Smallmouth Bass Population Characteristics and Minimum Length Limit Evaluation in Two Tennessee Rivers

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Abstract: Smallmouth bass (*Micropterus dolomieu*) are a popular sportfish in many Tennessee rivers. In the southernmost extent of the species native range, including Tennessee, smallmouth bass populations tend to display relatively fast growth rates and can benefit from harvest restrictions. Consistent with national trends, recreational access and use of Tennessee rivers has increased in recent years (e.g., paddlesports and angling), but quantitative assessments of this increased use on smallmouth bass fisheries are lacking. Popular smallmouth bass fisheries exist in the Elk River and its major tributary, Richland Creek, and angler access has increased in recent years. The goals of this study were to characterize population structure of smallmouth bass and assess the need for minimum-length limits (MLL) in response to increased fishing pressure in the two Tennessee streams. Both streams were sampled using boat-mounted electrofishing gear in May and June in 2018. Smallmouth bass proportional stock density was similar between systems; however, mean length and relative stock density preferred were higher in Richland Creek. Estimates of annual mortality were similar between systems (0.45–0.46). However, the von Bertalanffy asymptotic length differed between rivers. Smallmouth bass entered the fishery (254 mm TL) at 2.6 years in Richland Creek and 2.9 years in Elk River. In both systems, conditional fishing mortality rates were relatively low based on formulas (0.12–0.24), and thus, new regulations were not necessary to prevent overfishing but may improve size structure at low estimates of natural mortality. This study provides a baseline assessment upon which future research and monitoring should be conducted. Furthermore, this study underlines the need to monitor growth overfishing and evaluate fishing mortality to keep pace with the increasing levels of fishing pressure expected for rivers in Tennessee and throughout the southeastern United States.

Key words: *Micropterus dolomieu*, population dynamics, size structure, overfishing

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Minimum-length limits (MLLs) can be an effective tool to protect populations from growth overfishing and improve size structure. Growth overfishing occurs when growth potential of a fishery is limited by high exploitation and total yield decreases (Slipke et al. 2002). These regulations usually do not benefit populations characterized by slow growth and a short lifespan, where high natural mortality can decrease the number of potentially harvested fish (Colvin 2002). In contrast, populations with faster growth and low natural mortality can often benefit from MLLs, assuming exploitation approximates or is higher than natural mortality (Allen and Miranda 1995). Thus, implementation of an MLL requires evaluation of growth and mortality to allow a data-informed decision for regulation implementation.

Smallmouth bass (*Micropterus dolomieu*) fisheries are popular in many rivers across the southeastern United States. Tennessee is near the southern edge of the smallmouth bass native range. Warmer water temperatures and a longer growing season at low latitudes can lead to faster growth and larger sizes compared to populations at more northern latitudes (Pauly 1980, Etnier and Starnes 1993, Brewer and Orth 2014). Age at quality length (280 mm) of smallmouth bass populations decreases with latitude and increases with mean annual temperature (Beamesderfer and North 1995). Smallmouth bass in Tennessee rivers typically only live to age 12 (Fiss et al. 2001); however, specimens from northern fisheries can live 18 years or more (Etnier and Starnes 1993). Additionally, growth of smallmouth bass varies throughout Tennessee due to river-specific characteristics such as underlying limestone or sandstone geology (Fiss et al. 2001). Latitudinal differences in smallmouth bass growth and age structure suggests a need for state-specific, and, potentially, system-specific regulation evaluations.

Participation in recreational kayaking across the United States increased 21% between 2013 and 2018 (Outdoor Industry Association 2019). Further, recreational river use across Tennessee has increased dramatically over the past several years as a result of new public access points, kayak fishers, and outfitters that provide shuttle services that allow anglers to reach previously lightly fished populations. Increases in angler use can quickly reduce size structure of black bass fisheries through exploitation or catch-and-release mortality (Beamesderfer and North 1995). In Tennessee, most riverine black bass (*Micropterus* spp.) fisheries are managed with no MLL and a creel of five black bass combined across species. Variability in smallmouth bass growth and recent increased fishery access suggests the need to consider case-specific needs for implementing regulations that were not considered in the past.

