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Articles

Population Demographics of Sauger and Simulated Effects of Minimum Length Limits in the Kaskaskia and Ohio Rivers

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Abstract

Sauger *Sander canadensis* are a popular sport fish native to large turbid midwestern rivers and are in decline across much of their range due to habitat loss and exploitation. Specifically, within the lower Kaskaskia and Ohio rivers, Sauger are managed under different harvest regulations and a knowledge gap exists regarding the current status of both populations as well as the effects of the harvest regulations on the size and age structures of both populations. We collected Sauger by nighttime boat electrofishing during early winter 2014–2016 and used otoliths to age all fish. Sauger stocks in both rivers exhibited fast growth rates and high annual mortality rates. Yield-per-recruit modeling indicated that the current 356-mm minimum size limit for Sauger in the Kaskaskia River is sufficient to prevent growth overfishing and likely explains the consistently larger size structure (greater proportion of fish $\geq$356-mm total length) of Sauger sampled from the Kaskaskia River compared with the Ohio River. Modeling suggested that growth and recruitment overfishing of Sauger are likely occurring in the Ohio River with no minimum length limit based on available exploitation estimates for Sauger in the lower Ohio River. Implementing a 356-mm minimum length limit for Sauger in the lower Ohio River is predicted to prevent growth and recruitment overfishing based on available exploitation rate estimates and would be consistent with the statewide minimum length limit for Sauger in Illinois and minimum length limits on two major tributaries (Tennessee and Cumberland rivers downstream of Kentucky and Barkley lakes, respectively).

Keywords: population demographics; regulations; Sauger

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Introduction

Sauger *Sander canadensis* is a popular recreational fish species native to the Great Lakes–St. Lawrence, Hudson Bay, and Mississippi River basins (Page and Burr 1991). In the central United States, Sauger primarily occur in relatively large rivers and prefer slow-moving, turbid water relative to other members of the percid family (Pegg et al. 1997). Although once abundant, Sauger populations have experienced dramatic declines and have become extinct in some systems according to the International Union for Conservation of Nature Red List (NatureServe 2013). These declines have been attributed to a multitude of anthropogenic factors including habitat alteration and loss, exploitation, and hybridization with Walleye *Sander vitreus* (Graham 1997; Gerken and Paukert 2009). Their popularity as a sport fish and habitat requirements throughout their life make Sauger especially susceptible to population declines. Specifically, dam construction can impede access to suitable spawning habitat and therefore potentially limit natural reproduction (Nelson 1968; Pegg et al. 1997). Anthropogenic influences such as alteration of flow and temperature regimes, channelization, and sedimentation have negatively affected Sauger populations due to their specific life-history requirements and have also led to declines in some populations (Baxter and Glaude 1980; Pegg et al. 1997; Humphries and Lake 2000; Jaeger et al. 2005; Graeb et al. 2009; Haxton and Findlay 2009).

Despite declining populations, Sauger remain an important sportfish throughout their range and are highly sought after because of their quality as a food fish. Sauger were once believed to be a relatively unexploited species; however, recent studies have documented exploitation rates on Sauger populations commonly exceeding 40% (Pegg et al. 1996; Maceina et al. 1998; Pitlo et al. 2004). Dams concentrate Sauger in tailwater areas by impeding their upstream movements and spawning migrations, which make them susceptible to overfishing (Hesse 1994; Pegg et al. 1996; Maceina et al. 1998). Heavily exploited Sauger populations generally exhibit high mortality rates and truncated size and age structures, with few individuals surviving past age 3 (Buckmeier 1995; Pegg et al. 1996; Maceina et al. 1998). As a result of overexploitation, management agencies have implemented various fishing regulations to attempt to prevent high mortality rates associated with harvest (Maceina et al. 1998). Graham et al. (2015) suggested that Sauger minimum length limits in Kentucky Lake and Watts Bar Lake on the Tennessee River likely prevented recruitment and growth overfishing, which is defined as the point at which fish are being harvested before the maximum growth potential of the population can be reached, thereby reducing yield. For example, a minimum size limit of 381 mm coupled with a reduced daily bag limit was implemented in the upper Tennessee River, which resulted in improved size and age structure of the population, compared with previous population surveys (Hickman et al. 1990; Buckmeier 1995; Maceina et al. 1998). Without a minimum length limit in the lower Tennessee River and Cumberland River, Sauger older than age 3 were rare (Buckmeier 1995; Maceina et al. 1998). Additionally, in the lower Tennessee River in Alabama, a 356-mm minimum length limit was imposed on an overexploited, declining Sauger population in an attempt to improve population size structure and limit recruitment and growth overfishing (Maceina et al. 1998).

The Kaskaskia and Ohio rivers support popular Sauger sport fisheries, particularly in winter and early spring, and are currently managed under different regulations. Sauger in the Kaskaskia River in Illinois are managed under a 356-mm minimum length limit with a daily harvest limit of 6 fish, whereas there is currently no minimum length limit and a 10-fish daily harvest limit in place for Sauger in the lower Ohio River, which forms the boundary between Kentucky and both Indiana and Illinois. Differences in management strategies for Sauger between these two rivers may have contributed to differences in size structure observed in previous surveys of each river (Schell et al. 2004). However, the effects of the current regulations have not been further evaluated, despite the potential for great exploitation on Sauger populations in these rivers. Annual sampling of the Sauger population in the Kaskaskia River is conducted, but population dynamics have not been evaluated. A previous study and creel survey conducted on the lower Ohio River from 1998 to 2003 found that Sauger were abundant, but populations had truncated size and age structures along with high mortality rates in all seven navigation pools (Schell et al. 2004). The creel survey indicated that Sauger were the second-most popular sport fish in this system and harvested Sauger were generally 300–400-mm in length and 1–3 y old (Schell et al. 2004).

There is currently a lack of recent analyses of Sauger populations in the Ohio and Kaskaskia rivers despite the potential for overexploitation to occur. Therefore, the objective of our study was to determine whether Sauger populations in the lower Kaskaskia River and five navigation pools on the lower Ohio River exhibited characteristics of overexploitation. To reach our objective, we 1) compared population metrics from published data on other Sauger populations with those for Sauger in the Ohio and Kaskaskia rivers, and (2) identified potential factors contributing to differences in population demographics of Sauger between these two rivers. Additionally, to determine alternative management practices for Sauger populations, we simulated effects of current and potential (356-mm minimum length limit for Ohio River Sauger) length limits on Sauger fisheries in the lower Kaskaskia and lower Ohio rivers.

Study Area

Kaskaskia River

The Kaskaskia River is the second-longest river that flows entirely within Illinois (~523 km) and drains 15,022 km^2 in the southern half of the state (Figure 1) with a mean annual discharge of 155 m^3/s (U.S. Geological Survey 2017). Two impoundments originally constructed for flood control occur along the river. The uppermost dam creates Lake Shelbyville, a 4,451-ha reservoir. Further downstream, the second dam creates 10,522-ha Carlyle Lake, which is the largest inland lake in the state. A navigation lock and dam was later constructed near the confluence with the Mississippi River, thus converting the lowermost section of the Kaskaskia River into an impoundment-like, 58-km-long navigation channel (Krohe 2001).

