Exploring the Utility of Various Minimum-length Limits for the Largemouth Bass Fishery in the Arkansas River, Arkansas

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Abstract: Largemouth bass (*Micropterus salmoides*) on the Arkansas River have been regulated by a 381-mm minimum-length limit (MLL) regulation since 1 January 1998; however, little evaluation of this regulation has been conducted. During 2004–2005 and 2010, largemouth bass populations were sampled from throughout all navigation pools in the Arkansas River. All bass were aged using sagittal otoliths, and population metrics were calculated to conduct simulation modeling using the Fisheries Analyses and Simulation Tools (FAST) software. Composite model parameters were developed using data from all 3 yrs of sampling. Model predictions of fishery yield, average size of harvested fish, and number of preferred-sized (≥381-mm TL) fish in the population were compared among the current MLL and three alternative limits: 430 mm (higher than the current MLL), 330 mm (lower than the current MLL), and 255 mm (representing no MLL). At the relatively low levels of fishing mortality present in the Arkansas River fishery (μ ~ 12% from creel surveys), fishery yield would be improved with a lower or no MLL. Conversely, the 380-mm and 430-mm MLLs were predicted to have better potential to improve mean size of harvested fish and overall population size structure. Results of the population modeling indicated that the current 381-mm MLL regulation was an appropriate management strategy for the Arkansas River largemouth bass fishery, providing the best overall balance among fishery yield, mean size of harvested fish, and population size structure. However, a 330-mm or 356-mm MLL might be acceptable to accommodate competitive tournament anglers that are only interested in weighing in more bass.

Key words: largemouth bass, length-limit evaluation, simulation modeling, yield, size structure

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Largemouth bass (*Micropterus salmoides*) is the most highly sought-after freshwater sportfish in Arkansas and the United States (USFWS-USBOC 2006). In managing largemouth bass fisheries, many states employ various length-limit regulations, commonly a variation of a minimum-length limit (MLL) (Wilde 1997). In general, MLL regulations are recommended and work best for fisheries characterized by low to moderate rates of natural mortality, average to fast growth rates, and higher rates of fishing mortality (Novinger 1984). Objectives of MLLs vary across fisheries and include preventing overharvest, maintaining favorable population and community structure, increasing fishery production, and sustaining the quality of fish and fishing (Brousseau and Armstrong 1987). When applied specifically to largemouth bass fisheries, expected results may include an increase in numbers of largemouth bass caught (e.g., Paragamian 1982), greater abundance of harvestable-sized largemouth bass (Wilde 1997), delayed mortality until a certain age or size (Anderson 1974), and in some cases, increased predation on prey species (Novinger 1984).

As with any management strategy, length-limit regulations should be evaluated following implementation to assess whether intended impacts have occurred. One approach to evaluate length-limit regulation is to analyze data collected within a before-after experimental design (Neumann et al.1994, Wilde 1997). Response variables used for assessment may include proportional size distribution measures (Guy et al. 2007), number or weight of fish harvested, electrofishing catch-per-unit-effort (CPUE), angler CPUE, or CPUE of certain size groups (Novinger 1987, Neumann et al. 1994, Quinn and Limbird 2008). Statistically significant responses in one or more of these measures following implementation of a regulation may provide inference regarding the overall effectiveness of the regulation. However, high variation in sampling efficiency and fish recruitment can mask the true effects of a regulation changes, making evaluation of success problematic.

Another approach commonly used to evaluate the potential effectiveness of length-limit regulations is simulation modeling. Simulation modeling allows the fisheries manager to evaluate a range of potential outcomes that might result from a proposed regulation with a given set of fishery conditions (Slipke and Maceina 2006). Modeling can be useful when long-term data sets are unavailable to evaluate the effects of a regulation on a fishery. In these cases, modeling can be used to compare the present MLL regulation against alternative regulations, usually including one that represents a no-length limit scenario (e.g., Allen and Pine 2000). The Fishery Analyses and Simulation Tools (FAST) model has become a common tool to assess length-limit regulations (Slipke and Maceina 2006). Given that growth, mortality, and recruitment are the major forces affecting fishery dynamics, modeling assists in processing the complex interactions among these three interactive functions to provide insights into the likely responses of the fishery to a set of conditions (i.e., length-limit regulation). The FAST program has previously been used in MLL evaluations for a variety of species including bluegill (Paukert et al. 2002), crappies (Boxrucker 2002, Isermann et al. 2002a, Eggleton et al. 2009), sauger (Maceina et al. 1998), white bass (Lovell and Maceina 2002), blue catfish (Holley et al. 2009), muskellunge (Fronhauer et al. 2007), shovelnose sturgeon (Quist et al. 2002), and black basses (Slipke et al. 1998, Slipke et al. 2004).