Increased access and fishing pressure do not necessarily result in an increase in harvest. Catch-and-release of black basses is more popular among anglers compared to the harvest-oriented fisheries from decades ago (Goedde and Coble 1981). Studies from the 1980s documented smallmouth bass harvest accounting for up to 50% of annual mortality (Paragamian 1984, Reed and Rabeni 1989). Across the United States, Allen et al. (2008) reported a 50% decline in fishing mortality rates since 1990 from a broad range of largemouth bass (*Micropterus salmoides*) fisheries. However, Sammons (2016) observed that up to 86% of shoal bass (*M. cataractae*) caught by anglers were harvested in some areas of the Flint River, Georgia; overall, exploitation riverwide was estimated at 26%. In Tennessee, anglers were observed harvesting 28% of riverine smallmouth bass caught during a creel survey in the South Holston River (Black 2019). Overall, there is a lack of information on exploitation and the need for regulations since catch and release has increased in popularity over recent decades. Therefore, our objectives were to 1) estimate growth and mortality of smallmouth bass in two Tennessee riverine smallmouth bass fisheries, 2) evaluate the potential for growth overfishing, and 3) simulate an array of MLLs to evaluate potential trade-offs in yield that would be associated with implementation of new regulations.

Methods

The Elk River (mean annual discharge = 39.7 m^3 sec^{-1}) is a medium-size tributary to the Tennessee River. Richland Creek (mean annual discharge = 15.8 m^3 sec^{-1}) is the largest tributary to Elk River. The Elk River is 314 km long and flows west along the southern border of Tennessee before entering Wheeler Reservoir in Alabama. Sampling was conducted within a 117-km reach of the Elk River and a 57-km reach of Richland Creek. The headwaters of Elk River are impounded by Tims Ford Dam, which created an 18-km tailwater capable of sustaining a year-round trout fishery (Tennessee Valley Authority 2008). Cooling effects of the hypolimnetic release vary seasonally but typically overlap about 30 km of the upstream Elk River sampling reach (Tennessee Valley Authority 2008). From June through September, daily average water temperature for the lower Elk River and Richland Creek fluctuate between 26°–29° C (USGS water data gage 03584600 and 03604000, respectively). Both systems contain an abundance of instream woody debris, rocky substrate, rooted aquatic vegetation along the bank, and a diversity of pools, large shoals, and islands. Although close in proximity, differing water temperature regimes and angler access could affect population structure and fishing exploitation. Thus, we evaluated each river independently.

Fish were collected May–June 2018 using boat-mounted pulsed DC electrofishing (Type VI-A GPP, Smith-Root Inc., Vancouver, Washington) at 12 sites in the Elk River and 11 sites in Richland Creek. Each site was sampled with an 1800-sec transect that included a variety of available habitats. All smallmouth bass were measured (TL, mm) and weighed (g). A subsample of fish was retained for age analysis (10 fish per 25-mm length bin per river system); the remainder of fish were released. Sagittal otoliths were removed, broken at the nucleus, briefly heated on a hot plate, mounted in clay, soaked in immersion oil, and read under a microscope with fiber optic illumination. The method of fracturing otoliths and mounting in clay was demonstrated to be 97% accurate with known-age fish (Buckmeier and Howells 2003). Two readers estimated ages of otoliths independently and disagreements were examined simultaneously to reach a consensus.

As a measure of abundance, mean catch per hour (CPH, fish h^{-1}) for smallmouth bass was determined for each river from electrofishing data. Length-frequency distributions between Elk River and Richland Creek were compared using a Kolmogorov-Smirnov two-sample test using Program R (version 3.5.1). Length frequencies, proportional size distribution (PSD, 280 mm), relative stock density preferred (PSD-P, 350 mm) and relative stock density memorable (PSD-M; 430 mm) were calculated to assess size structure of the populations (Neumann et al. 2012). Relative weight (W_r) was calculated to assess condition (Kolander et al. 1993). Relative weights were compared among size classes for each river and between rivers using a Kruskal-Wallis test (R Core Team 2018). Age frequencies were derived from otolith age estimates and an age-length key was developed and applied to unaged fish from both rivers. Age classes with one fish or less were excluded from growth and mortality estimates. Growth was evaluated for each river using a von Bertalanffy (1938) growth model with Fisheries Analysis and Modeling Simulator Tools (FAMS) program (version 1.64, Slipke and Maceina 2014). Growth curves between rivers were comparted with least-squares model of Akaike's information criterion (AIC, Akaike 1973) to determine if von Bertalanffy growth parameters differed between the rivers using the FSA package in R (Ogle et al. 2018). All growth parameters were modeled collectively and separately to isolate the best fitting model to estimate growth. The general model consists of separate parameter estimates for each river, whereas the common model has the same parameter estimates for each river.

