An Assessment of Sauger Population Characteristics on Two Tennessee River Reservoirs

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Abstract: In 1992, a 356-mm minimum length limit (MLL) was enacted on Kentucky Lake and a 381-mm MLL was enacted on Watts Bar Lake, two mainstem reservoirs on the Tennessee River, in an attempt to reduce exploitation and improve the size structure of the sauger (*Sander canadensis*) populations. The objectives of this study were to compare sauger population characteristics immediately following (1993–1994) and 15 years after (2008–2009) the regulations took effect, examine spatial and temporal patterns in growth, examine recruitment patterns in each reservoir using a recruitment variability index (RVI), and assess the current likelihood of overfishing. Saugers were collected with experimental gill nets in each reservoir and aged using otoliths. A Beverton-Holt yield-per-recruit model was used to simulate angler yields and estimate the likelihood of growth overfishing. Recruitment overfishing was assessed by examining spawning potential ratios under various MLL and exploitation rate scenarios. The sauger population in Kentucky Lake experienced modest improvements in size and age structure over the 15 years following enactment of more restrictive harvest regulations, whereas the population in Watts Bar Lake changed very little, if at all, in terms of size and age structure. Mean lengths of age-3 sauger were significantly greater in Watts Bar Lake than in Kentucky Lake in both time periods. The RVI values indicated that between 1993 and 2009 the sauger in Kentucky Lake displayed more stable recruitment than the Watts Bar Lake population. Neither population exhibited signs of growth overfishing in 2008–09 under the current length limits; however, the Watts Bar Lake population would be susceptible to recruitment overfishing at high (>40%) exploitation rates if natural mortality was as low as 20%. These analyses have demonstrated that the Watts Bar Lake and Kentucky Lake populations, in terms of size and age structure, have remained relatively stable over 15+ years and the MLLs appear to be conserving the stocks.

Key words: overfishing, recruitment, growth, minimum length limit

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Native to the Mississippi River drainage, sauger (*Sander canadensis*) populations in Tennessee have historically been an important component of sport fisheries in the Tennessee and Cumberland Rivers (Hackney and Holbrook 1978). Establishment of multiple impoundments along these two rivers created tailwaters where saugers congregate during winter months when moving upstream to spawn (Hackney and Holbrook 1978, Pegg et al. 1997). Although saugers are highly susceptible to anglers while congregated below dams (Pegg et al. 1996), no length limits for sauger in Tennessee existed prior to 1992 and populations were thought to be declining statewide. Concerns about the declines prompted investigations into population structure, recruitment, and exploitation of sauger populations (Bettoli and Fischbach 1998).

Studies conducted by the Tennessee Wildlife Resources Agency (TWRA), Tennessee Technological University (TTU), and the Tennessee Valley Authority (TVA) in the late 1980s and early 1990s documented poor size structure, truncated age distributions, and variable recruitment in mainstem reservoirs throughout Tennessee (Hickman et al. 1990, Churchill 1992, Thomas 1994). Most (≥77%) sauger collected in impoundments throughout the Tennessee River in the 1990s were younger than age-3 but population structure differed among reservoirs. For example, from 1993 to 1997, 37% of all saugers collected in Watts Bar were age-3 or older, compared with only 9% in Kentucky Lake. During that same time, 38% of Watts Bar sauger were longer than 400 mm total length (TL), compared with only 3% of Kentucky Lake saugers. Sauger populations in the Alabama portion of the Tennessee River in the 1990s were similar to the Kentucky Lake population and were also dominated by age-1 and age-2 fish (Maceina et al 1998). Recruitment variability and high exploitation were thought to be important factors in explaining why few large saugers were present in the lower Tennessee River (Thomas 1994). Hackney and Holbrook (1978) also found sauger recruitment in Tennessee to be highly variable. Highly variable recruitment characterizes sauger, a lithophilic riverine specialist, when it attempts to reproduce in regulated rivers (Bozek et al. 2011).

As a result of the early investigations, the TWRA recommended a statewide minimum length limit (MLL) of 381 mm in 1992; however, angler concerns in western Tennessee prompted TWRA to modify their recommendation to allow for a 356-mm limit on

Kentucky Lake only. The TWRA also initiated a sauger fingerling stocking program in the upper Tennessee River because those populations appeared to be suffering from poor natural recruitment (e.g., Hickman et al. 1990), but the efficacy of that program was difficult to judge. Large variations in sauger recruitment were thought to overshadow stocking effects in the upper Tennessee River (Bettoli and Fischbach 1998), which has also been suggested for walleye (*Sander vitreus*) populations in South Dakota (Hansen and Lucchesi 1991).