The specific area of interest for this study was the lower Kaskaskia River, which includes the section of river from Carlyle Lake dam to the confluence with the Mississippi River. Most of the land use surrounding the study area is agricultural, which results in siltation and turbid water throughout much of the lower river. An important recreational Sauger population exists in this reach. The population origin is unknown, but it is likely a combination of naturally reproduced and stocked individuals; suitable spawning habitat exists throughout this reach, but Carlyle Lake and this reach are semi-

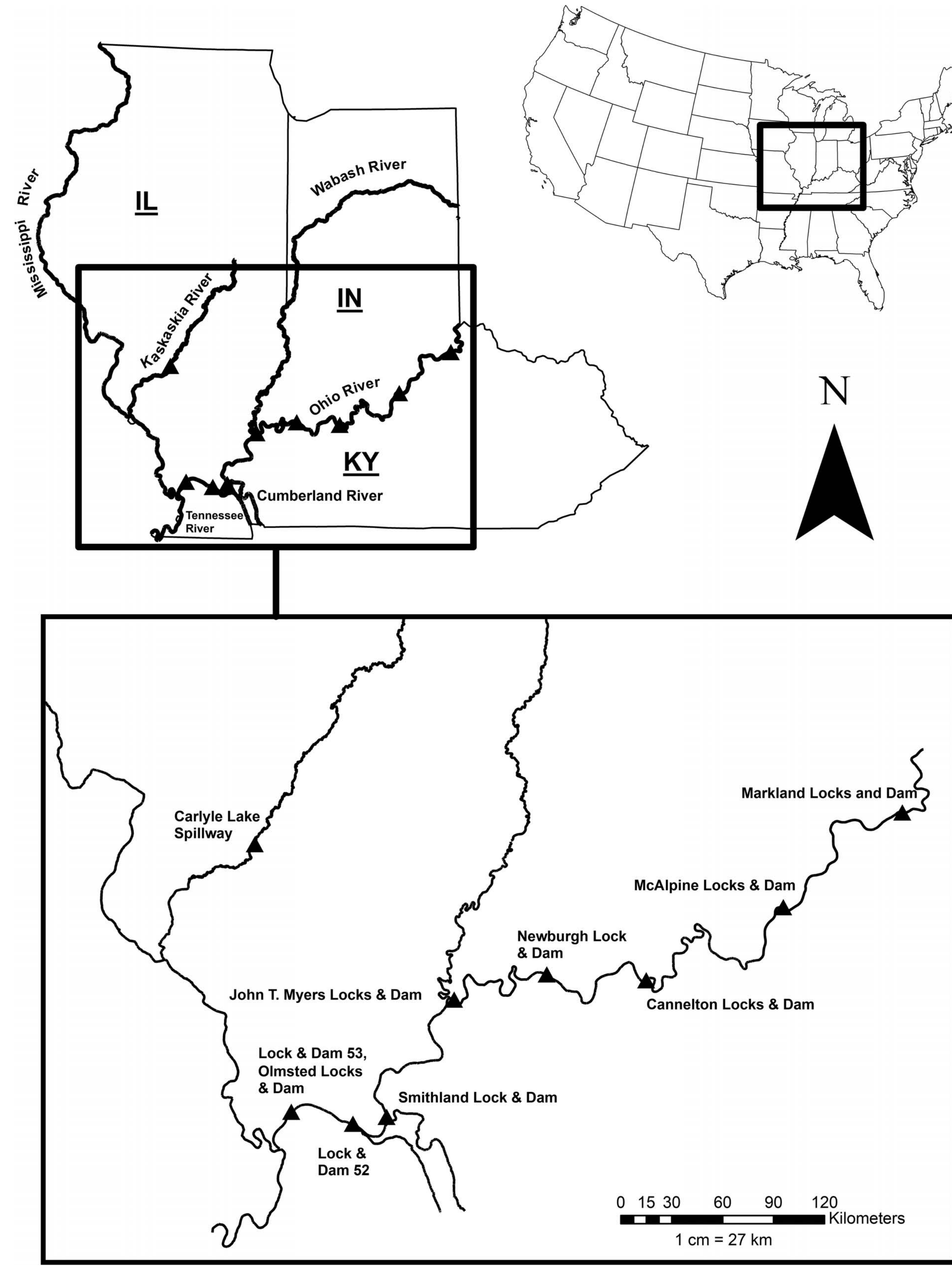

Figure 1. Map of Sauger *Sander canadensis* sampling locations on the Kaskaskia and Ohio rivers during 2014–2016. Triangles denote locations of locks and dams at which sampling occurred directly downstream of.

regularly stocked with fry and fingerlings (R. Sauer, Illinois Department of Natural Resources, personal communication). The fishery in this reach is managed with a 356-mm minimum length limit and a 6-fish daily bag limit for both Sauger and Walleye.

Ohio River

The Ohio River is a heavily impounded and channelized river that is the largest tributary by volume to the Mississippi River, with a mean annual discharge of 7,957 m^3/s (Leeden et al. 1990). The headwaters occur at the confluence with the Allegheny and Monongahela rivers in Pennsylvania and the river ends at Cairo, Illinois, where it flows into the Mississippi River. Water levels are regulated by a series of 20 locks and dams constructed to support commercial navigation. The lower Ohio River study area forms the border between Kentucky and both Indiana and Illinois (Figure 1). This study focused on five navigation pools; we conducted sampling in the tailwaters of five locks and dams, including Markland Lock and Dam (McAlpine Pool; river km 855.4), Cannelton Lock and Dam (Newburgh Pool; river km 1,159.9), John T. Myers Lock and Dam (river km 1,362), Smithland Lock and Dam (river km 1,478.8), and the open river below the farthest downstream dam (Lock and Dam 53) on the Ohio River. Olmsted Lock and Dam is under construction and will replace two wicket-style dams (dams 52 and 53) that are the first dams on the Ohio River upstream from its confluence with the Mississippi River. Popular tailwater Sauger fisheries exist below each of these dams and there is currently no minimum length limit for Sauger and a 10-fish daily bag limit (aggregate with Walleye or Sauger × Walleye hybrid) in this section of the Ohio River.

Methods

Fish sampling and age estimation

We collected Sauger from the tailwater of Carlyle Lake dam on the Kaskaskia River during autumn 2015 and from the five navigation pools specified on the Ohio River during November–December 2014–2016 using pulsed, direct-current boat electrofishing at 60 pulses/s standardized to a 3000-W power goal (Burkhardt and Gutreuter 1995). We did not sample Smithland Pool and the open river section of the Ohio River in 2014 or 2016. Sampling occurred after sunset and until we reached a target sample size of 90 fish in the Kaskaskia River and recorded the total time sampled. We sampled the Ohio River pools with six 10-min runs/pool that resulted in a 1 h of electrofishing for each navigation pool during each year following protocols established by the Ohio River Fisheries Management Team. Sampling occurred in the tailwaters of each dam with three sites on each side of the river, beginning near the dam and working downstream. We recorded total length (nearest mm) and weight (nearest g) of Sauger and removed sagittal otoliths (Table S1, *Supplemental Material*). For fish >127 mm in length, we kept 3 fish/25.4-mm length group for age estimation from the McAlpine, J.T. Myers, and Newburgh pools. We retained all fish from the Smithland and open river pools for age estimation.

We embedded sagittal otoliths in epoxy and allowed them to dry for 24 h. We then sectioned one otolith from each fish in the transverse plane on both sides of the otolith primordium using a Buehler low-speed ISOMET saw and polished it to reveal annuli (Zeigler and Whitledge 2011). Readers observed otolith sections using a dissecting microscope to estimate fish age based on annuli counts. Ages were estimated by two independent readers who had no knowledge of fish length. If age estimates differed between readers, both readers reobserved the otolith section until they reached a consensus; consensus was reached in all cases.