On 1 January 1998, the Arkansas Game and Fish Commission (AGFC) implemented a 381-mm MLL for largemouth bass throughout the Arkansas River. The only formal assessment of this MLL during the past 12 yrs has been a before-after analysis of cove-rotenone and electrofishing datasets (Quinn and Limbird 2008). However, this evaluation was limited to three navigation pools in western Arkansas, and no simulation modeling using datasets collected from throughout the river has ever been conducted. Thus, the objective of this study was to evaluate the appropriateness of the current 381-mm MLL on the Arkansas River largemouth bass fishery using simulation modeling. Modeling was used to compare the current MLL regulation to alternative regulations above and below the current regulation in addition to one that simulated no length limit.

Methods

Study Area

Within Arkansas, the Arkansas River flows northwest to southeast over a distance of 500 km and, with the exception of the lowermost 50 km below Dam No. 2, is contained entirely within the McClellan-Kerr Arkansas River Navigation System (MKARNS; Limbird 1993). The MKARNS consists of 19 lock and dam systems, of which 11 are located in Arkansas. These navigation pools range in size from approximately 1,500 ha to over 11,000 ha. Additional descriptive information about the MKARNS can be found in Eggleton et al. (2009).

Fish Collections

Largemouth bass were collected using nighttime boat-mounted electrofishing during the summers of 2004, 2005, and 2010. Collections in 2004 and 2005 were conducted in all 11 navigation pools of MKARNS whereas sampling during 2010 occurred in only four navigation pools (2, 4, 6, and 10). Electrofishing settings were determined based on conductivity of each sampling location to achieve an approximate power output of at least 3,000 W during all sampling (Burkhardt and Gutreuter 1995), which typically produced a current of 7–10 amps (Eggleton et al. 2010). Sampling sites were selected using the stratified random sampling scheme described in Eggleton et al. (2010), with sampling effort allocated equally between main channel margin and backwater macrohabitats in each pool. Other aspects of sampling methods and design are described in Eggleton et al. (2010).

All largemouth bass collected ($n = 2,201$) were returned on ice to the laboratory and frozen for later processing. In the laboratory, largemouth bass were measured for total length (TL) to the nearest mm and weighed for total weight to the nearest g. Sagittal otoliths were removed for aging using standard procedures (Schramm et al. 1992, Buckmeier and Howells 2003). All otoliths were initially double-blind read whole view while immersed in water under a compound dissecting microscope. All otoliths of largemouth bass aged 3 yrs or greater were cracked and re-aged from the cross sections following Buckmeier and Howells (2003).

Model Development

Because largemouth bass are currently managed by the same regulation throughout the Arkansas River, fish collected across navigation pools and sampling years were combined to generate modeling parameters. A composite total weight-total length (W-L) equation was fitted using all largemouth bass ≥150-mm TL, with the slope and intercept of this equation used during all modeling. Largemouth bass growth was modeled using total lengths and ages from all fish collected using a von Bertalanffy growth model (Ricker 1975, SAS Institute 2008); these parameters were used during all modeling simulations. The theoretical maximum length for the population (L_∞) was fixed at 572 mm, with the other parameters left to fit the data. The L_∞ chosen was actually larger than previously modeled values (mean 474 mm during 2004–2005, Eggleton et al. 2010; and 460 mm during 2010, Peacock 2011). Populations during all sampling years did contain relatively small proportions of larger (>500-mm TL) bass. Modeled L_∞ values were relatively small in spite of competitive tournament reports and creel surveys that verified larger bass were present in the fishery. Thus, to approximate a more realistic L_∞ for modeling, the average weight of the largest individual bass from the last four Arkansas River Big Bass Bonanza tournaments (3,270 g) was used to approximate L_∞. The corresponding length that predicted this weight from the composite W-L equation (572 mm) was used to estimate of L_∞ for the purposes of this modeling.