The MLL for the lower Tennessee River was amended in March 1997 to allow anglers to harvest three fish under 356-mm TL, but that regulation was rescinded in March 1998 following investigations that determined that sauger populations in the lower Tennessee River and the Alabama portion of the Tennessee River were experiencing growth overfishing (Maceina et al. 1998). Growth overfishing occurs when the average size of a harvested fish is less than the size that would maximize yield (Colvin et al. 2013). Although sauger exploitation was low (about 6%; unadjusted for non-reporting) in the 1980s in the upper Tennessee River (Hevel 1988, Hickman et al. 1990, St. John 1990), Pegg et al. (1996) estimated that exploitation of sauger in the lower Tennessee River exceeded 40% in the early 1990s. Sauger brood stocks in the 1990s were primarily supported by one age-group; thus, brood stock abundance appeared to be increasingly dependent on individual year classes. Bettoli and Fischbach (1998) observed that the MLLs imposed during that time were preventing recruitment overfishing, where the population would be in danger of being exploited to the point where recruitment is reduced or fails (Sissenwine and Shepard 1987). However, they cautioned that any liberalization of the length and creel limits would increase the risk of recruitment overfishing and exacerbate the effects of growth overfishing. Subsequent computer simulations of sauger population dynamics in Alabama water of the Tennessee River (Maceina et al. 1998) and in the Tennessee waters of the Tennessee River (P. Bettoli, Tennessee Cooperative Fishery Research Unit, unpublished data) demonstrated that potential yield was maximized with MLLs of either 356 or 381 mm.

As with any management strategy, length-limit regulations should be evaluated following implementation to assess whether intended impacts have occurred. The primary objective of this study was to compare sauger population characteristics immediately following (1993–1994) and 15 years after (2008–2009) the sauger regulations in Tennessee took effect. Any changes observed over time in Watts Bar Lake would also reflect the possible influence of the stocking program. We also examined spatial and temporal patterns in growth, recruitment patterns in each reservoir, and the likelihood of growth and recruitment overfishing in recent years. No changes to the MLLs for sauger in the Tennessee River occurred between 1998 and 2008, but the MLL on Kentucky Lake was increased to 381 mm TL in 2014. Thus, this study will also be used to determine whether the new length limit is appropriate given past population characteristics and dynamics observed during this study.

Study Area

Kentucky Lake and Watts Bar Lake in Tennessee, two mainstem impoundments, were chosen to represent impoundments in the lower and upper reaches of the Tennessee River that were investigated in previous sauger studies (Churchill 1992, Thomas 1994, Buckmeier 1995, Fischbach 1998). These fisheries supported some of the greatest fishing pressure for sauger in Tennessee from 1999–2006 (P. Black, TWRA, unpublished data).

Pickwick Dam (Tennessee River km [TRkm] 332.7) serves as the upper boundary of Kentucky Lake on the lower Tennessee River and provides hydroelectric power, navigation, and flood control for the area. Kentucky Lake is Tennessee's largest reservoir (64,900 ha at full pool) and TWRA creel data indicated that it supported the highest amount of fishing pressure for sauger in Tennessee between 1999 and 2006 (P. Black, TWRA, unpublished data); sportfishing yields over that same interval averaged 0.41 kg ha^{-1} $year^{-1}$; range:0.02–0.85). Sauger populations in Kentucky Lake were supported entirely by natural recruitment (i.e., no stocking) during the course of this study.

Ft. Loudoun Dam (TRkm 969.3) and Melton Hill Dam (Clinch River km 37.2) serve as the upper boundaries of Watts Bar Lake, which covers 15,820 ha at full pool. Creel data from TWRA indicated that Watts Bar Lake supported the third highest amount of fishing pressure for sauger in the state from 1999–2006, when yields averaged 0.32 kg ha^{-1} $year^{-1}$ (range: 0.10–0.73). Unlike Kentucky Lake, sauger have been stocked into Watts Bar Lake over many years. Sauger fingerlings (mean TL = 51 mm) were stocked five times between 1990 and 2000 at a rate of 6.1 fish ha^{-1} and every year from 2004 to 2008 at a rate of 7.1 fish ha^{-1}.