Estimation of population demographics

To assess differences in population demographics between rivers and among Ohio River navigation pools, we evaluated relative abundance (catch per unit effort), size structure, recruitment indices (i.e., year class strength), mortality, growth, and condition of Sauger (Table S2, *Supplemental Material*). We calculated catch per unit effort as the number of Sauger captured per hour of electrofishing. We evaluated size structure by estimating proportional size distribution (Neumann and Allen 2007) and minimum relative size distribution (MIN-RSD) based on a 356-mm minimum length limit (number of fish $\geq$356 mm total length / number of fish $\geq$minimum stock length [203-mm total length]). We used nonparametric tests (Kruskal–Wallis test, Wilcoxon 2-sample rank sum test) to evaluate differences in mean length at age at capture between the Kaskaskia and Ohio rivers because data were not normally distributed and did not exhibit variance homogeneity. We maintained an alpha level of 0.05 in all statistical analyses.

We assessed differences in mean length at age between Ohio River pools combined by examining 95% confidence limits of L_{inf} and K derived from the Gompertz growth model. We estimated mortality rates and year class strength using weighted catch curves constructed from log-transformed catch-at-age data (Maceina and Pereira 2007). We calculated residuals separately for each year of sampling for the Ohio River. The sign and magnitude of residuals from the catch-curve regression indicated relative year-class strength, where larger, positive residuals indicated years of higher recruitment and zero or negative residuals indicated years of poorer recruitment. We calculated instantaneous mortality (Z) from the slope of the regression from the descending right limb of the age-frequency distribution for Sauger from each river (Miranda and Bettoli 2007). We considered all age classes fully recruited to our gear at the time of sampling because the majority of fish were $\geq$200 mm in length during the autumn survey period, and were therefore used in mortality estimates.

For the Ohio River, we pooled data across all sampling years and estimated mortality for each pool separately and then combined data from each pool for an overall estimate for the Ohio River. We then estimated total annual mortality (*A*, %) as $1 - e^{-z}$. We assessed growth by first fitting multiple growth models (von Bertalanffy and Gompertz models) for Sauger from each of the two rivers to determine which model provided the best fit to mean-length-at-age data. We chose a model based on coefficient of determination values and examination of parameters resulting from each models. We then chose the Gompertz growth model to evaluate Sauger growth because of unrealistic parameters (L_{inf}) produced by the von Bertalanffy model and predicted length vs. age formed an S-shaped curve that best fit the data (Quinn and Deriso 1999a). WE calculated relative weight (*Wr*) for each Sauger to describe condition and estimated mean *Wr* values for fish from the Kaskaskia River and from each of the five pools in the Ohio River (Guy et al. 1990).

Population modeling

We used Fisheries Analysis and Modeling Simulator (FAMS) version 1.64 to develop yield-per-recruit simulation models to assess the effect of the current 356-mm minimum length limit for Sauger in the Kaskaskia River (in comparison with no minimum length limit) and to predict effects of potential implementation of a 356-mm minimum length limit for the lower Ohio River Sauger fishery in comparison with the current absence of a minimum length limit for Ohio River Sauger. We selected a 356-mm minimum length limit for modeling simulations of Ohio River Sauger because this is the current statewide minimum length limit for Sauger in Illinois, excluding the Mississippi, Ohio, and Wabash rivers and other locations where site-specific regulations are in effect. A 356-mm minimum length limit for Sauger is also currently in effect in the Tennessee and Cumberland rivers in Kentucky downstream of Kentucky Lake and Lake Barkley; the Tennessee and Cumberland rivers are tributaries of the Ohio River within the study area.

We obtained Brody growth coefficients, L_{inf}, and slopes and intercepts of weight–length relationships from data collected from this study and used them in the yield-per-recruit model for each river; and we maintained an alpha level of 0.05 throughout analysis. We used L_{inf} and *K*-values obtained from fitting the Gompertz growth model to length-at-age data in FAMS modeling simulations because the von Bertalanffy model fit to length-at-age data yielded unrealistically high L_{inf} values for Sauger. The FAMS model uses the von Bertalanffy growth model in simulations; however, we manually entered L_{inf} values estimated from Gompertz growth models in FAMS software to avoid use of unrealistic L_{inf} values in modeling simulations. We obtained maximum age from each river and set it at age 5 for the Kaskaskia River and age 4 for the Ohio River. We estimated conditional natural mortality (CNM) in FAMS using all possible estimators (Pauly 1980; Hoenig 1983; Peterson and Wroblewski 1984; Chen and Watanabe 1989; Lorenzen 1996; Quinn and Deriso 1999b). We then used the average of all estimated rates and the lowest estimator in the models to determine the effects of 356-mm and no minimum length limits on yield under the full range of potential exploitation rates (0–100%). The Lorenzen (1996) natural mortality estimator yielded the lowest estimate for both rivers. We modeled the Ohio River Sauger stock using data from all pools combined at 33% and 53% CNM and modeled the Kaskaskia River stock at 31% and 46% CNM (Table S3, *Supplemental Material*). Our estimates of CNM were similar to previous estimates reported for other studies that ranged from 25 to 40% for Sauger populations (Maceina et al. 1998; Graham et al. 2015).

To evaluate the potential for the occurrence of recruitment overfishing under each simulated minimum length limit, we assessed spawning potential ratio (SPR) at all ranges of exploitation (0–100%; Table S4, *Supplemental Material*). Spawning potential ratio is the number of eggs produced by females in a population at a given level of exploitation divided by the total number of eggs produced in the population if exploitation rate was zero (Goodyear 1993; Maceina and Pereira 2007). Spawning potential ratio ranges from 0 to 1 and decreases toward 0 as exploitation increases; SPR values below some critical threshold are considered indicative of recruitment overfishing (Maceina and Pereira 2007). A critical SPR value has not been determined for Sauger, so we used an SPR value of 0.2 as the point at which recruitment overfishing would theoretically begin to occur, based on its application to other freshwater sport fishes (Slipke et al. 2002). We used a linear fecundity (number of mature eggs per female)–total length (mm) relationship derived from Sauger in Pool 22 of the Mississippi River (number of eggs = 150,708 total length − 510.78; K. Seibert, unpublished data). Based on published literature, we assumed Sauger were sexually mature at age 3 (Carufel 1963; Walburg 1972), spawned annually, and had a 50:50 sex ratio (Bozek et al. 2011). We ran all simulations with the fixed recruitment option and began with an initial population size of 1,000 recruits.

Results

Population demographics

Kaskaskia River. We captured 90 Sauger in 1 h of electrofishing in the Kaskaskia River in 2015. The Kaskaskia River population was composed of a larger size structure relative to the Ohio River population, with 42% of individuals sampled from the Kaskaskia River being ≥356 mm total length (Figure 2). Additionally, Kaskaskia River Sauger exhibited an older age structure than the Ohio River where fish age ≥3 represented 17% of the population (Figure 3). Similar to the Ohio River, the 2012 (age 3) year class was strongest with a residual of 0.38, while the 2014 and 2011 year classes were weakest with residuals of −0.64 and −0.10, respectively.