Total instantaneous mortality (Z) and total annual mortality (A) were calculated using ages 2 through 9 with the Chapman-Robson method (Program R, Chapman and Robson 1960) since it is more robust to bias when using smaller sample sizes (Dunn et al. 2002). Instantaneous natural mortality rates (M) were calculated with FAMS by averaging seven estimators of M (Hoenig 1983, Chen and Watanabe 1989, Djabali et al. 1993, Jensen 1996, Lorenzen 1996, Cubillos et al. 1999, Quinn and Deriso 1999). Conditional natural mortality (cm) was calculated from M as $cm = 1 - e^{-M}$. No empirical estimates of angler harvest exist for smallmouth bass populations in Elk River or Richland Creek. Instantaneous fishing mortality (F) was estimated based of Chapman-Robson mortality estimates,

$$F = \frac{(u \cdot Z)}{(1 - S)}$$

Conditional fishing mortality ($cf = 1 - e^{-F}$) and exploitation (u) were estimated using values of A, M, and Z (Ricker 1975).

Beverton-Holt equilibrium yield-per-recruit (YPR, Beverton and Holt 1957) models were used to detect evidence of growth overfishing and changes in yield (kg) at various MLL scenario for each system: no MLL, 305 mm, and 355 mm. A 254-mm MLL was assumed to simulate a no length limit scenario, as fewer than 2% of Tennessee anglers harvest smallmouth bass less than 254 mm (Fiss et al. 2001). For each river, YPR models were run at three levels of M: the mean, maximum, and minimum estimates provided by the FAMS program. The dynamic pool model option in FAMS was used to simulate responses to management scenarios that have been considered elsewhere in Tennessee: no MLL, 305-mm MLL, and 355-mm MLL (Fiss et al. 2001). Models were calculated to simulate effects of MLL on yield (kg), total number harvested, and the number reaching 430-mm TL. Using the dynamic pool model, proportional size structure indices were simulated under the different MLL. Models were simulated with an initial population size of 1000 age-0 fish, constant recruitment, 0.9 cm of age-0 fish, and mean cm for all other ages. We chose to use steady-state recruitment in our models because Beamesderfer and North (1995) demonstrated that random and normally distributed recruitment variation compared to constant recruitment resulted in similar yield and PSD (i.e., flooding).

Results

Sampling resulted in a total of 102 smallmouth bass collected from Elk River (range = 117–489 mm TL) and 82 smallmouth bass collected from Richland Creek (range = 166–492 mm TL, Figure 1). Mean CPUE of smallmouth bass was 17 (SE = 4.0) fish h^{-1} in the Elk River and 15 (SE = 6.2) fish h^{-1} in Richland Creek. Length-frequency distributions differed between Elk River and Richland Creek populations (KSa = 0.26, $P = 0.004$). Observed PSD was similar between systems, but smallmouth bass in Richland Creek had a PSD-P (23) and PSD-M (10) that was higher than PSD-P (14) and PSD-M (3) in the Elk River population (Ta-

Table 1. Results from electrofishing surveys (EF data) and simulated estimates of smallmouth bass response to no minimum length limit (MLL; none), a 305-mm MLL, and a 355-mm MLL in the Elk River and Richland Creek. Proportional size distribution (PSD), PSD-preferred (PSD-P), and PSD-memorable (PSD-M) of smallmouth bass populations are calculated for the electrofishing sample and predicted for each MLL scenario. Also, predicted number of fish harvested (*n* harvested), yield (kg), and number of fish reaching 430 mm TL are presented for each MLL scenario.