Methods

Population Characteristics

We collected sauger from late winter to early spring in 2008 and 2009 from both reservoirs using horizontal sinking monofilament experimental gill nets (1.8 × 45.5 m) containing five equal-length panels (bar mesh sizes 19, 25, 38, 51, and 64 mm). Sampling effort was confined to the waters immediately below dams and downstream at Diamond Island in Kentucky Lake (TRkm 314.5) and Browder Shoals in Watts Bar Lake (TRkm 961.6). These sampling sites were areas where saugers were known to congregate in each reservoir (Churchill 1992). Nets were set after dusk and fished for at least 15–60 min, depending on catch rates. At each reservoir, we attempted to collect 25 individuals per trip and a minimum of 100 individuals each year. Upon capture, each fish was tagged with a uniquely numbered Floy tag, placed on ice, and returned to the lab.

In the lab, sauger were measured (TL, mm) and weighed (g). Gonads of sexually mature females were excised and weighed; immature individuals were assigned a gonad weight of zero. Sagittal otoliths were extracted from each individual and stored in numbered vials that corresponded to the Floy tag number. Otoliths were read twice, independently, in whole view under 40X magnification using reflected light. If more than one annulus was visible, otoliths were cracked perpendicular to the longest axis, polished using 600-grit sandpaper, and viewed using transmitted light from a fiber optic element (Heidinger and Clodfelter 1987). Otoliths were read a third time when there were disagreements between the first and second readings.

We pooled all data from 1993 and 1994, which were the two years immediately following enactment of the MLLs on Kentucky Lake and Watts Bar Lake and the reduction of the daily creel from 15 to 10 fish per day. Those data, representing the "early period" after regulation enactment, were contrasted with sauger data pooled for 2008 and 2009, the "late period." Mean lengths and ages in each lake were compared between periods using Wilcoxon's two-sample test. The frequency-distributions for each variable were also compared between periods in each lake using the Kolmogorov-Smirnov (K-S) test (Neumann and Allen 2007). Spatial and temporal patterns in growth were examined using a randomized block design ANOVA with interaction term that compared mean total lengths of saugers at age-3 in each reservoir in 1993–1994 [early] and 2008–2009 [late]. Statistical significance for all tests were declared at alpha levels of $P = 0.05$.

We compared recruitment patterns in each reservoir using a recruitment variability index (RVI; Guy and Willis 1995):

$$RVI = [S_N/(N_M + N_P)] - (N_M/N_P),$$

where S is the summation of the cumulative relative frequencies across year-classes included in the sample; N_M is the number of year-classes missing from the sample, and N_P is the number of year-classes present in the sample. The RVI ranges from −1 to 1, with values close to 1.0 representing more stable recruitment. We calculated the average RVI for each population over the four years of sampling (1993, 1994, 2008, and 2009) because mean RVI values calculated using multiple years of sample data tend to better describe actual recruitment variability (Quist 2007). Mean RVI values were then compared between reservoirs using a Wilcoxon sign-rank test at an alpha level of 0.05.

Population Modeling Simulations

The yield-per-recruit option in Fishery Analysis and Simulation Tools (FAST) software (Slipke and Maceina 2001) was used to determine the current likelihood of growth overfishing in these populations. This option uses the Jones (1957) modification of the Beverton-Holt equilibrium yield model to calculate yield (Slipke and Maceina 2001). Yields (kg of fish per 100 recruits) were simulated at four different MLLs: the assumed minimum length of sauger that anglers would harvest given no harvest restriction (i.e., 254 mm TL; Bettoli 1998), the two current MLLs: 356 mm and 381 mm, and a 406-mm MLL. Inputs to the model included parameters derived from the von Bertalanffy (1938) growth equation and the $\log_{10}$length: $\log_{10}$weight regression models (Table 1). Conditional natural mortality rates (*cm*) were estimated in FAST using two methods. Quinn and Deriso (1999) estimated natural mortality (M) as:

$$M = -\log_e(P_s) / t_{max},$$

where the proportion of the population that survived (P_s) to t_{max} (12 years; Brown 1990) was assumed to be either 0.01 or 0.05 (Shepard and Breen 1992). Then, $cm = 1 - e^{-M}$. Hoenig's (1983) approach to estimating natural mortality was:

$$\text{Log}_e(M) = 1.46 - 1.01(\log_e[t_{max}]).$$

Conditional fishing mortality rates (*cf*) from 0% to 60% were used to simulate yield over a wide range of possible exploitation rates. In yield-per-recruit plots, growth overfishing is occurring when yields decline with increasing exploitation (Slipke and Maceina 2001).