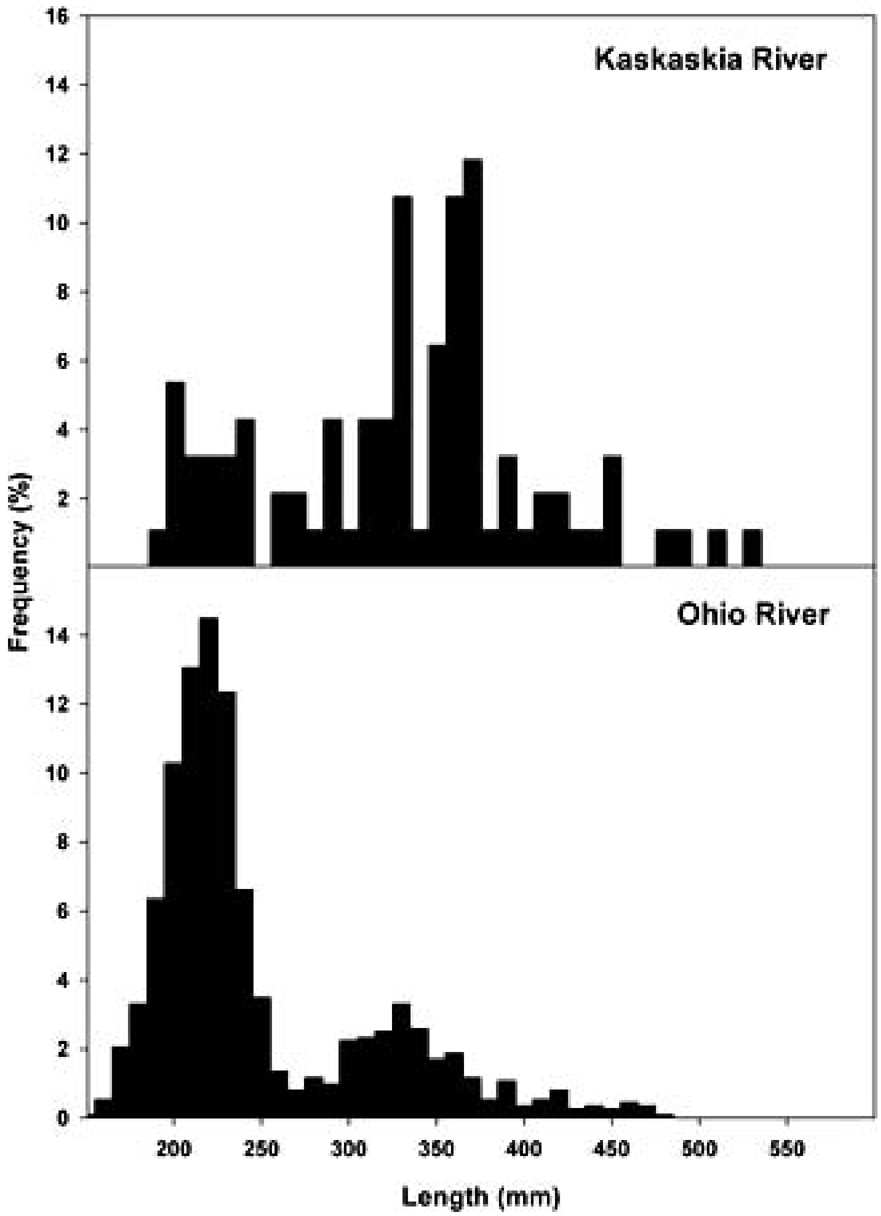

Figure 2. Length frequency distribution of Sauger *Sander canadensis* collected from Kaskaskia River (top) below Carlyle Lake dam and from five pools of the lower Ohio River (bottom) including McAlpine, Newburgh, J.T. Myers, and Smithland pools and the lower (open) river via nighttime boat electrofishing during autumn 2014–2016.

Sauger mean length at age in the Kaskaskia River was significantly smaller than mean length at age for Ohio River Sauger at ages 0–3 ($\chi^2 = 6.53–17.03$, $df = 1$, $P <$ 0.0001–0.01; Figure 4). Growth coefficients (*K*-values) were also high for the Kaskaskia River, although less than for fish from the Ohio River (Table 1). Growth coefficients estimated by the Gompertz growth model best described mean length at age ($r^2 = 0.99$, $df = 3$, $P < 0.0001$; Table 1a).

Ohio River. We collected 1,776 Sauger from the Ohio River during 2014–2016. Catch rates were high across all pools and were highest in 2016 with a mean of 223 fish/h (SE = 101.8). We observed the highest catch rates in the Newburgh Pool in 2016 and 2015, followed by the J.T. Myers pool in 2015. The length frequency distribution pooled for all years consisted of mostly small individuals with only 6% of the total sample being $\geq$356 mm total length (Figure 2). The age 0 and age 1 year classes dominated the samples in all pools and represented 65% and 32%, respectively, of the total sample (Figure 3). We only observed the 2012–2015 year classes; our residual analysis indicated a strong year class in 2012 across all pools while the 2013 and 2014 year classes were weakest.

The Gompertz growth model adequately described Sauger mean length at age for all pools combined ($r^2 =$ 0.99, $df = 3$, $P < 0.0001$; Table 1a). Predicted length vs. age formed an S-shaped curve that best fit the data

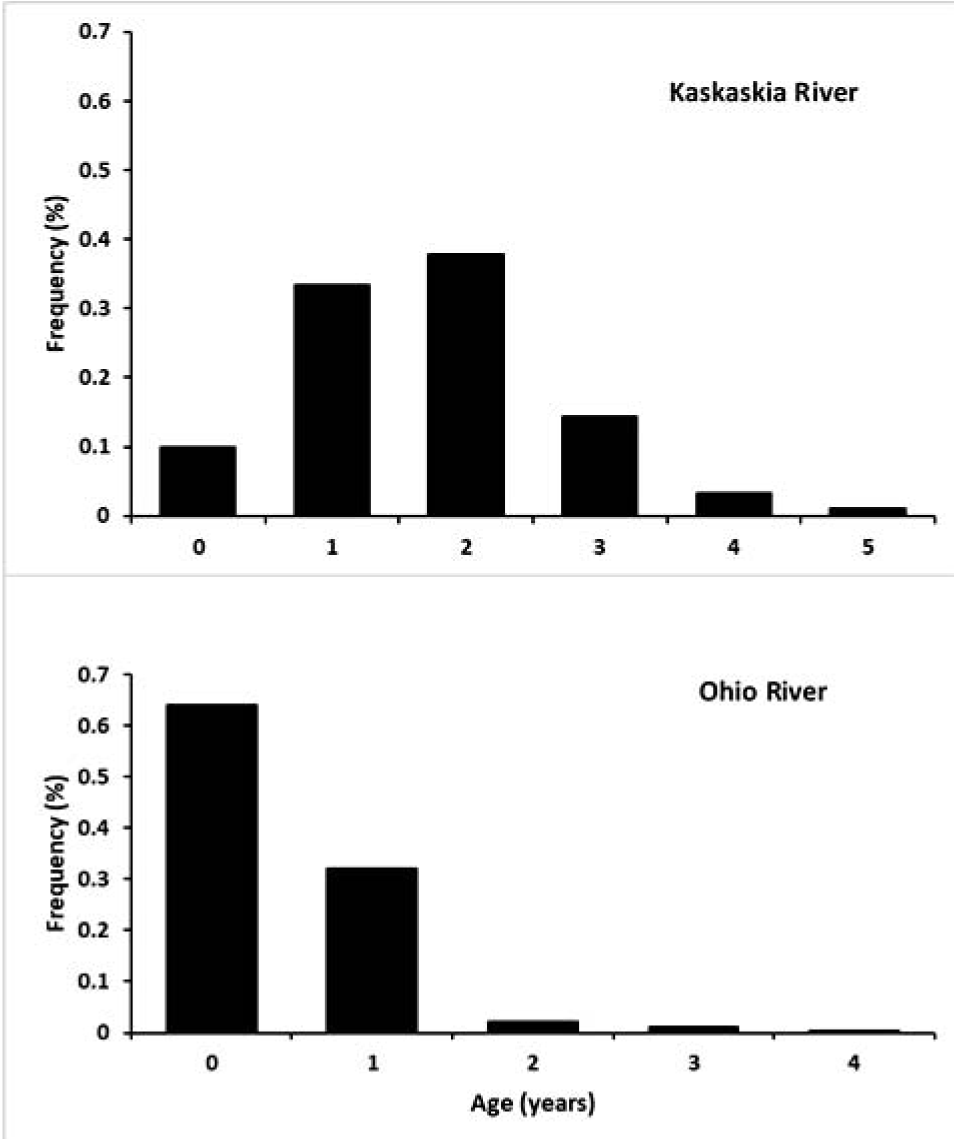

Figure 3. Age frequency distribution of Sauger *Sander canadensis* collected from the Kaskaskia River (top) below Carlyle Lake dam and five pools of the lower Ohio River (bottom) including McAlpine, Newburgh, J.T. Myers, and Smithland pools and the open river via nighttime boat electrofishing during autumn 2014–2016.

