4.4	0.07	8.9
		year + walleye + saugeye	591.0	5.2	0.05	12.4
		year + *Sander* s.	592.7	7.0	0.02	31.0
		null	593.3	7.5	0.01	62.0
		year	595.2	9.5	0.01	62.0

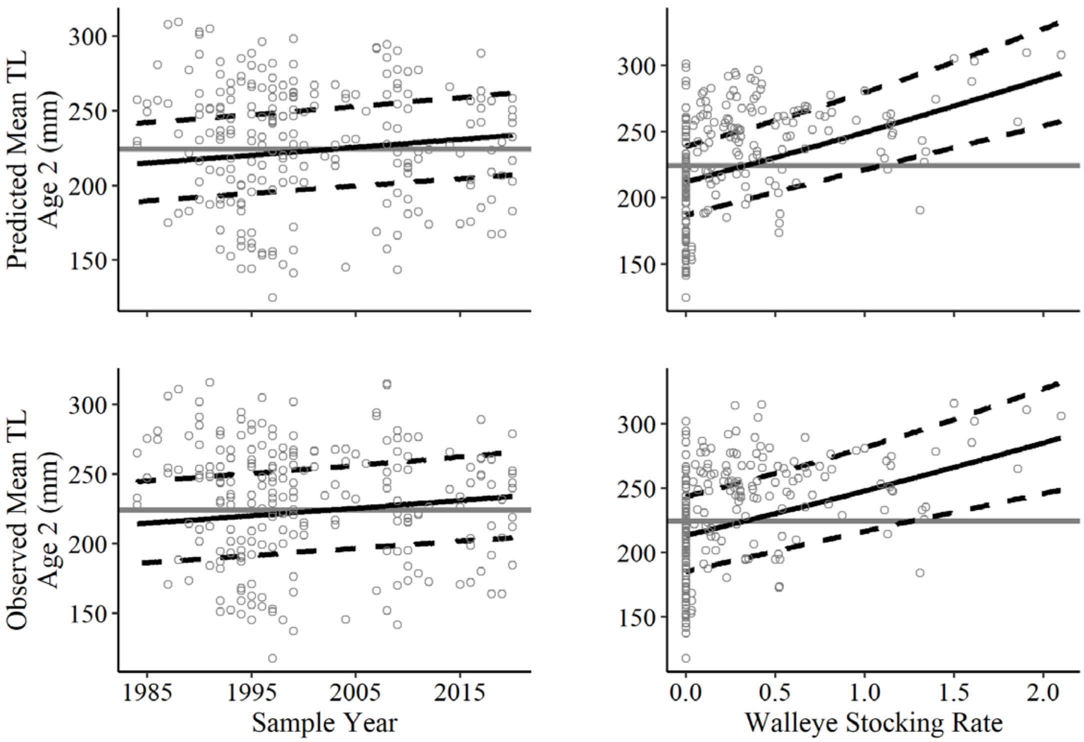

Figure 5. Predicted mean (black line) and 95% confidence intervals (dashed lines) for significant predictors (i.e., different from zero) from top ranked linear mixed-effects models (Table 2) for predicting observed and predicted mean total length (TL) at age 2 for white crappie across Oklahoma sample reservoirs. Included are individual observations (gray circles) and mean across all observations (gray line) of observed and predicted mean TL at age 2.