The Spawning Potential Ratio (SPR; Goodyear 1993), which is the ratio of the lifetime egg production by the average recruit in a fished and an un-fished population, was used to assess recruitment overfishing (Goodyear 1993, Scholten and Bettoli 2005).The SPR was simulated in FAST using age and length data from this study, fecundity data from Churchill (1992), and a developed maturation schedule. We developed the maturation schedule for female sau-

Table 1. Parameters used to simulate sauger yield in Kentucky Lake and Watts Bar Lake using the Beverton-Holt yield-per-recruit model in FAST (Slipke and Maceina 2001). Sample size (*n*) is the number of individuals used to estimate the parameters of the von Bertalanffy growth model, where L_∞ is the theoretical maximum length (held constant at 550 mm for both populations), K is the Brody growth coefficient, and to is the theoretical time when total length would equal zero. Slope (β_1) and Intercept (β_0) were derived from the $\log_{10}$length:$\log_{10}$weight relationship for saugers in each reservoir.

Reservoir	*n*	β_1	β_0	L_∞	K	t_0
Watts Bar Lake	201	−5.868	3.341	550	0.384	−0.925
Kentucky Lake	243	−6.235	3.486	550	0.297	−1.357

ger by determining the percent of mature fish in each size- and age- class, per the methods of Scholten and Bettoli (2005). SPR values less than 20% were used to identify recruitment overfishing (Goodyear 1993).

Results

Population Characteristics

Mean lengths and ages of saugers in Kentucky Lake increased 17%–22% between 1993–1994 (290 mm, SE = 2.95; 1.51 yrs, SE = 0.03) and 2008–2009 (340 mm, SE = 3.66; 1.95 yrs, SE = 0.06) (Wilcoxon Test; $P = 0.0001$). Likewise, the frequency-distributions for both variables were dissimilar between periods (K-S test; $P = 0.0001$; Figures 1, 2). Saugers in Watts Bar Lake did not show the same trends over time as in Kentucky Lake. Mean lengths of saugers in Watts Bar Lake were similar ($P = 0.5635$) in 1993–1994 (408 mm; SE = 6.30) and 2008–2009 (403 mm; SE = 5.13) but mean ages declined slightly ($P = 0.0128$) from 2.7 yrs (SE = 0.10) to 2.5 yrs (SE = 0.08). Mirroring those findings, the frequency-distributions in each period were similar in terms of lengths ($P = 0.5902$; Figure 2) but dissimilar in terms of ages ($P = 0.0060$; Figure 1).

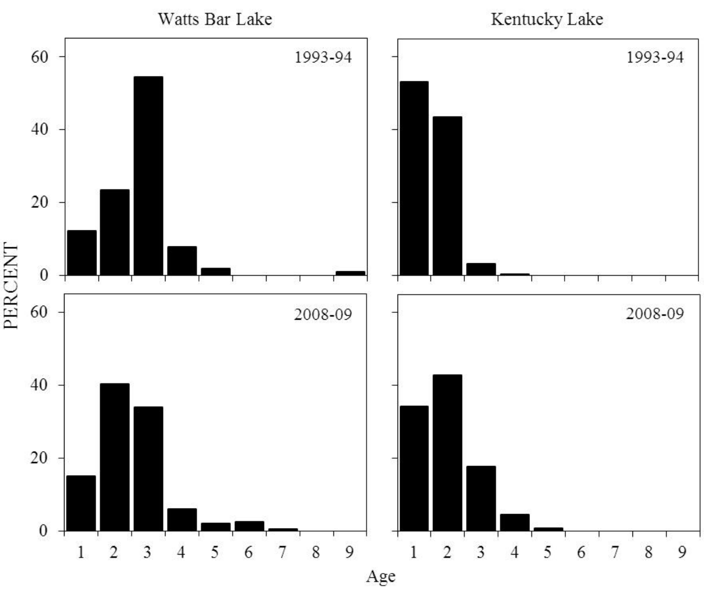

Figure 1. Age-frequency distribution for all saugers collected in Watts Bar Lake (WB) and Kentucky Lake (KENT) 1993–1994 and 2008–2009.

