Population Characteristics of White Bass and an Evaluation of Minimum Length Limits in Kentucky Lake, Tennessee

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Abstract: Relatively few studies have been conducted for white bass (*Morone chrysops*) populations in large river impoundments. Our study focused on population characteristics of white bass in Kentucky Lake, a mainstem impoundment of the Tennessee River. A total of 994 fish were collected using electrofishing during April 2006 and 2007 to evaluate age, growth, and mortality. Kentucky Lake white bass exhibited relatively fast growth compared to previously studied populations. Females were already larger than males by age-1 and continued to grow faster than males; both genders were sexually mature by age-2 when complete recruitment to the fishery occurred. Mortality did not differ between males and females and the pooled annual mortality rate (*A*) was 45%–46% each year. Beverton-Holt equilibrium yield models were used to evaluate the potential for minimum-length limits (MLL; 254 mm [no MLL], 279 mm, 305 mm, and 305 mm) to increase yield and harvest potential in the population. Yield models were run at two conditional natural mortalities (0.35 and 0.45) and varying exploitation. These models did not predict appreciable changes in yield or number of fish available for harvest across MLLs. Although Kentucky Lake white bass grew rapidly, a MLL for white bass was not recommended because the models predicted only nominal benefits. Future evaluations of size limit feasibility should include a concurrent exploitation study to better determine the relative influence of natural and fishing mortalities in the yield models.

Key words: reservoirs, harvest restrictions, yield models

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White bass (*Morone chrysops*) provide popular and economically important fisheries in the southeastern United States. The species is native to watersheds across Tennessee, where it provides seasonal fisheries, especially during the spring spawning period. The species thrives in both tributary and mainstem reservoirs, but populations sometimes have declined as reservoirs aged (Yellayi and Kilambi 1975). Most mainstem reservoirs in Tennessee have more consistent spring flows and thus support more consistent white bass fisheries than those of tributary impoundments. Many white bass fisheries across the country are harvest-oriented (Bauer 2002, Betsill and Pitman 2002), and up to 63% of caught fish are harvested in Tennessee reservoirs (Black 2014).

Kentucky Lake, located in west Tennessee, supports one of the state's most popular white bass fisheries. There is no length limit for white bass on Kentucky Lake, but anglers were limited to 30 fish per day until 2008, when the bag limit was dropped to 15 fish daily. Pre-spawning activity begins in late February and March as fish move upstream into tributaries and the Pickwick Dam tailwater. Most spawning occurs during April, corresponding to peak fishing effort for white bass. Recruitment of white bass in Kentucky Lake is variable, but not to the extent that it causes a "boom or bust" fishery, as has been observed for other white bass populations and other freshwater species such as crappie (*Pomoxis* spp.) (e.g., Allen and Miranda 2001, DeBoer et al. 2013). White bass recruitment in southeastern U.S. reservoirs is generally influenced by factors related to reservoir hydrology such as discharge and inflow (Sammons and Bettoli 2000, DiCenzo and Duval 2002).

Tennessee Wildlife Resources Agency (TWRA) initiated a study of the Kentucky Lake white bass population in 2006 to collect information that would aid biologists in managing that stock. The specific objectives of that study were to assess: 1) growth and mortality; 2) recruitment patterns and age structure; and 3) potential effects of implementing a minimum-length limit (MLL). Although previous published studies on Tennessee white bass populations focused on tributary reservoirs, this study represented the first to focus on a mainstem reservoir population.

Methods

Kentucky Lake was impounded in 1944, has a surface area of 64,800 ha, and is the last mainstem reservoir on the Tennessee River. Its headwaters begin at Pickwick Dam (TRKm 331) and the lake ends at Kentucky Dam (TRKm 35). The reservoir is managed by the Tennessee Valley Authority (TVA) for flood control, navigation, and hydropower generation. The lake provides popular sport fisheries for black bass (*Micropterus* spp.), crappies (*Pomoxis* spp.), sunfish (*Lepomis* spp.), sauger (*Sander canadensis*), and temperate basses (*Morone* spp.), including white bass. Angling effort for Kentucky Lake is consistently the highest in the state and was over 1.3 million angler-hours in 2013, and angler effort for white bass was approximately 2.4% of Kentucky Lake's total fishing effort (Black 2014).