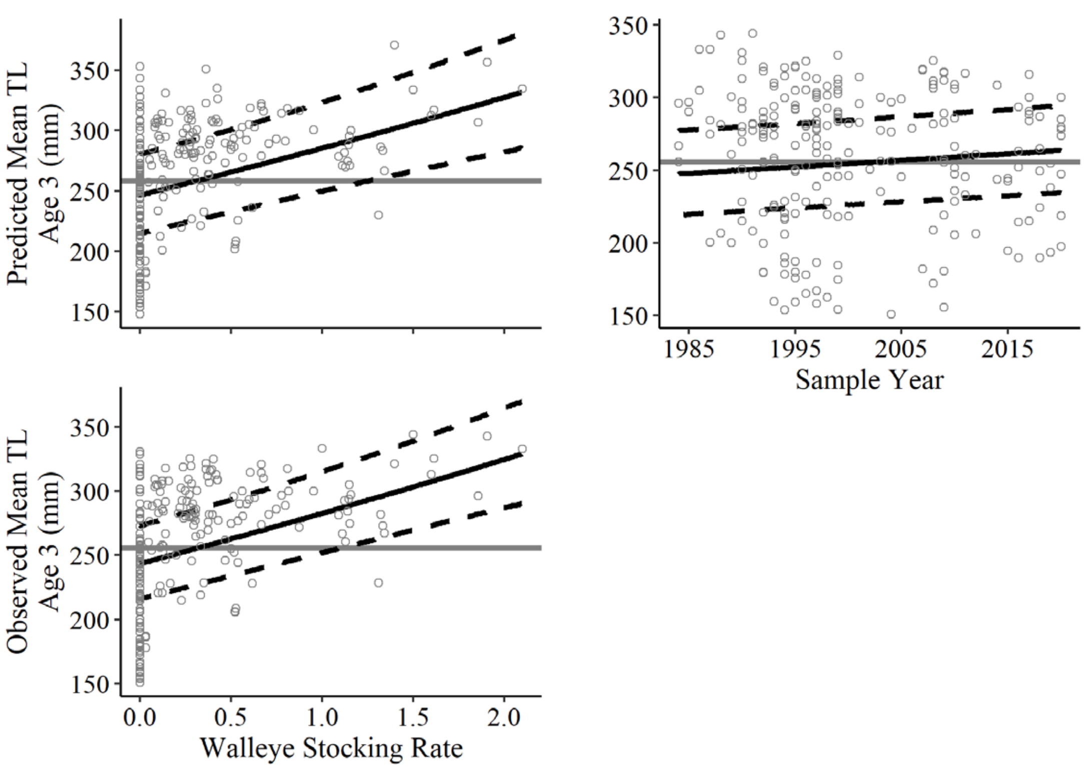

Figure 6. Predicted mean (black line) and 95% confidence intervals (dashed lines) for significant predictors (i.e., different from zero) from top ranked linear mixed-effects models (Table 2) for predicting observed and predicted mean total length (TL) at age 3 for white crappie across Oklahoma sample reservoirs. Included are individual observations (gray circles) and mean across all observations (gray line) of observed and predicted mean TL at age 3.

Discussion

Our study demonstrates that walleye stocking may improve white crappie maximum size (based on L_∞), along with observed and predicted size at age 2 and 3. However, variation in K across our sample reservoirs was dictated primarily by the dynamics of each reservoir. This suggests that although L_∞ and average TL at modeled ages may increase with stocking, reservoir-specific biotic or abiotic effects are likely important when determining the actual rate of growth. Reservoir-specific abiotic (e.g., water temperature, precipitation; Hale 1999, Pope et al. 2004) and biotic factors (e.g., predator density, density dependence; Guy and Willis 1995, Miazga et al. 2024) have been related to growth in crappie across North America. Statistically, this was confirmed by the large amount of variation explained by the reservoir random effect in our analyses.

Interestingly, saugeye stocking and annual saugeye stocking rate were insignificant (based on 95% CI) when included in top ranked models. This suggests saugeye stocking had minimal effects on white crappie growth rates within our reservoirs. This confirms prior findings by Shoup and Carl (2023) who suggested saugeye stocking did not improve white crappie demographics in Oklahoma reservoirs. However, this disagrees with Boxrucker (2002) who found saugeye introductions improved white crappie demographics on Lake Thunderbird, Oklahoma. However, Boxrucker (2002) also observed declines in relative weights of quality-sized white crappie, which they attributed to increased intraspecific competition of 200–249 mm TL fish. Therefore, it is possible that inconsistent results among studies are due to system-specific differences across a broader range of Oklahoma reservoirs exacerbating intraspecific competition of white crappie through trophic cascade processes.