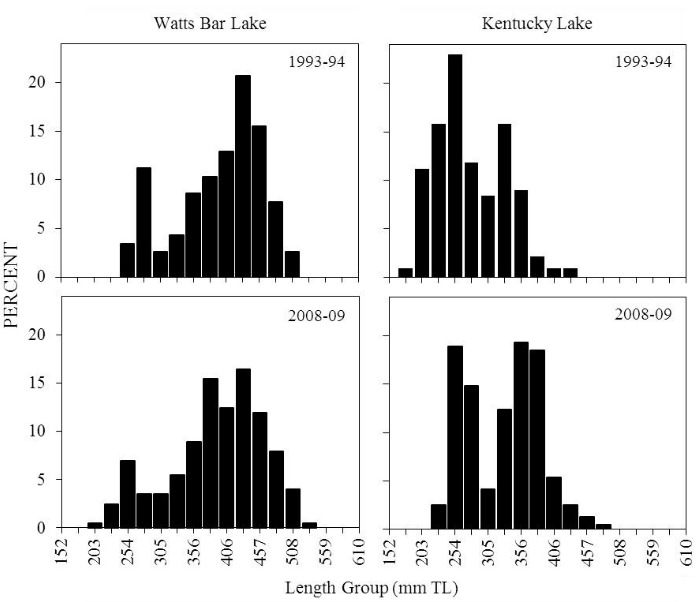

Figure 2. Length-frequency distribution for all saugers collected in Watts Bar Lake (WB) and Kentucky Lake (KENT) 1993–1994 and 2008–2009.

When those same four population metrics were compared between lakes in each sample period, all statistical tests revealed significant differences ($P = 0.0001$). That is to say, in the two years immediately following the enactment of stricter harvest regulations and 15+ years later, Kentucky Lake saugers were shorter and younger than Watts Bar Lake saugers. The main effect *Period* (early versus late) did not explain a significant amount of variation in the size of saugers at age-3 (df = 1,180; $F = 1.06$; $P = 0.3056$) but age-3 sauger were significantly longer on average in Watts Bar Lake (both periods combined; mean = 446 mm TL; SE = 3.5) than in Kentucky Lake (mean = 400 mm TL; SE = 3.8)) ($F = 41.35$; $P = 0.0001$). The interaction term was not significant ($F = 1.04$; $P = 0.3096$).

Sauger displayed more stable recruitment between 1993 and 2009 in Kentucky Lake than in Watts Bar Lake. Over the four annual samples, RVI values in Kentucky Lake ranged from 0.719 to 0.927 and the average was 0.806 (SE = 0.029). In contrast, RVI values in Watts Bar Lake were significantly lower ($P = 0.0188$) and ranged from –0.065 to 0.780 with a mean of 0.493 (SE = 0.104).

Population Modeling Simulations

Only two sauger older than age-4 and none over age-5 were collected in Kentucky Lake and the von Bertalanffy model could not converge to estimate L_{inf}; therefore, L_{inf} for the Kentucky lake population was assumed to be the same as L_{inf} for the Watts bar population (i.e., 550 mm TL). Estimates of conditional natural mortality ranged from 0.22 to 0.32 and for simplicity's sake the simulations were conducted using *cm* levels of 0.20 and 0.30. Other parameters used to estimate sauger yields were reservoir-specific (Table 1).

At a conditional natural mortality rate of 30%, growth overfishing was not apparent in either reservoir, regardless of the size limit modeled (Figure 3). However, if *cm* was 20% and exploitation exceeded 25%, severe growth overfishing was evident in the absence of a size limit. The benefits to yield were most evident at the lower natural mortality rate once exploitation exceeded 20%; yields were higher in both reservoirs when size limits were in place (Figure 3). In contrast, if natural mortality was 30%, size limits provided no increase in yield in either reservoir until exploitation exceeded