Electrofishing was conducted during April in 2006 and 2007 at white bass spawning shoals and staging areas in the upstream portion of Kentucky Lake (i.e., the Pickwick Dam tailwater). All white bass observed were collected and returned to the lab on ice where fish were measured (total length [TL], mm), weighed (g), and sexed by gonad examination. Sagittal otoliths were extracted for aging and ovaries were excised and weighed to the nearest 0.1 g. Age was estimated by two independent readers viewing whole otoliths under a dissecting scope (40X magnification). If readers disagreed, otoliths were sectioned and read by both readers together to achieve consensus (Quist et al. 2012).

Total annual mortality (A) was calculated for each sex each year from weighted catch curves using Fisheries Analysis Modeling Software (FAMS, Slipke and Maceina 2014). Mortality rates were compared between sexes in each sampling year using analysis of covariance (GLM procedure, SAS Institute 2012). Growth data were pooled for both sampling years to calculate mean length-at-age. Growth was modeled using the von Bertalanffy (1938) growth equation and comparisons of growth between sexes were made using analysis of covariance. This and all other statistical tests were conducted with a significance level of $P < 0.05$. Length frequencies and Incremental Proportional Size Distributions were calculated to assess population size structure in both years.

Female white bass maturity was indexed via a gonadosomatic index (GSI) using methods described by Guy et al. (2002). Females and excised ovaries were weighed whole to the nearest gram to calculate GSI values (GSI = [Ovary Weight X 100]/Weight of Fish). Fish were deemed mature when ovaries were developed and GSI values exceeded 5.0. Values were plotted over total length to determine what percentage of spawning females would be protected under 305 and 330 mm MLLs.

The main objective in our length limit evaluation was to determine whether any of the modelled MLLs would increase white bass yield and number available for harvest. Evaluation of harvest restrictions (MLLs) was conducted using Beverton-Holt equilibrium yield models. Equilibrium yield modeling followed the procedures described by Lovell and Maceina (2002) for FAMS population modelling (Slipke and Maceina 2014). FAMS was also used to calculate conditional natural mortality (*cm*) following Jensen (1996), Quinn and Deriso (1999), Hoenig (1983), and Chen and Watanabe (1989). The maximum hypothetical length was set at the longest fish collected in our samples to prevent overestimation of *cm*. Likewise, our maximum age was increased by one in our yield per recruit modelling to reflect the fact that we likely did not collect the oldest fish in the population. The MLLs modelled were 254 mm, 279 mm, 305 mm, and 330 mm over a range of conditional fishing mortality and estimated *cm* values. Recruitment to the fishery starts at 254 mm, a size at which most anglers begin to harvest what they catch (TWRA unpublished creel survey data).

Results

We collected 362 white bass in 2006 and 632 in 2007. The sex ratio of fish collected over both years was 1:2.6 males to females (Table 1). The samples were largely composed of young fish; individuals age-3 and younger accounted for 78% of all fish collected. Length frequencies and incremental PSDs were similar between sampling years with most white bass in the PSD Q-P size class and few fish in the PSD P-M size class (Figure 1). No sub-stock or trophy fish were collected in either year. Population size structure was likely skewed by sampling bias as electrofishing was conducted over known spawning sites during the spring white bass spawning run.

Growth was rapid, and nearly 100% of age-2 fish were mature. Females grew faster than males at all ages after age-1 (analysis of covariance, $P < 0.01$, Figure 2). Asymptotic growth from the von Bertalanffy model was achieved prior to age 5 for females at 383 mm TL and prior to age 6 and at 360 mm TL for males. Although fish recruited to the gear at age-2, full recruitment to the fishery was observed at age-3 when all fish exceeded 254 mm. The oldest male fish collected was age-8, while the oldest female was age-7 (Table 1). Total annual mortality from ages-2 through 8 was

Table 1. Number collected (n), percent mature (%), mean total length (TL, mm), and mean weight (WT, g) by age class and sex for white bass collected from Kentucky Lake, 2006–2007. Standard errors are in parentheses.