The coarse nature of our analysis precluded us from determining the mechanism behind larger white crappie TLs; however, walleye stocking, sample year, and annual walleye stocking rate were suggested to be significant predicters (based on 95% CIs). Sample year has been noted as an important predictor of crappie population metrics in prior studies (Shoup and Carl 2023); however, it had a relatively weak relationship in our study. We are unable to explain why walleye stockings or the rate at which walleye were stocked were the top significant predictors in our models. Walleye are known to prey upon black crappie and other *Microperus* spp. (e.g., bluegill [*Lepomis macrochirus*], Chipps and Grab 2011); however, it is unclear if these observations are applicable to white crappie populations (see McInerny and Cross 2008, Garvaglia 2019). Conversely, it is possible that walleye stocking is a bottom-up control, as white crappie have been documented feeding on walleye fry (Chipps and Graeb 2011). Furthermore, white crappie abundance has been inversely correlated with walleye recruitment in Kansas reservoirs (Quist et al. 2003). This suggests that walleye stocking may exhibit both top-down and bottom-up influences on white crappie TL metrics (i.e., L_∞; TL at age). Furthermore, system-specific biotic or abiotic factors may interact with walleye stocking, resulting in variable effects on white crappie TL metrics, similar to what was observed for saugeye (Boxrucker 2002; Shoup and Carl 2023). We recommend future studies look at effects of walleye stocking strategies (e.g., fingerling; fry) and their effects on white crappie population metrics to determine the mechanistic cause (i.e., top-down; bottom-up) behind the relationships we observed.

Our analysis comparing results from observed and predicted mean white crappie TL at ages 2 and 3 suggests that predicted mean TL may be substituted for known mean TL when observations at that age are unavailable. However, interpretation of the results should be conducted cautiously as several differences were noted when we compared candidate sets and coefficient estimates from linear mixed-effects models estimated using observed and predicted data. The top-ranked models for observed and predicted mean TL at ages 2 and 3 were the same, but other differences were observed in candidate set model rankings. Observed and predicted mean TL at age 2 produced similar coefficient estimates for all parameters. Conversely, sample year was significant (i.e., different from zero) for predicted mean TL at age 3 and insignificant for observed mean TL at age 3. Regardless, the strongest predictor, annual walleye stocking rate, was similar across all models. This suggests von Bertalanffy estimates reflected the observed size distribution from each sample and that estimates from growth curves may be used to estimate mean size for when data for particular age groups are lacking (e.g., Bonvechio et al. 2015) or when deriving size at age from literature growth parameters. However, caution is advised when interpreting results with weak (i.e., marginally different from zero) relationships, especially when using predicted mean TLs from growth models as a response variable.

Our results suggest that walleye stocking may be a more effective management strategy than saugeye stocking for improving white crappie size metrics. Given the potential mechanism (i.e., bottom-up, top-down) behind walleye stocking effects on white crappie populations are poorly understood, further evaluation of stocking strategies (e.g., fingerling; fry) is needed. Likewise, a large proportion of variance in all models was explained by reservoir-specific effects. This suggests abiotic and biotic variables known to influence white crappie population dynamics (e.g., lake size, predator density; Miazga et al. 2024) should be studied in tandem with walleye stocking to better understand its potential usefulness for unstocked reservoirs. Studies such as these would allow managers to better discern the potential success of walleye stocking relative to other potential management actions (e.g., prey manipulation, harvest regulations; Boxrucker and Irwin 2002) as walleye are nonnative to many parts of the southeast U.S. (Billington et al. 2011). Given we hypothesized walleye may influence white crappie growth based on their diet, it also may be worthwhile to investigate the potential effects of sauger population manipulation on crappie population dynamics (Chipps and Graeb 2011). This is especially true in areas where saugers are native.

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