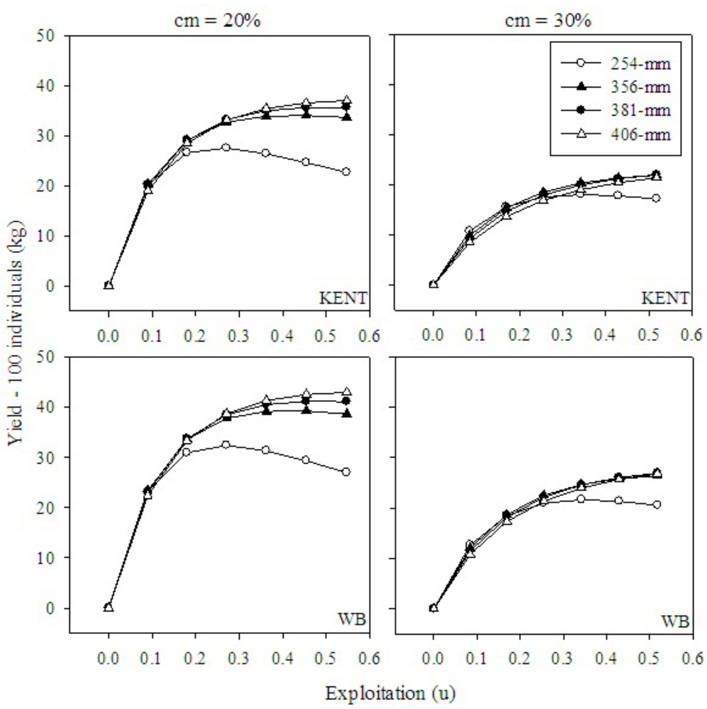

Figure 3. Simulated yields for sauger populations in Kentucky Lake (KENT) and Watts Bar Lake (WB) under four minimum length limit scenarios and two conditional natural mortality (*cm*) rates.

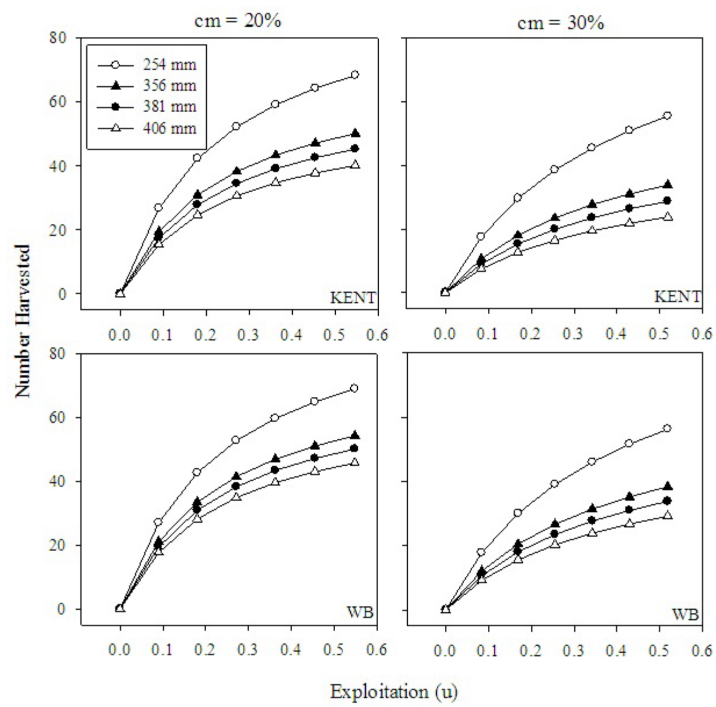

Figure 4. Simulated number of sauger harvested in Kentucky Lake (KENT) and Watts Bar Lake (WB) under four minimum length limit scenarios and two conditional natural mortality (*cm*) rates.

40%. Also, size limits in both reservoirs provided less benefits in terms of yield if *cm* was 30% than if it was 20%. Although yields changed little among the simulated size limits, the number of sauger harvested decreased progressively with higher size limits (Figure 4). Over the range of exploitation rates modeled, an increase in the size limit on Kentucky Lake from 356 mm to 381 mm would result in 10% and 15% declines in the number of harvested sauger if *cm* was 20% and 30%, respectively. Similarly, in Watts Bar Lake, an increase in the size limit from 381 mm to 406 mm would result in 9% and 14% declines in the number of sauger harvested if *cm* was 20% and 30%, respectively (Figure 4).

The potential for recruitment overfishing (i.e., SPR < 20%) was higher in Watts Bar Lake than Kentucky Lake at both *cm* levels and all MLL scenarios, and was more likely in both reservoirs when *cm* was 20% and no size limits were in place (Figure 5). At a *cm* of 20% with no size limit, SPR fell below the 20% threshold in Watts Bar Lake when exploitation exceeded 27%; in contrast, this did not occur under the 381-mm MLL until exploitation exceeded 46% (Figure 5). At a *cm* of 30% with no size limit, recruitment overfishing was evident in Watts Bar Lake when exploitation exceeded 34%. However, SPR did not fall below the 20% threshold in Kentucky Lake under any MLL regardless of the *cm* level, but under the no-size-limit scenario, recruitment overfishing became evident when exploitation exceeded 36% and 39% when *cm* was 20% and 30%, respectively (Figure 5).