Instantaneous total mortality (Z) and total annual mortality (A) of largemouth bass were estimated using standard catch-curve analysis (Ricker 1975) using weighted ordinary least-squares regression following Miranda and Bettoli (2007). Catches of largemouth bass younger than age 2 were excluded to adjust for sampling bias relative to underrepresentation of these cohorts (Miranda and Bettoli 2007). A mean catch curve was computed by averaging *Z* from each sampling year. This approach was used to approximate a composite *Z* in order to place equal weight on each sampling year. All statistical analyses were conducted using the Statistical Analysis Software (SAS Institute 2008).

Simulation Modeling of Different MLL Regulations

Using the composite age, growth, and mortality data generated as described above, four different MLL scenarios were simulated using the yield-per-recruit form of the Jones-modified Beverton-Holt equilibrium yield model in FAST (Slipke and Maceina 2006). Four different MLL regulations were simulated: 380 mm (current regulation), 330 mm (of interest to tournament anglers for weigh-in purposes), 430 mm (assess potential for trophy fishery), and 255 mm (simulating no length limit). Response variables chosen to evaluate each MLL scenario were fishery yield (kg), number of fish harvested, and numbers of fish in the population at 381 mm ("preferred size" [Anderson and Neumann 1996]; equivalent to 0.90 kg or 2 lbs in the Arkansas River fishery), 430 mm (equivalent to 1.28 kg or 3 lbs in the Arkansas River fishery), and 510 mm (equivalent to 2.25 kg or 5 lbs in the Arkansas River fishery). Initial cohort size was set to 1,000 individuals and maximum age was set to 10 yrs, which corresponded to the oldest individual collected during the 3 yrs of sampling. To account for probable error in mortality estimation, modeling was conducted at levels of conditional fishing mortality (*cf*) ranging from 0.1 to 0.5, which were reported as exploitation (μ). Although natural mortality rates were unknown for the Arkansas River, a range of possible instantaneous natural mortality (M) estimates were generated using five empirical models contained in FAST following the approach of Maceina et al. (1998). Instantaneous natural mortality estimates from these models ranged 0.254–0.530, and averaged 0.372. Corresponding estimates of conditional natural mortality (*cm*) ranged from 22%–41% and averaged 31%; thus, all modeling was done using a fixed *cm* rate of 30%.

Results

Fishery Statistics

A total of 2,201 largemouth bass were collected across the three sampling years for this evaluation; ages were obtained from all but nine individuals. Largemouth bass aged 6 yrs or younger comprised 98% of the sample, with 2- to 6-year-old individuals accounting for 65% of the sample (Table 1). Although age-1 bass were well represented in all years, they were still likely underrepresented during sampling. Growth of largemouth bass in the Arkansas River was moderate, with fish reaching 254-mm TL in 1.7 yrs, 330-mm TL in 2.9 yrs, and 381-mm TL in 4.0 yrs (Table 2). Overlaying these estimates with age structure data estimated that about 18% of the population was of legal harvest size on average under present conditions, which was similar to the actual percentage (15%) of fish greater than 381 mm from length-frequency histograms (Figure 1). Mean total

Table 1. Age frequency of largemouth bass collected from the Arkansas River during the summers of 2004, 2005, and 2010. Numbers in parentheses represent relative abundances.

Age	2004 Frequency (%)	2005 Frequency (%)	2010 Frequency (%)	Overall Frequency (%)
0	1 (0.1)	0 (0)	40 (9)	41 (2)
1	394 (42)	166 (21)	144 (32)	704 (32)
2	306 (32)	323 (40)	90 (20)	719 (33)
3	139 (15)	151 (19)	31 (7)	321 (15)
4	58 (6)	94 (12)	73 (16)	225 (10)
5	31 (3)	30 (4)	50 (11)	111 (5)
6	13 (1)	20 (3)	7 (2)	41 (2)
7	2 (0.2)	5 (0.6)	8 (2)	15 (0.6)
8	1 (0.1)	2 (0.3)	3 (1)	5 (0.2)
9	3 (0.3)	5 (0.6)	0 (0)	8 (0.3)
10	2 (0.2)	0 (0)	0 (0)	2 (0.1)

Table 2. Composite parameters used to conduct simulation modeling on the Arkansas River largemouth bass fishery.