	Males				Females			
Age	*n*	% Mature	Mean TL	Mean WT	*n*	% Mature	Mean TL	Mean WT
1	17	59	217(3)	124(7)	13	0	225(5)	139(13)
2	287	100	301(1)	347(4)	120	99	317(2)	449(8)
3	230	100	329(1)	460(5)	107	100	351(1)	671(11)
4	48	100	340(3)	509(11)	16	100	367(4)	701(32)
5	33	100	347(3)	526(17)	8	100	386(5)	900(59)
6	53	100	363(2)	600(13)	12	100	386(5)	755(41)
7	40	100	365(3)	588(16)	3	100	393(7)	813(65)
8	7	100	369(6)	632(35)	0	–	–	–

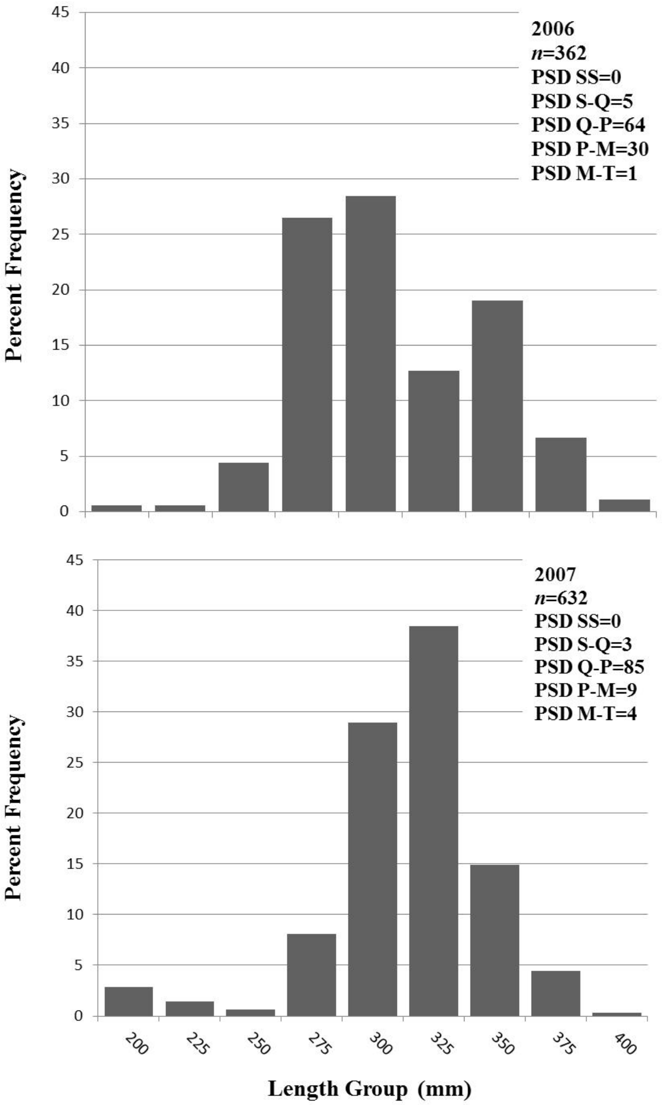

Figure 1. Percent frequency by total length group for Kentucky Lake white bass collected during spring samples in 2006 and 2007. Proportional Size Distribution values (%) for Substock (SS), Stock to Quality (S-Q), Quality to Preferred (Q-P), Preferred to Memorable (P-M), and Memorable to Trophy (M-T) fish are displayed in the legend.

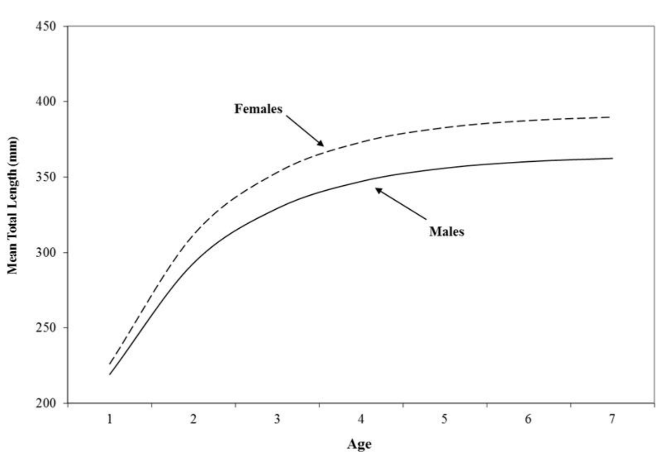

Figure 2. Mean total length at age of female and male white bass collected from Kentucky Lake (pooled for both sampling years).