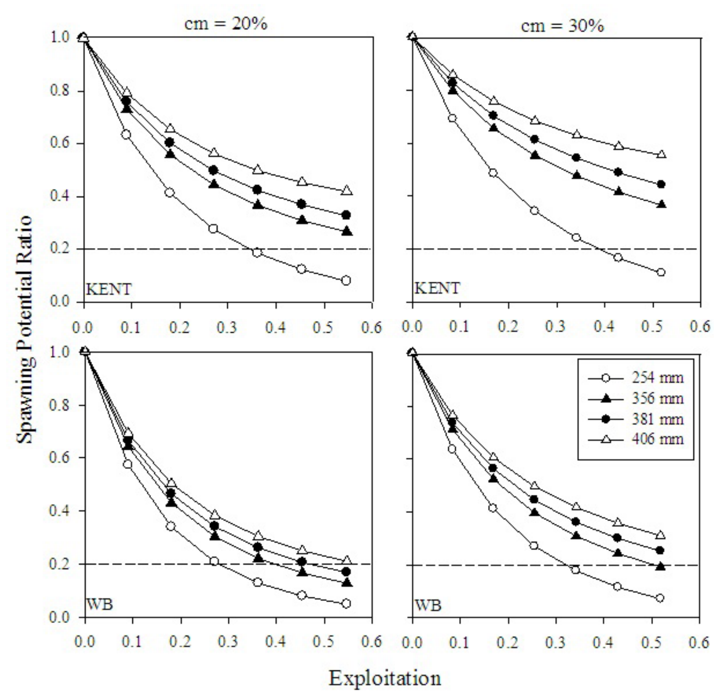

Figure 5. Simulated Spawning Potential Ratio values in Kentucky Lake (KENT) and Watts Bar Lake (WB) under four minimum length limit scenarios and two conditional natural mortality (*cm*) rates.

Discussion

The heavily exploited sauger population in Kentucky Lake experienced modest improvements in size and age structure over the 15 years following enactment of more restrictive harvest regulations; whereas, the population in Watts Bar Lake changed very little, if at all, in terms of size and age structure. No good estimates of exploitation exist for the Watts Bar sauger population. Several estimates of sauger exploitation exist in the reservoir immediately downstream (Chickamauga Lake) and those estimates were uniformly low (≤8%) in the late 1980s (Hevel 1988, Hickman et a. 1990); however, none of those estimates were corrected for non-reporting which can exceed 40% in other sport fisheries (e.g., Maceina et al. 1998, Denson et al. 2002). In the absence of any good historical estimates of exploitation in Watts Bar Lake, but given the fact that targeted fishing pressure for saugers in that system ranked third behind Kentucky Lake, we conclude that the Watts Bar Lake sauger population has always been more lightly exploited than Kentucky Lake's population. Regardless of the actual exploitation rates experienced by saugers in Watts Bar Lake between 1993 and 2009, our analyses have demonstrated that the population, in terms of size and age structure, remained relatively stable over 15+ years. The sauger population in this reservoir was once considered on the verge of collapse (Alexander 1987, St. John 1990), but the role that the stocking program and higher MLL in that system have played in conserving this stock remains unknown. Likewise, it is not known whether the MLL helped improve sauger age and size structure in Kentucky Lake. However, in the absence of any evidence, anecdotal or otherwise, that exploitation declined over time, the MLL would appear to be helping to conserve that stock.

As with nearly all fish populations, fluctuations in sauger year-class strength are commonplace throughout Tennessee waters and elsewhere in North America (Fischbach 1998, Pitlo 2002). In the 1990s, the Watts Bar Lake population was characterized by low abundance, an age structure skewed towards older fish, and erratic recruitment patterns (Fischbach 1998). Slight improvements were observed following establishment of length limits, and a decrease in the mean size of saugers in the upper Tennessee River indicated recruitment was improving in that region (Bettoli and Fischbach 1998). In the present study, the Watts Bar Lake population displayed the greatest fluctuation in recruitment, continued to have older and longer fish on average compared to the Kentucky Lake population, and was more stable over time in terms of age and size-structure. The Watt Bar Lake population was also the only population to be stocked with sauger fingerlings (10 times between 1990 and 2008). It unclear whether the stocking program exacerbated recruitment variability in Watts Bar Lake.

Sauger recruitment is strongly linked to discharge in the Tennessee River (Buckmeier 1995) and Fischbach (1998) suggested that in drought years, the recruitment of sauger populations may suffer. Models conducted by Bettoli and Fischbach (1998) suggested that sauger recruitment in the upper Tennessee River was related to total volumes discharged the previous spring, with greater recruitment when discharge was between 8.4×10^9 and $15.4 \times 10^9\, m^3$ but lower recruitment when discharge was above or below that range. Most years between 1999 and 2009, total volumes discharged from February to April (TVA unpublished data) were below that range. This may help to explain why the mean age of sauger in Watts Bar Lake in 2008 was the second highest mean age recorded from 1993 to 2009.