Metric	Parameter value
von Bertalanffy growth coefficients	$L_\infty = 572$ mm (fixed) $K = 0.2217$ $t_0 = -0.9882$ years
Maximum age	10 years
Conditional natural mortality (*cm*)	0.30
Conditional fishing mortality (*cf*)	0.10–0.50
Log_{10} weight – log_{10} length coefficients	Intercept (a) = −5.480 Slope (b) = 3.262
Minimum-length limits modeled (age at which the length is attained)	255 mm (1.7) 330 mm (2.9) 380 mm (4.0) 430 mm (5.3)

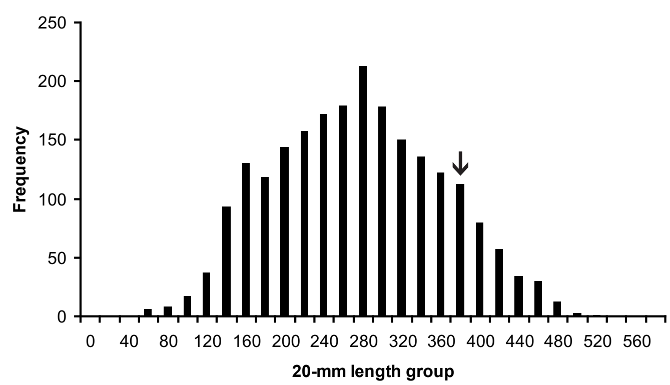

Figure 1. Length-frequency histogram of largemouth bass in the Arkansas River. Data from 2004, 2005, and 2010 were combined; fish were classified into 20-mm length groups based on midpoints. Vertical arrow represents total length of 381, which is the current MLL regulation.

annual mortality rates generated from 3 yrs of catch curves were –0.630 and 0.464 for *Z* and *A*, respectively.

Simulation Modeling

At conditional natural mortality rates of 30%, modeling consistently predicted greater fishery yields under lower length limits (Figure 2). This trend was evident for all MLLs, but only when exploitation levels were less than about 20%. At exploitation levels above 20%, the greatest fishery yields were predicted under the 330-mm MLL compared to all of the other MLLs (Figure 2). Additionally, greater fishery yields also were predicted under the current 380-mm MLL compared to no MLL, but only when exploitation exceeded 30% (Figure 2). Across all levels of μ, yields under the 430-mm MLL were predicted to be 65%–75% of those predicted under the other MLLs. Although the 330-mm MLL provided the greatest overall fishery yield across all levels of exploitation, the net improvement over the current 380-mm MLL and no MLL scenarios was only 5%–15%.

The number of largemouth bass harvested was inversely related to the MLL used and increased 2–3 fold as exploitation increased from 10% to 40%, with sharper increases at lower MLLs (Figure 3). The number of harvestable-sized largemouth bass in the fishery also was inversely related to the MLL regulation used. Under the no-MLL scenario, 55% of the population was predicted to be harvestable size, whereas 36%, 24%, and 15% of the population was of harvestable size under the 330-mm, 380-mm, and 430-mm MLLs, respectively. In all cases, the model predicted that lower MLLs reduced the proportion of largemouth bass from a given cohort reaching "preferred size" (381 mm, equivalent to 0.9 kg or 2 lbs; Figure 4) and larger sizes of interest to anglers (e.g., 430 mm, equivalent to 1.28 kg or 3 lbs; Figure 5). Production of "memorable sized" fish (510 mm) was predicted to be extremely low in the Arkansas River under all MLLs given observed growth and L_∞ values for the fishery. Under all MLL scenarios, fish in this size range were predicted to comprise only about 1%–2% of the population, with sharp declines as exploitation increased above 10%.