45% in 2006 and 47% in 2007 (44% when pooled for both years). Annual mortality did not differ between sexes (analysis of covariance, $P = 0.2664$).

No missing year classes were detected in either year. Both sampling years indicated variable recruitment, with stronger year-classes in 1999, 2000, 2002, and 2004 and relatively weak year-classes in 2001, 2003, and 2005 (Figure 3). The 2004 year-class appeared especially strong, representing 65% of fish collected during 2006 and 53% of samples collected during 2007. Conversely, the 2003 year-class strength was very weak, comprising <1% of fish collected each year. White bass collected were relatively young during both sample years. Age-2 and age-3 fish comprised 69% of

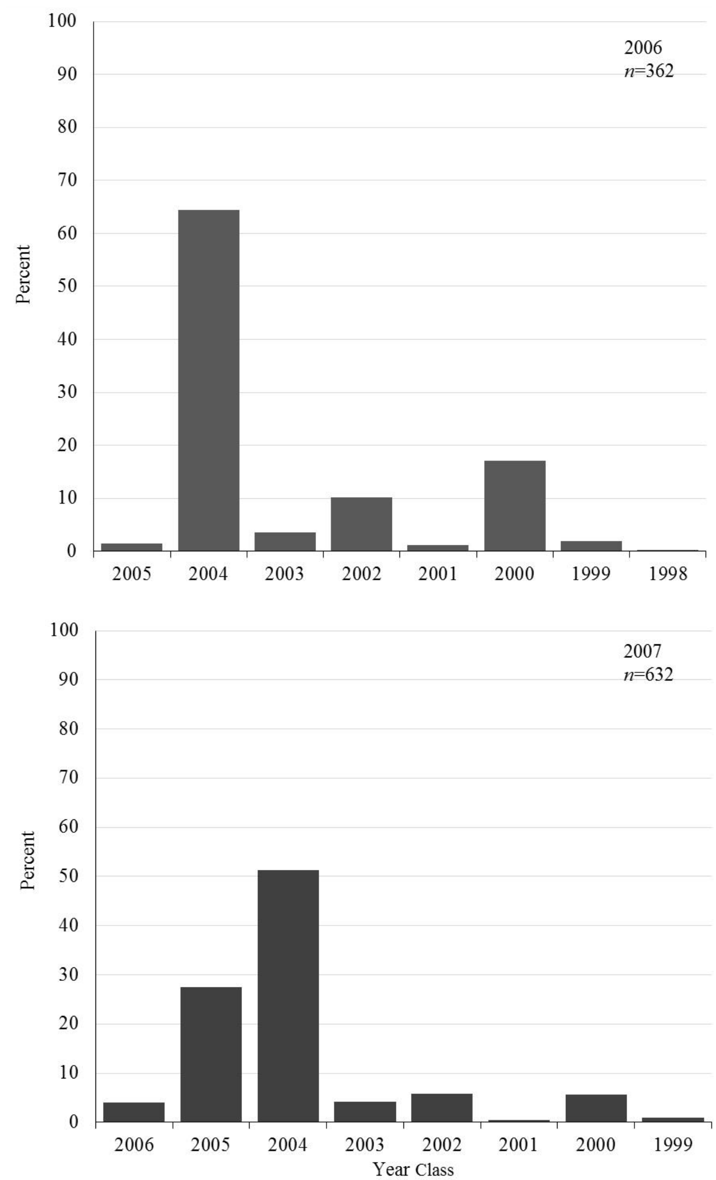

Figure 3. Age frequency of white bass collected from Kentucky Lake, during spring sampling in 2006 and 2007.

Table 2. Parameters used for Beverton-Holt yield per recruit models for Kentucky Lake white bass population with years pooled for 2006 and 2007.