Growth rates also continue to be faster in Watts Bar Lake than in Kentucky Lake, as found by Buckmeier (1995). The observed mean lengths-at-age in this study were almost always greater in Watts Bar Lake than in Kentucky Lake; however, mean lengths-at-age in both reservoirs were within ranges reported by Buckmeier (1995).

Growth overfishing was evident in the Kentucky Lake population in the late 1990s (Fischbach 1998). Bettoli and Fischbach (1998) predicted that rescinding the temporary three-fish exemption of the 356-mm MLL regulation would reduce exploitation of small saugers and help increase sauger yield in Kentucky Lake. In 2008–2009, the Kentucky Lake sauger population did not exhibit signs of growth overfishing, suggesting that exploitation of smaller individuals had been reduced. Simulated yields in Watts Bar Lake and Kentucky Lake were always greatest with a minimum size limit; however, as reported for other fisheries (e.g., Allen and Miranda 1995, Isermann et al. 2002), benefits to yield were less evident when natural mortality rates were high. Previous modeling of sauger and walleye populations in southern reservoir systems also indicated that yield would be higher with size limits (Maceina et al. 1998, Vandergoot and Bettoli 2001). Elimination of size limits in either reservoir would likely result in growth overfishing when exploitation exceeds 30%.

The size limit in Watts Bar Lake (381 mm TL) has remained unchanged since the early 1990s but the size limit in Kentucky Lake was raised in March 2014 from 356 mm TL to 381 mm TL. Based on the results of our models, we predict that the number of saugers harvested will decline slightly (10%–15%), but chances of recruitment overfishing will be further reduced. It remains to be seen whether the predicted decrease in the number of sauger harvested will overshadow the predicted benefits to anglers of slightly higher yields. Anglers who target sauger in Tennessee River reservoirs are harvest-oriented; most (60%) who target sauger do so with the intention of harvesting them (Bettoli 1998). Attitudes of anglers regarding harvest preference (fewer, large fish or more, small fish) are unknown, but obviously numbers of fish caught and released under a higher size limit will increase. With higher numbers of fish being released, especially in Kentucky Lake where the MLL was recently raised, come concerns with cryptic or catch-and-release (CR) mortality. Previous studies of Tennessee River sauger populations reported CR mortality rates ranging from 12% to 32% (Bettoli et al. 2000, Kitterman and Bettoli 2011) and saugers caught at depths exceeding 9 m in the Mississippi River experienced 33% CR mortality (Meerbeek and Hoxmeier 2011). In that same Mississippi River study very few (2%) saugers caught at shallower depths succumbed to CR mortality. Further confounding a discussion of the potentially negative effects of CR mortality are conflicting reports that percid CR mortality was inversely related to fish length in some studies (Kitterman and Bettoli 2011) but not in others (Schreer et al. 2009, Meerbeek and Hoxmeier 2011). The population-wide effect of potentially high CR mortality under the new higher size limit in Kentucky Lake is not known, but could further reduce any benefits of higher MLLs predicted by our models.

To our knowledge, no critical values of SPR have been defined nor used to evaluate recruitment overfishing in sauger fisheries prior to this study; however, SPRs have been calculated for paddlefish (*Polyodon spathula*) in the Tennessee River (Scholten and Bettoli 2005, Colvin et al. 2013) and channel catfish (*Ictalurus punctatus*) in the Mississippi River (Slipke et al. 2002). Our SPR models suggested that elimination of size limits in both reservoirs would subject the sauger populations to the possibility of recruitment overfishing. According to the SPR models, the current size limit is protecting saugers in Kentucky Lake from recruitment overfishing over the range of exploitation rates and natural mortality rates modeled. We predict that the current size limit in Watts Bar Lake will protect sauger from recruitment overfishing unless exploitation rates exceed 40%. However, Watts Bar Lake is unlikely to be subjected to such high exploitation, as evidenced by historical rates of exploitation that were less than 6% (Hevel 1988, Hickman et al. 1990, St. John 1990). Minimum length limits for saugers were enacted in Tennessee River reservoirs with the objective of reducing exploitation, preventing growth and recruitment overfishing, and improving the size distribution of sauger populations (Fischbach 1998). The regulations appear to have protected these two Tennessee sauger populations from overfishing and have contributed to their relative stability over the last 16 years.

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