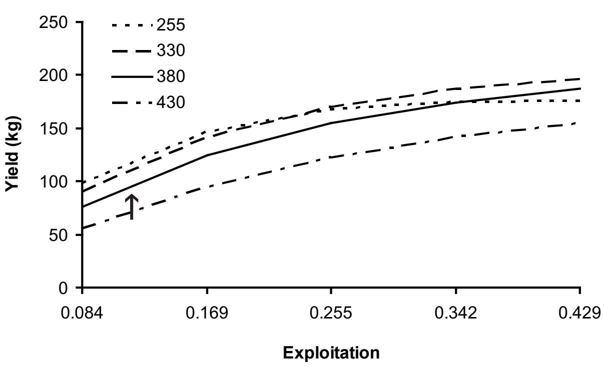

Figure 2. Predicted yield under different MLL regulations and exploitation levels. Conditional natural mortality rates (*cm*) were fixed at 30%. Vertical arrow represents 12% exploitation of largemouth bass, which was estimated from creel surveys in the Arkansas River.

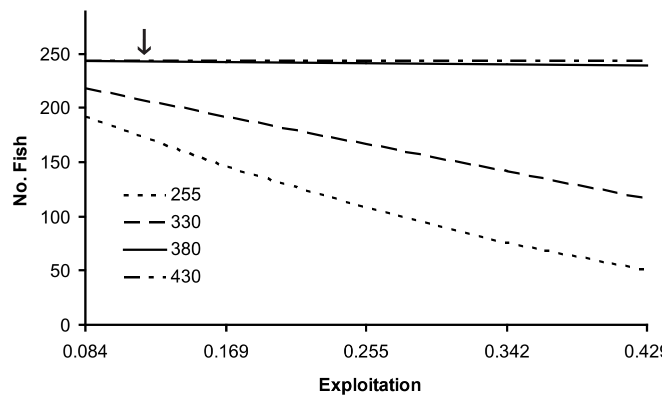

Figure 4. Number of fish to reach 381-mm TL ("preferred size") from a theoretical cohort of 1,000 fish under different MLL regulations and exploitation levels. Conditional natural mortality rates (*cm*) were fixed at 30%. Vertical arrow represents 12% exploitation of largemouth bass, which was estimated from creel surveys in the Arkansas River.

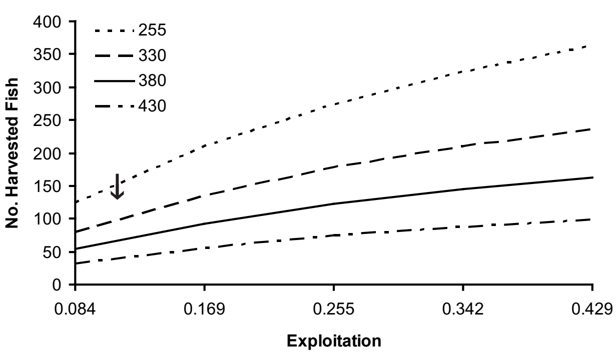

Figure 3. Predicted number of fish harvested under different MLL regulations and exploitation levels. Conditional natural mortality rates (*cm*) were fixed at 30%. Vertical arrow represents 12% exploitation of largemouth bass, which was estimated from creel surveys in the Arkansas River.

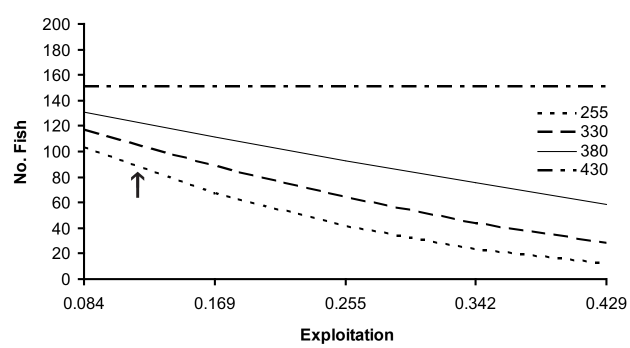

Figure 5. Number of fish to reach 430-mm TL from a theoretical cohort of 1,000 fish under different MLL regulations and exploitation levels. Conditional natural mortality rates (*cm*) were fixed at 30%. Vertical arrow represents 12% exploitation of largemouth bass, which was estimated from creel surveys in the Arkansas River.