Parameters	Values
von Bertalanffy growth coefficients	$L_{inf} = 420$; $K = 0.497$; $t_0 = -0.134$
log10(weight):log10(length) coefficient	Intercept = −5.330; slope = 3.177
Maximum age	9 years
Conditional natural mortality (*cm*)	0.28, 0.41, and 0.53
Conditional fishing mortality (*cf*)	0 – 0.50 by 0.05
Recruits entering population	1000 at age 0
Minimum length limits	254, 279, 305, and 330 mm

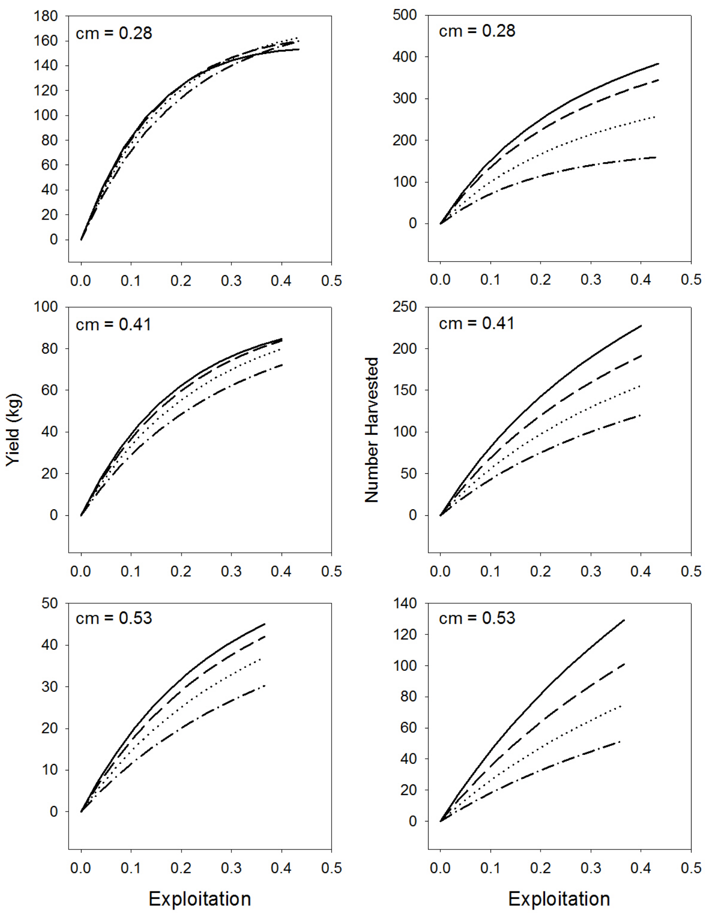

Figure 4. Beverton-Holt equilibrium yield model results for yield and number of fish available for harvest over two levels of *cm* and varying *u*. Each line represents a different MLL model: 254 mm (no size limit-solid line), 279 mm (dashed line), 305 mm (dotted line), and 330 mm (dashed-dotted line).

mature fish in 2006 and 82% in 2007. Mortality of older fish appeared to be equally apportioned among year classes during the two sampling years.

Model inputs are listed in Table 2. The five *cm* estimates were 0.28, 0.37, 0.40, 0.45, and 0.53 and the average was 0.41. Therefore, we modeled the population at a *cm* 0.28, 0.41, and 0.53 to encompass the approximate range of estimated *cm*. No significant increases in yield were observed from the current lack of MLL (254 mm) to any of the MLL at all modeled *cm* values (Figure 4). Predicted yield actually decreased with increasing exploitation in most comparisons between MLL. At a *cm* value of 0.41 and *u* of 0.20, predicted yield decreased by 25% from no size limit (254 mm) to a 330 mm MLL. Drops in yield were less (6%) with a *cm* of 0.35 at the same *u*. A slight increase in yield was observed between the 254 mm (no size limit) and 279 mm MLL when *cm* = 0.35 and *u* exceeded 0.35. Decrease in yield appeared to be greater as *u* increased for both models. Likewise, the model predicted decreases in number of fish available for harvest as MLL and exploitation increased. These decreases were even greater with number harvested decreasing by more than 50% when *cm* = 0.45 and *u* = 0.40. Decreases in predicted yield and harvest appeared greater with increasing *cm* and *u*.