(Quinn and Deriso 1999a). When we examined pools separately, we found that J.T. Myers Pool resulted in a higher L_{inf} relative to the other pools followed by Newburgh, McAlpine, Lower, and Smithland pools (Table 1b). Mean *Wr* for Sauger was highest in 2014 ($Wr = 92.60$, SE = 1.02) and lowest in 2016 ($Wr = 89.60$, SE = 1.83). *Wr* was similar among pools of the Ohio River, while mean *Wr* was slightly higher for the Ohio River (pools combined) when compared with the Kaskaskia River sample.

Population simulations

Kaskaskia River. Modeling simulations indicated that, under the current 356-mm minimum length limit, growth overfishing did not appear to be an influence when modeled at 31% CNM (Figure 5). Yield increased with increasing levels of exploitation rates under the 356-mm minimum length limit with 46% CNM rate (Figure 5). However, the 356-mm minimum length limit did not produce an increase in yield until exploitation exceeded 34% when CNM was high (46%; Figure 5). Theoretically, if no minimum length limit were in place, growth overfishing would be apparent when exploitation rates exceeded 30% with CNM at 31% (Figure 5). Growth overfishing was also evident at exploitation rates >35% when modeled at 46% CNM (Figure 5). Overall, with the 356-mm minimum length limit, yields were much higher when CNM was low (31%) and when exploitation exceeded 20% (Figure 5). Additionally, the current regulation prevented SPR from falling below the 20% threshold until 48% exploitation (Figure 6). With no minimum length limit, the spawning-potential ratio

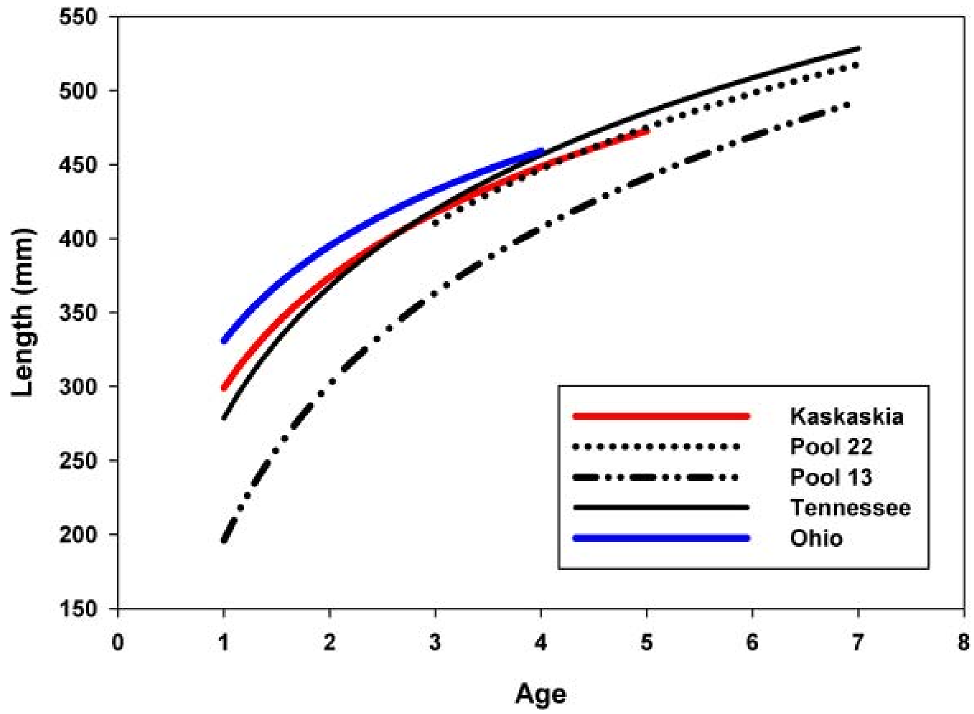

Figure 4. Mean length (mm) at age of Sauger *Sander canadensis* collected from the Kaskaskia River below Carlyle Lake dam, and five sections of the lower Ohio River (McAlpine, Newburgh, J.T. Myers, and Smithland pools; open river), Pool 22 of the Mississippi River, Pool 13 of the Mississippi River, and the Tennessee River, Tennessee, USA. We obtained mean length at age data for Pool 22 of the Mississippi River from Yallaly et al. (2014), data from Pool 13 of the Mississippi River from Pitlo et al. (2004), and Tennessee River data from Buckmeier (1995).

model predicted that the potential for recruitment overfishing would likely occur at exploitation rates ≥25% (Figure 6).

Ohio River. Under the no-length-limit regulation (current regulation), the yield-per-recruit model predicted that yield would be greatly reduced when compared with the 356-mm minimum length limit at all exploitation rates >20% and when CNM was 33% (Figure 7). Additionally, a 356-mm minimum length limit would prevent growth overfishing, which was apparent at exploitation levels >35% under no minimum length limit (Figure 7). Yield was also reduced under the no-length-limit regulation and growth overfishing was apparent at exploitation rates >35% when modeled at a CNM rate of 53% (Figure 7). Exploitation is likely 30–40% within the Ohio River, based on anecdotal evidence and characteristics of the fishery; however, no current estimate of exploitation exists. Overall, yield was highest when CNM was low (33%) with a 356-mm minimum length limit. The spawning-potential ratio model indicated that SPR fell

Table 1. Estimated population demographic parameters for Sauger *Sander canadensis* collected from a) the Kaskaskia and Ohio rivers (data from 5 sampled navigation pools combined) during 2014–2016, and b) each of five navigation pools of the lower Ohio River during 2014–2016. Growth parameters are reported as theoretical maximum total length (L_{inf}, mm) and the growth coefficient (*K*) with 95% confidence limits (CL). Mortality is reported as instantaneous total mortality (*Z*) and total annual mortality (*A*, %). Also shown are mean relative weight (*Wr*) ± standard error (SE), proportional size distribution (PSD) and minimum relative size distribution (MIN-RSD) based on a 356-mm minimum length limit.