Discussion

Precise knowledge of exploitation can add resolution and realism to length-limit modeling, and thus, aid fisheries management. We have recent information on largemouth bass exploitation rates in different navigation pools of the Arkansas River. Fontaine (2009), Fontaine et al. (2009), and related research conducted during 2009–2010 (Peacock 2011) have reported largemouth bass exploitation rates in the lower Arkansas River to average about 12% (range 6%–15%). Estimates were generated from 3 yrs of bus-route creel surveys done in conjunction with tag-reward studies in four different navigation pools of the river (Pool 2 in 2008–2009, Pool 4 in 2007–2008, and Pools 6 and 7 in 2009–2010). All exploitation estimates were adjusted for tag loss, tagging-associated mortality, and angler non-response as described in Fontaine et al. (2009). In a recent study by Allen et al. (2008), mean exploitation of largemouth bass nationally had declined from 35% during 1976–1989 (35 estimates) to 18% during 1990–2003 (32 estimates). Although our estimates from the Arkansas River are only about ⅔ of this figure, these estimates are all less than 5 yrs old. Given that the latter figure reported by Allen et al. (2008) contains estimates that are now 10–20 years old, we feel that our largemouth bass exploitation rates are reasonable and reflective of national trends.

Whether a MLL regulation can be effective at improving the largemouth bass population in the Arkansas River at the present time can be debated. Integrating our mean exploitation (12%, range 6%–15%) with our total annual mortality (*A*, 46%) estimate generated from the present study suggested that interval natural mortality (*v*) to be approximately 34% (range 31%–40%). This estimate was comparable with another estimate derived from natural mortality models contained in FAST (mean 31%). Given that exploitation of largemouth bass was not excessive in the Arkansas River, the effectiveness of any MLL regulation may be difficult to detect (Novinger 1984). Additionally, although rates of largemouth bass natural mortality also do not appear to be excessive, there are indications that they may have been in recent years, which may have affected model predictions. During 2010, the age distribution of Arkansas River largemouth bass indicated a very weak age-3 cohort (2007 year class) and moderately weak age-2 cohort (2008 year class) coincident with above-average flows during the period 2007–2009 (Peacock 2011). During 2004–2005 sampling, these two cohorts combined comprised 47% and 59% of the samples, respectively, compared to only 27% of the 2010 sample (Table 1). Furthermore, recruitment coefficient of determination values (RCD; Isermann et al. 2002b) values in 2010 (0.689) were lower than previous values derived in 2004 (0.958) and 2005 (0.954) (Peacock 2011). These results are consistent with recruitment variation in largemouth bass, and that natural mortality was likely above average during recent years. These characteristics may be further hindering the present-day MLL regulation from having the desired effects, at least over the short-term.

Over longer-term time scales by which fisheries management is conducted, there was some evidence that the MLL regulation on Arkansas River largemouth bass has potential to have modest effects on the fishery. Modeling results for fishery yield, numbers of harvested fish, numbers of preferred-size fish (≥381-mm TL), and numbers of fish at least 430-mm TL suggested that fisheries managers would need to consider trade-offs among these variables that balance size, numbers, and perhaps angler preferences. In most situations, the trade-off will be between the numbers of harvested bass versus the numbers of larger-sized bass desired by most anglers under different MLL regulations. Under recent fishery conditions, the current 381-mm MLL for the Arkansas River appears to be the most suitable MLL regulation for the fishery. Lower MLLs were predicted to provide greater yields, but predicted increases were usually not greater than 10%–18% over the current 381-mm MLL under the assumed *cm* (30%) and observed rates of μ (12%). At 12% μ for the Arkansas River, the model predicted that yield would increase 14% and number of harvested bass increase 46% when MLL was decreased from the current 381-mm MLL regulation to 330 mm. However, these increases were tempered by a predicted 21% reduction in the number of both 381-mm and 430-mm size fish. Similar findings were observed when the 380-mm MLL was compared to the no-MLL scenario. In both cases, the decline in numbers of larger-sized fish was relatively sharp when exploitation increased above 10%. Given that exploitation is slightly above this figure in the Arkansas River, it is unlikely that largemouth bass anglers would find this trade-off appealing. This may be especially true of competitive tournament anglers that value size more than numbers in terms of weigh-ins.