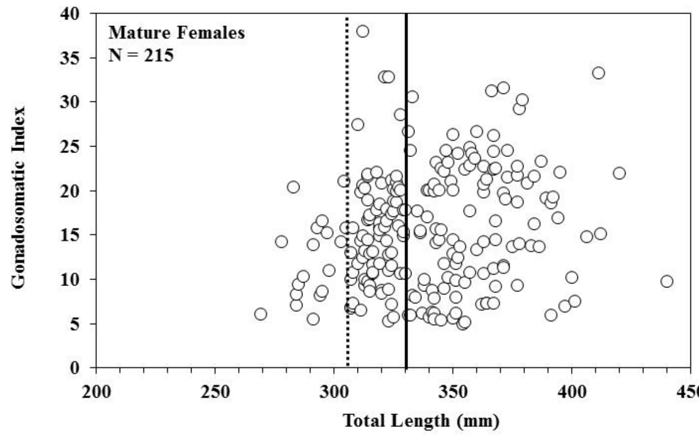

Figure 5. Gonadosomatic index values as a function of total length for female white bass collected during 2006 and 2007. The vertical lines represent possible 305-mm (dotted) and 330-mm (solid) minimum-length limit (MLL) regulations. Fish to the left of these lines would be protected from harvest under these MLLs.

Although collections did not span prolonged periods in either sampling year, highest GSI values for female white bass varied during the spring spawning season (Figure 5). The relationship between GSI and total length revealed that a 305 mm MLL protected only 8% of spawning females in the fishery, but a 330 mm MLL increased the proportion of protected spawning females to 43%. The current lack of MLL (angler-imposed 254-mm MLL) appeared to protect almost no spawning-sized female white bass in Kentucky Lake.

Discussion

Growth and mortality

White bass in Kentucky Lake grew fast, achieved maturity quickly, and exhibited moderate longevity. Females grew faster, but males were collected up to age-8; whereas, only 3 age-7 and no older females were collected. Asymptotic growth in the von Bertalanffy growth model occurred around age-5 for both sexes with growth increments relatively slow after that. Maximum length observed was 420 mm which is similar to L_{inf} reported by other researchers (Lovell and Maceina 2002, Baker and Lochmann 2012). Despite a relatively wide distribution of lengths in the population, few memorable and no trophy-sized individuals were collected during two years of sampling. Fish younger than age-2 and below PSD quality size were also not abundant. The maximum age of 8 was slightly higher than what has been observed for other white bass studies in the southeastern United States (Webb and Moss 1967, Houser and Bryant 1970, Myhr 1971, Colvin 2002a, Lovell and Maceina 2002, Baker and Lochmann 2012).

Lovell and Maceina (2002) and Baker and Lochman (2012) observed similar size and age structures for white bass populations in Alabama and Arkansas reservoirs, respectively. Like our study, both studies were conducted using electrofishing as the sampling method during spring spawning runs. Colvin (2002b) cautioned that while spring sampling with electrofishing provided good estimates of age structure, size structure assessments could be biased due to overrepresentation of males present in spawning runs. He recommended fall gill net sampling on Missouri reservoirs as the best means to minimize sampling bias toward larger, older fish. Muoneke (1994) found similar gear limitations for white bass sampling in a Texas reservoir. Fall sampling with gill nets may be difficult on large, riverine systems like Kentucky Lake due to scattered distribution of white bass and resulting high sampling effort.

Total annual mortality (*A*) was slightly lower than expected, but consistent between sampling years and within the range observed (40%–60%) for most Tennessee sport fish populations. Our combined-year value (both sexes) of 44% was similar to those recorded for white bass in other reservoirs located in surrounding states (Lovell and Maceina 2002, Colvin 2004, Baker and Lochmann 2012). The moderate mortality that we observed was attributable to the presence of all year classes between age-2-and age-8. Although some bias toward older fish may have occurred in our sampling, there was no significant difference in mortality between years. Colvin (2002b) found that electrofishing and gill net sampling of white bass populations provided similar profiles of population age structure but that gill netting surveys provided better estimates of age class abundance. Using electrofishing to sample white bass during a spawning run may produce high catch rates, but tend to underestimate A. However, this sampling method may be the only way to collect enough fish to determine growth and age structure for large main river systems like Kentucky Lake.

Recruitment

Recruitment appeared variable between years, but all eight year classes previous to our two collection years were present in the samples. We were unable to reliably estimate the magnitude of recruitment variation between years because precise estimates for white bass recruitment to age-1 are best made from gill net samples (Colvin 2002a). However, catch-curve residuals provided a rough measure of the magnitude of recruitment variability. As Lovell and Maceina (2002) observed in Alabama reservoirs, the Kentucky Lake catch curves suggested that white bass recruitment variation was moderate between years. Timing of spawning was also similar to that observed in other Tennessee reservoirs being protracted with peak activity between mid-March and end of April (Webb and Moss 1967, Myhr 1971). This period coincided with the highest GSI values observed for Kentucky Lake female white bass.