	Parameters					
	L_{inf} (CL)	*K* (CL)	*Z* (*A*)	*Wr* (SE)	PSD	MIN-RSD
a. River						
Kaskaskia	584 (395–773)	0.36 (0.15–0.58)	−0.70 (0.50)	88.30 (0.90)	69	44
Ohio	531 (505–558)	0.50 (0.46–0.55)	−0.73 (0.52)	90.80 (0.45)	26	10
b. Pool						
Lower	458 (401–514)	0.81 (0.53–1.09)	−0.91 (0.60)	89.24 (0.80)	36	7
Smithland	453 (408–498)	0.96 (0.62–1.31)	−0.84 (0.57)	90.24 (0.79)	23	15
J.T. Myers	507 (477–539)	0.77 (0.67–0.88)	−0.44 (0.35)	92.33 (1.53)	21	4
Newburgh	486 (457–515)	0.64 (0.55–0.74)	−0.73 (0.52)	91.79 (0.84)	32	4
McAlpine	465 (432–499)	0.71 (0.59–0.84)	−0.64 (0.47)	91.56 (1.12)	29	15

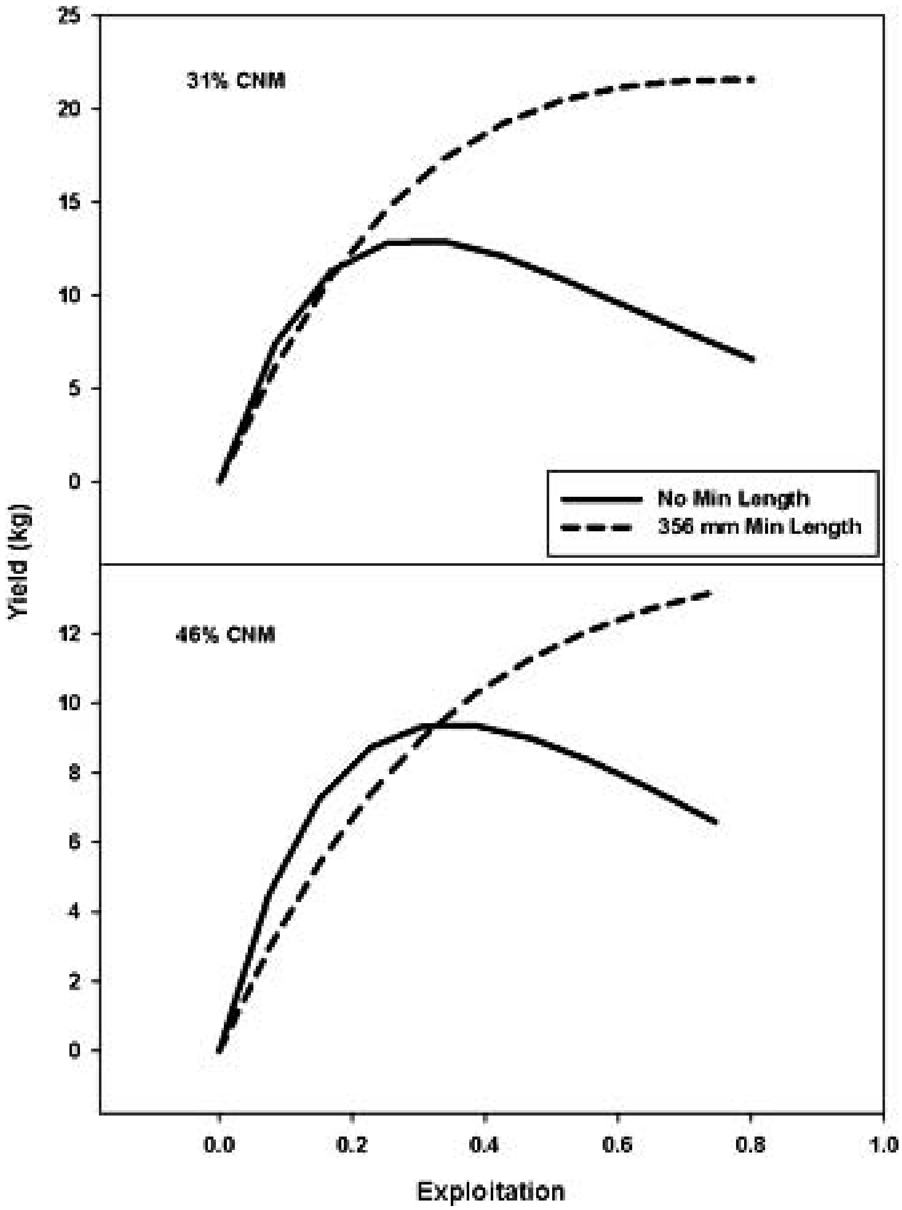

Figure 5. Simulated yields (kilograms) for Sauger *Sander canadensis* collected from the Kaskaskia River below Carlyle Lake dam during 2014–2015 under two minimum (Min) length limit scenarios and two conditional natural mortality (CNM) rates.

below the 20% threshold at approximately 30% exploitation with no minimum length limit (Figure 6). However, with imposition of a 356-mm minimum length limit, recruitment overfishing would be unlikely to occur until approximately 53% exploitation (Figure 6).

Discussion

Sauger were abundant in both study rivers; however, the Ohio River had much higher catch rates than the Kaskaskia River. Specifically, we observed the highest catch rates in the Newburgh Pool throughout 2 y of sampling. Similar catch rates have been observed in the Ohio River since 2000 when surveys documented catch per unit effort as high as 591 fish/h in McAlpine Pool during spring electrofishing (Schell et al. 2004). The high catch rates of age 0 and age 1 fish throughout multiple years of sampling likely indicate high and fairly consistent recruitment in the Ohio River. In the present study, the 2012 class was strongest in all pools of the Ohio River and in the Kaskaskia River. According to the Ohio River Newburgh Lower gauge station, water level fluctuations were considerably lower during the spring and summer of 2012 compared with 2013–2015, which may have aided Sauger recruitment (U.S. Army Corps of Engineers 2017). Moreover, years with negative catch-curve residuals (2013–2014) exhibited more variable water levels throughout the spawning and growing seasons (i.e., March–August; U.S. Army Corps of Engineers 2017). Negative effects of high water-level fluctuations on Sauger recruitment have been docu-