In terms of the higher 430-mm MLL, modeling predicted that this regulation would decrease yield by at least 30% over the current 381-mm MLL or smaller MLLs. However, the higher MLL also was predicted to increase the numbers of 430-mm largemouth bass by at least 40% compared to the current 381-mm MLL or smaller MLLs. However, at observed levels of μ in the Arkansas River, the overall numbers of harvested fish was predicted to be relatively low under the 430-mm MLL, and only about 60% of that predicted under the current 381-mm MLL and 40% of that predicted under the 330-mm MLL. Thus, a higher MLL may not be advisable for the Arkansas River because only about 15% of the population would survive the 5.3 yrs needed to reach 430-mm TL on average compared to the 24% that reaches 381-mm TL in 4.0 yrs under the current MLL regulation. Although the greater abundance of larger bass may be appealing to competitive tournament anglers, such a high MLL might restrict the ability of tournament anglers to weigh-in the five fish allowed by most tournaments. It may be unlikely that such a regulation would be widely supported by anglers despite that the quality of the fewer bass harvested may be very good.

Other evidence supported that the current 381-mm MLL would likely be more effective than the other MLL regulations. Assuming the no-MLL scenario as the maximum possible yield for the fishery, we found that the current 381-mm MLL was predicted to produce about 81% of this value (Table 3; interpolated between 8% and 17% exploitation). Decreasing the MLL to 330-mm TL was predicted to increase yield 11%–14%, or to about 93% of the maximum possible yield. Although speculative, it is doubtful that such a small increase in yield would be detectable by anglers. Additionally, although the 330-mm MLL was predicted to maximize the number of harvested fish, this MLL also was predicted to produce only about 84% as many preferred-sized fish (i.e., 381 mm or larger; Anderson and Neumann 1996) (Table 4). Under the moderate levels of *cm* and relatively low levels of μ observed in the Arkansas River, the two higher MLLs were predicted to produce the maximum possible number of preferred-size (≥381-mm TL) largemouth bass (Table 4). However, the number of harvestable-sized fish was predicted to be 30%–60% reduced with these higher MLLs compared to the lower 330-mm MLL. Given the high proportion of catch-and-release and/or competitive tournament anglers in the Arkansas River, the abundance of larger bass and population size structure are frequently of greater interest to anglers than fishery yield (Allen et al. 2008, Myers et al. 2008). Thus, the current 381-mm MLL regulation appears to be the most appropriate management strategy for the Arkansas River largemouth bass fishery under present conditions, providing the best overall balance among fishery yield, numbers of fish available for harvest, and population size structure.

Since implementation of the 381-mm MLL in the Arkansas River 12 yrs ago, it has been evaluated using before and after datasets in one section of the river. Using a combination of cove-rotenone and electrofishing datasets collected from Arkansas River Pools 10, 12, and 13, Quinn and Limbird (2008) reported that largemouth bass total CPUE and CPUE of largemouth bass ≥381-mm TL increased approximately 30% following implementation of the MLL. Their research also indicated a general decrease in the CPUE of largemouth bass ≥450-mm and ≥533-mm TL. Thus, although there was some evidence of an improved size structure, there was a concurrent decrease in the abundance of memorable-sized (TL ≥ 510 mm) and trophy-sized (TL ≥ 630 mm) largemouth bass. Low numbers of these larger-sized (>500-mm TL) bass were consistent with findings in the present study. Although they concluded that the MLL had an overall positive effect on largemouth bass abundance, they also acknowledged that their results might have been influenced by an outbreak of largemouth bass virus and the invasion by exotic zebra mussels that occurred approximately 2 yrs following implementation. Our model predictions that higher MLL regulations (e.g., 380 mm or 430 mm) would be more effective at increasing population size structure is generally consistent with management options suggested by Quinn and Limbird (2008). However, we collected too few largemouth bass >450-mm TL (< 2% of the sample) to make inferences about the largest individuals in the fishery.