White bass recruitment in reservoirs has been tied to factors such as temperature, reservoir inflows, and age-0 gizzard shad abundance (Beck et al. 1997, Sammons and Bettoli 2000, DiCenzo and Duval 2002). Bauer (2002) concluded that Nebraska reservoirs with gizzard shad had higher, more stable recruitment. Starnes et al. (1983) found that high peak flows negatively influenced white bass recruitment by interrupting spawning activity in the Holston River, Tennessee. These factors likely also affected Kentucky Lake white bass recruitment, which has and abundant gizzard shad forage base and higher, consistent spring inflows relative to upper Tennessee River impoundments and tributary reservoirs. Lovell and Maceina (2002) concluded that strong year classes every 3–4 years were sufficient to sustain white bass fisheries. Strong year classes appeared to be occurring at Kentucky Lake every 2–3 years.

Potential effects of minimum length limits

Although increasing size limits provided a greater degree of protection to spawning female white bass, there was no indication that the spawning population was overexploited. Buchanan (1994) estimated exploitation ranging from 15%–20% during a three-year study in Chickamauga Lake, Tennessee, but no corrections were made for non-reporting and tag loss. He concluded that the white bass population there was healthy and "not stressed" by overfishing or other factors. Other recent exploitation studies with corrections have estimates ranging from 17%–33% in Kansas; 22%–36% in Missouri; and 47% in Texas (Muoneke 1994, Colvin 2002a, Schultz and Robinson 2002). Exploitation in our study appeared to be very low (<10%) although our lowest *cm* estimate (0.28) yielded a *u* value of 19%. The presence of older year classes and similar year-class abundances between sampling years further suggested that angler exploitation was low. Angler cropping and high exploitation have been observed for sauger (*Sander canadense*), another species with an annual spawning migration present in Kentucky Lake (Pegg et al. 1996).

Baker and Lochmann (2012) concluded that, because white bass at the southern portion of their range had moderate longevity, low natural mortality is possible. The moderate estimates of *cm* calculated (0.28–0.53) by FAMS in our study were not considered low. Sammons et al. (2006) concluded that *cm* values for bluegills (*Lepomis macrochirus*) were high enough to negate the utility of MLLs in Georgia and Alabama. The relative role of fishing mortality was modelled over a range of values since we were unable to determine it precisely. Harvest rates of Kentucky Lake white bass can be high, but higher natural mortality suggests that fishing mortality and exploitation are low. Hooking mortality has not been found to be significant for the species (Muoneke and Childress 1994, Black 2014).

Our equilibrium yield models resulted in no meaningful increases in predicted yield or number of fish available for harvest for any MLL scenario. None of the higher MLLs held potential to improve the white bass fishery under our population parameters. Given that natural mortality estimates (*cm*) may have been a significant portion of our estimate of *A*, it is unlikely that angler exploitation was a major limiting factor for Kentucky Lake white bass.

Recommendations

We concur with Baker and Lochmann (2012) that tagging studies be conducted concurrently with white bass length limit evaluations to better estimate the components of *A* (i.e., natural and fishing mortalities). Based on the ranges of *cm* and *u* used in our yield per recruit modelling, it appeared that an MLL would not likely benefit the Kentucky Lake population which appeared to have fast growth, steady recruitment, moderate natural mortality, and low angler exploitation. Similar conclusions were reached for white bass populations in Alabama and Arkansas based on these criteria (Lovell and Maceina 2002, Baker and Lochmann 2012).

This study resulted in TWRA's decision not to use a MLLs to manage white bass harvest at Kentucky Lake. Length limits were deemed unnecessary as equilibrium yield analysis demonstrated that harvest objectives were being met and that the fishery would benefit little from such a change. Daily creel limit was reduced from 30 to 15 during 2008 in an effort to buffer the fishery from weak year-classes and better distribute catch among anglers. This action caused little public controversy. Growth rates and recruitment dynamics for the Kentucky Lake white bass population are likely typical for lower Tennessee River mainstem reservoirs because hydrology and inflows are relatively consistent among years compared to tributary storage impoundments.

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