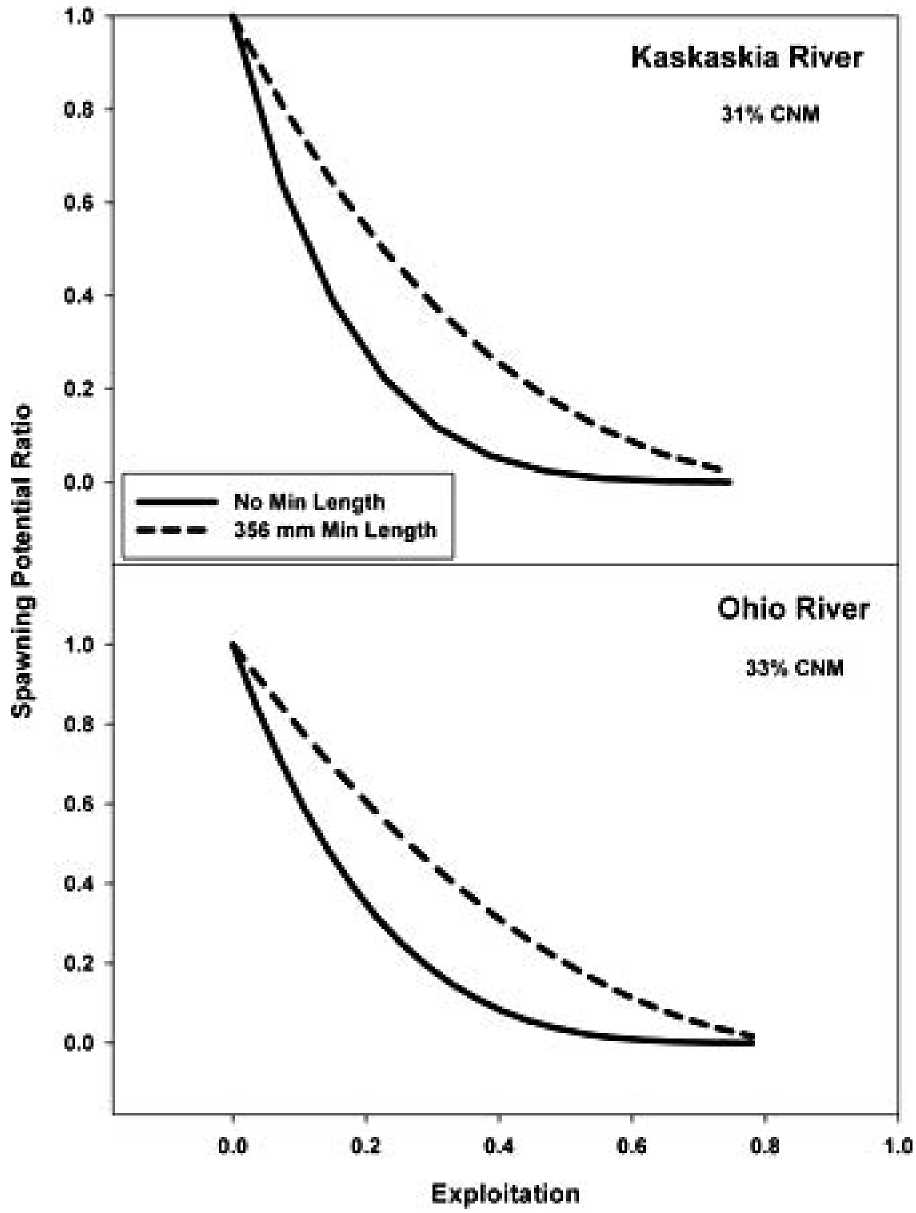

Figure 6. Simulated Spawning-Potential Ratio values of Sauger *Sander canadensis* collected from the Kaskaskia River (top) below Carlyle Lake dam and four Ohio River pools (McAlpine, Newburgh, J.T. Myers, and Smithland) and the open river section (combined; bottom) under two minimum (Min) length limit scenarios and their respective estimated conditional natural mortality (CNM) rates during 2014–2016.

mented by multiple studies, including effects on egg survival, larval abundance, and year-class strength (Nelson 1968; Walburg 1972; Nelson and Walburg 1977).

Although recruitment indices were similar in both the Kaskaskia River and all pools of the Ohio River, size and age structure were very different between the two rivers. Based on our sampling, the Kaskaskia River Sauger population exhibited a much larger size structure than the Ohio River and age 3 and older fish were much more prevalent. The Ohio River contained very few fish older than age 2 throughout all years of sampling, and only 2% of fish exceeded 400 mm total length. Similar findings were reported in the previous Ohio River percid survey from 1998 to 2003, which found that most Sauger were <300-mm total length and no Sauger older than age 4 were collected (Schell et al. 2004). Churchill (1992) and Buckmeier (1995) also reported population age structures heavily skewed toward young individuals and Sauger larger than 400-mm total length represented a small percentage of the populations in the Tennessee River in Alabama and in the Cumberland River. The small size and age structures of Sauger populations in the Tennessee River in Alabama was attributed to high angling pressure because of the lack of a length limit and a liberal bag limit that led to a reduction of older age classes of Sauger in the fishery (Churchill 1992; Maceina et al. 1998). Similar to the present study, Maceina et al. (1998) documented a comparable size and age structure

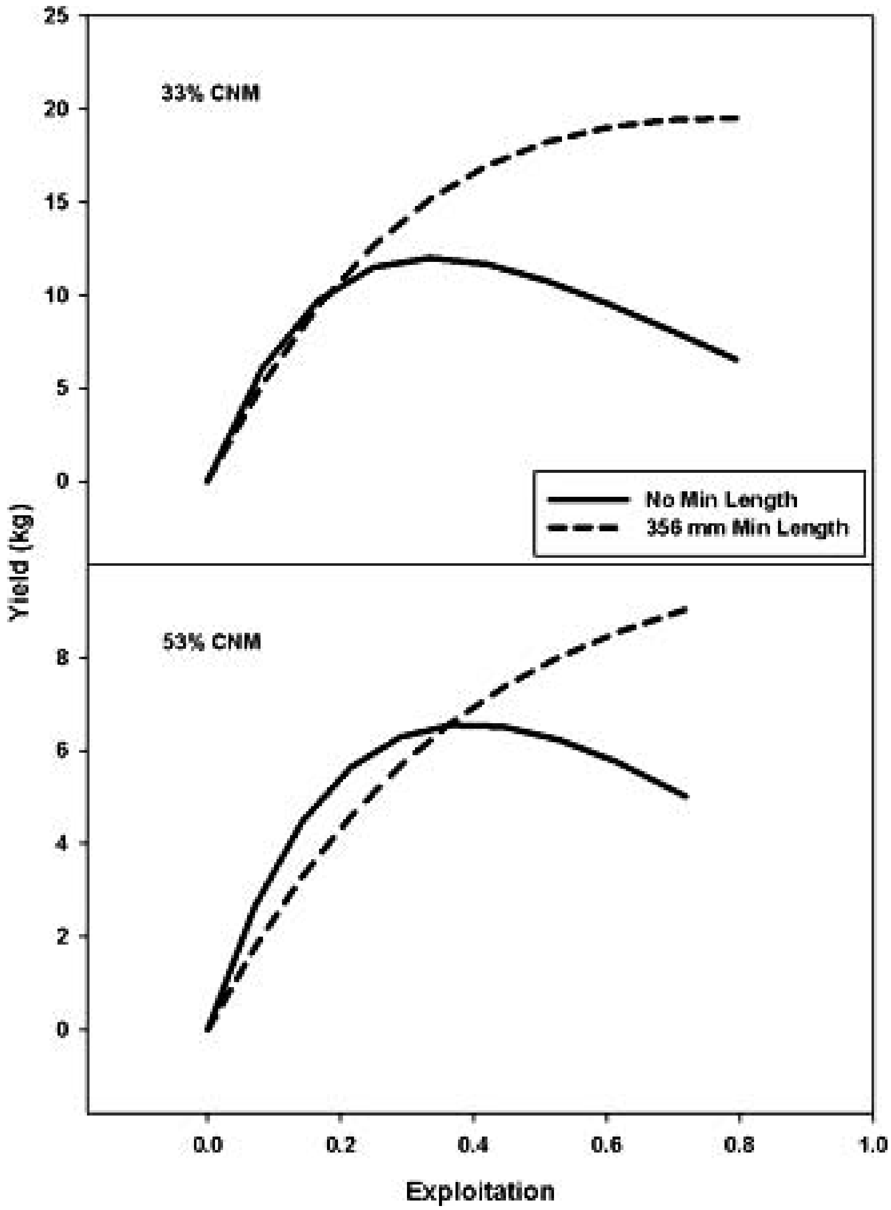

Figure 7. Simulated yields for Sauger *Sander canadensis* collected during the autumn of 2014–2016 from four Ohio River pools (McAlpine, Newburgh, J.T. Myers, and Smithland) and the open river section under two minimum (Min) length limit scenarios and two conditional natural mortality (CNM) rates.

in the Tennessee River in Alabama where Sauger younger than age 2 were prevalent but age 3 and older fish were rare. Because of the status of the Tennessee River Sauger in Alabama, high angling pressure, and liberal bag and length limits, a 356-mm minimum length limit was then implemented following the study (Maceina et al. 1998). Exploited, overfished populations often display truncated size structures similar to the Ohio River population. However, this and other studies indicate minimum length limits may mitigate effects of overharvest on population demographics.