Table 3. Proportion of the maximum predicted yield under different MLL regulations and levels of exploitation at 30% conditional natural mortality (*cm*). Proportions were calculated from the maximum yield predicted for a given MLL, which was assumed to be 100% **(bold type).**

	Exploitation				
MLL	**0.08**	**0.17**	**0.26**	**0.34**	**0.43**
254	**1.00**	**1.00**	0.98	0.94	0.90
330	0.91	0.96	**1.00**	**1.00**	**1.00**
381	0.77	0.85	0.91	0.93	0.95
430	0.57	0.65	0.72	0.76	0.79

Table 4. Proportion of the maximum number of preferred-sized fish under different MLL regulations and levels of exploitation at 30% conditional natural mortality (*cm*). Proportions were calculated from the maximum number of quality-sized fish predicted for a given MLL, which was assumed to be 100% (**bold type**).

	Exploitation				
MLL	**0.08**	**0.17**	**0.26**	**0.34**	**0.43**
254	0.79	0.60	0.44	0.31	0.21
330	0.89	0.79	0.68	0.58	0.48
381	**1.00**	0.99	0.99	0.99	0.98
430	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

The reasons for the lack of many larger and older bass in the population are unclear. The low numbers of these fish may have overestimated *Z* and *A* from catch curves, which influenced interpretation of model results. Given the relatively low exploitation that was estimated, total mortality was mostly attributed to natural mortality (as *cm*), though it was not conclusive that natural mortality rates were excessive in the Arkansas River (Peacock 2011). The few larger bass and lack of many older bass also may have underestimated L_∞ in von Bertalanffy models. Although we chose to use a larger L_∞ estimate than was generated from our field data to compensate for this during modeling, competitive tournament results and anecdotal claims from anglers do support that these larger bass are present in the fishery. However, they are likely a very small proportion of the population, and have been characterized as such (<1% of the total numbers) by the stratified random sampling scheme that was used during all sampling. In the case of the Arkansas River, it may be advisable that future research include some non-random sampling that better targets these larger bass. In any event, the contribution of these individuals to fishery yield and numbers of harvestable-sized fish would be negligible. The effects of the largemouth bass virus outbreak that occurred a decade ago (Quinn and Limbird 2008) may have influenced the abundance of larger bass during 2004–2005 sampling, but would not have been detectable in the fishery's size structure in 2010. Fontaine et al. (2009) discussed angling-related mortality associated with competitive bass tournaments in the Arkansas River. When his estimated exploitation rates from two Arkansas River pools were adjusted for tournament-associated mortality rates (mean 28%, 95% CL 22%–35%) reported by Holt (2009), the additional mortality increased exploitation by 40%–50% to a range of 16%–19% (Fontaine 2009). It is possible that all of these factors contributed to some extent to the absence of many larger and older bass.

Ultimately, it is critical that management agencies understand angler preferences in a given fishery before selecting or assessing the effectiveness of any MLL regulation. Although modeling predicted an increase in fishery yield at the lower 330-mm MLL compared to the current 381-mm MLL, the Arkansas River largemouth bass fishery does not appear to be a yield-oriented fishery. Because the predicted decrease in the number of largemouth bass reaching 381-mm would be a consequence of the increased yield from a lower MLL, it would be critical to know whether or not anglers would actually harvest these additional bass from a lower MLL. If the only significant change in the fishery is that largemouth bass from 330- to 380-mm TL are then available for weigh-ins at competitive bass tournaments (e.g., Slipke et al. 2003), then a regulation change to a 330-mm MLL (or 356-mm MLL) may be acceptable for the Arkansas River without major effects on population size structure. There would probably be an increase in the associated tournament-related mortality due to holding and handling under a lower MLL. Depending on the extent of this additional mortality, model interpretations may need to focus on higher levels of exploitation, which could alter management recommendations in the future. We feel reliable answers to these questions are needed before altering the MLL for the Arkansas River largemouth bass fishery.

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