Sauger populations in the Ohio River may be experiencing angling pressure that could be contributing to the truncated size and age structure. Examination of length frequencies revealed that the Kaskaskia River population contained a much higher proportion of larger individuals protected by a 356-mm minimum length limit and 6-fish daily bag limit. Ohio River Sauger exhibited faster growth rates than other midwestern and southern U.S. populations, including Pools 13 and 22 of the upper Mississippi River and the Tennessee River in Tennessee and Alabama (Buckmeier 1995; Maceina et al. 1998; Pitlo et al. 2004; Yallaly et al. 2014). Therefore, because of fast growth rates and good condition, Sauger in the Ohio River are likely not experiencing either abiotic or biotic (density-dependent) constraints that may be negatively influencing growth. Estimated mortality rates were also high across all sampling locations in the Kaskaskia and Ohio rivers. During the previous percid survey in the Ohio River, high rates of natural or angling mortality or a combination of both were reported; estimated total annual mortality ranged from 63 to 98% (Schell et al. 2004). During the season of highest angler harvest rates (November and December), total annual mortality was estimated at 79% for Sauger collected in the 2002 autumn electrofishing survey (Schell et al. 2004). Schell et al. (2004) surmised that the high mortality rates and small size and age structure of the abundant Ohio River Sauger population were likely due to overharvest. The high mortality rates observed in the Ohio River in the present and previous study are likely heavily influenced by high angling pressure during seasons when Sauger are most targeted (Schell et al. 2004).

Mortality rates of Sauger in the Kaskaskia River may also be influenced by angling pressure; however, harvest effects are likely curtailed because of the minimum length and bag limits and contributions of Sauger stocked directly into the lower Kaskaskia River and escapement of stocked fish through the Carlyle Lake dam to the Sauger stock in the lower Kaskaskia River. We acknowledge the potential for sampling bias to have occurred, which may have led to undersampling of older, larger Sauger because of depth restrictions with boat electrofishing. In the future, a complement of gears such as overnight gill nets and nighttime boat electrofishing is recommended to assess whether the potential for lower catchability of Sauger >400 mm total length using electrofishing may have affected mortality rate estimates, particularly for the Ohio River.

Annual exploitation of Ohio River Sauger was previously estimated at 27% (Schell et al. 2004), but exploitation may likely be much higher, especially during the peak of the Sauger angling-harvest season in winter and early spring and may potentially vary considerably depending on angler access to the river in relation to river stage and discharge. From anecdotal observations, the previous survey and population demographics evaluated by this study, fishing mortality is likely higher than previous estimates. Using our estimates of Z and the lowest values of CM, annual exploitation would be approximately 28% for both populations. The high values of CM used in FAMS modeling simulations, coupled with our estimates of Z, yield annual exploitation rates of <5%; therefore, the lower values of CM used in modeling simulations appear to be more realistic for Ohio River and Kaskaskia River Sauger populations. Based on our modeling, growth and recruitment overfishing are expected to occur at or above the 27% exploitation level determined in the previous study (Schell et al. 2004). A current exploitation estimate is also needed to fully ensure success of the minimum length limit in the future and natural mortality could potentially be estimated by using a combined telemetry and tagging approach (Quinn and Deriso 1999b). Future studies should also characterize fecundity–length relationships for female Sauger from the Ohio River as well as estimate critical threshold SPR values.

Our modeling suggested that implementing a 356-mm minimum length limit on the Ohio River would likely prevent growth overfishing at all levels of exploitation and would reduce the probability of recruitment overfishing at exploitation levels <50%. Based on our sample of the Kaskaskia River population, and previous studies in other systems, the size and age structure of the population in the Ohio River would likely be improved with a 356-mm minimum length limit because more Sauger would be allowed to realize greater growth potential (Hickman et al. 1990; Buckmeier 1995; Maceina et al. 1998). With the 356-mm minimum length limit in place on the Kaskaskia River, Sauger are allowed to reach larger lengths and older ages. We believe the minimum length limit on the Kaskaskia should remain in place because it is likely preventing growth and recruitment overfishing and the truncation of the size and age structure of the population. Sauger in the Ohio River were abundant and exhibited variable yet strong recruitment patterns, fast growth, high mortality rates, and a size and age structure heavily skewed toward small, young individuals; these population characteristics have been constant across multiple years and similar in all pools studied (Schell et al. 2004). Therefore, we recommend a 356-mm minimum length limit be implemented to reduce the probability of growth and recruitment overfishing, increase yields, and improve the size and age structure of the population. The 356-mm minimum length limit would simplify regulations by conforming to the statewide minimum length limit for Sauger in Illinois and the minimum length limit in place on the Cumberland and Tennessee rivers in Kentucky between their confluences with the Ohio River and Kentucky and Barkley dams. Currently, Illinois and Kentucky are considering implementation of an experimental 356-mm minimum length limit for Sauger in the section of the Ohio River between Illinois and Kentucky (Smithland Pool and the open river below Smithland Lock and Dam to the mouth of the Ohio River). We believe angler attitudes should be assessed prior to implementation because the majority of the Sauger population within the Ohio River would be protected with the 356-mm minimum length limit until fish can reach a harvestable size. Population characteristics were similar across all pools, indicating that similar influential factors are present; therefore, there is potential for a comparative study to test predictions from the yield-per-recruit model in sections of the river with and without the proposed 356-mm minimum length limit in the future.

Supplemental Material

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Table S1. Sauger *Sander canadensis* capture location, length, and estimated ages collected from the Kaskaskia River below Carlyle Lake dam and from the lower Ohio River pools (J.T. Myers, McAlpine, Newburgh, Smithland, and Lower river pools) during the autumn of 2014–2016.

Found at DOI: https://doi:10.3996/092017-JFWM-079.S1 (46 KB XLSX).

Table S2. Mean lengths at age of Sauger *Sander canadensis* from the Kaskaskia, Tennessee, Ohio rivers, and Pool 13 and 22 of the upper Mississippi River. We collected Sauger from the Kaskaskia from the Carlyle Lake tailwater and Sauger from the Ohio River from J.T. Myers, McAlpine, Newburgh, Smithland, and Lower river pools during the autumn of 2014–2016. We obtained mean length at age data for Pool 22 of the Mississippi River from Yallaly et al. (2014), data from Pool 13 of the Mississippi River from Pitlo et al. (2004), and Tennessee River data from Buckmeier (1995).

Found at DOI: https://doi:10.3996/092017-JFWM-079.S1 (46 KB XLSX).

Table S3. Yield-per-recruit model predictions for Sauger at 0- and 356-mm minimum length limits in the Kaskaskia and Ohio rivers. We collected Sauger from the Kaskaskia from the Carlyle Lake tailwater and Sauger from the Ohio River from J.T. Myers, McAlpine, Newburgh, Smithland, and Lower river pools during the autumn of 2014–2016.

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Table S4. Spawning-potential ratio model predictions for Sauger at 0- and 356-mm minimum length limits in the Ohio and Kaskaskia rivers. We collected Sauger from the Kaskaskia from the Carlyle Lake tailwater and Sauger from the Ohio River from J.T. Myers, McAlpine, Newburgh, Smithland, and Lower river pools during the autumn of 2014–2016.

Found at DOI: https://doi:10.3996/092017-JFWM-079.S1 (46 KB XLSX).

Reference S1. Krohe J Jr. 2001. The Kaskaskia River basin: an inventory of the region's resources. Springfield: Illinois Department of Natural Resources Office of Realty and Environmental Planning 8M/PRT3183339/1-2001.

Found at DOI: https://doi:10.3996/092017-JFWM-079.S2 (3.35 MB PDF).

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