		EF data	None MLL	305 MLL	355 MLL
Elk River	*n* Harvested		11.1	7.5	4.4
	Yield (kg)		5.0	4.3	3.2
	n at 430 mm		13.9	16.0	18.7
	PSD	29	43	45	47
	PSD-P	14	14	16	18
	PSD-M	3	2	2	2
Richland Creek	*n* Harvested		7.1	5.0	3.0
	Yield (kg)		3.9	3.4	2.6
	n at 430 mm		19.7	20.9	22.5
	PSD	30	47	48	49
	PSD-P	23	17	18	19
	PSD-M	10	3	3	3

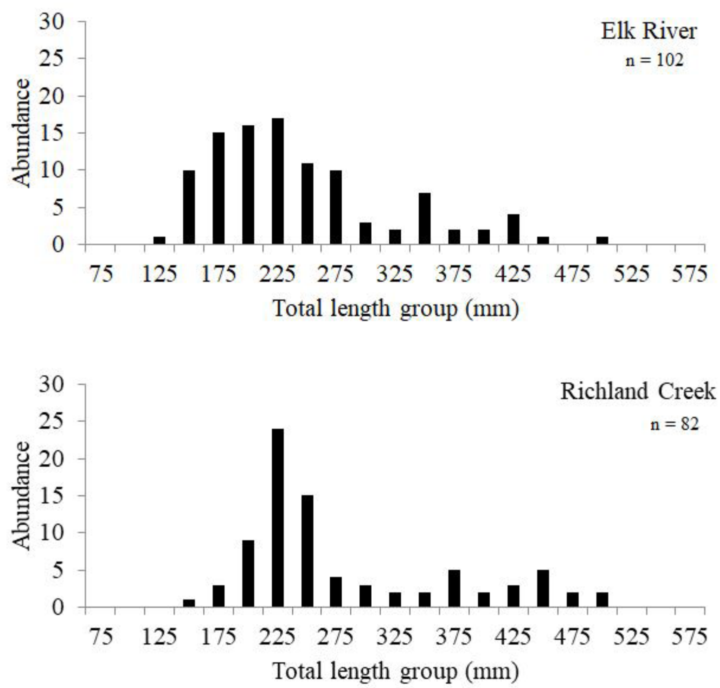

Figure 1. Length-frequency histograms (25-mm bins) of smallmouth bass sampled in Elk River and Richland Creek, Tennessee, during May and June 2018.

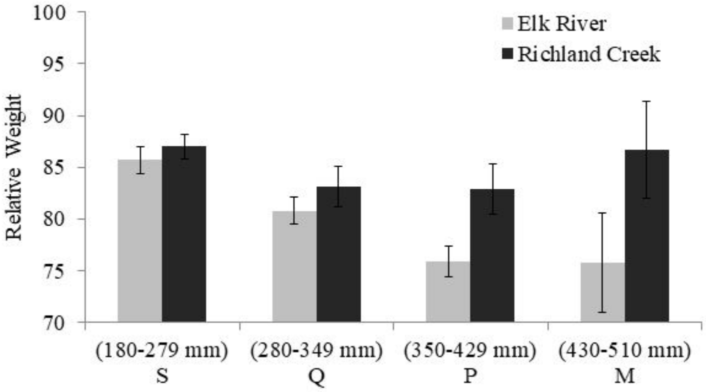

Figure 2. Mean relative weight of smallmouth bass from Elk River and Richland Creek, Tennessee, in four size categories (S = stock, Q = quality, P = preferred, M = memorable). Error bars for each size group represent SE.

Table 2. Number of smallmouth bass collected (*n*) and mean total length (Mean TL, SE in parentheses) by age class from Elk River and Richland Creek, in May and June 2018. Age classes with one fish were censored from analysis.

	Elk River		Richland Creek	
Age	*n*	Mean TL	*n*	Mean TL
2	59	186 (7.5)	49	214 (9.2)
3	21	236 (2.4)	12	273 (1.2)
4	1	–	3	348 (0.6)
5	2	344 (0.2)	2	420 (0.2)
6	10	344 (1.0)	5	391 (0.5)
7	5	395 (0.5)	5	407 (0.5)
8	1	–	0	–
9	3	405 (1.8)	4	462 (0.5)

Table 3. Parameter estimates used for Fisheries Analysis and Modeling Simulator Tools (FAMS) models (Slipke and Maceina 2014) with smallmouth bass sampled in Elk River and Richland Creek, Tennessee, during May and June 2018. Length-weight, von Bertalanffy growth coefficients, Chapman-Robson mortality rates were estimated. A suite of eight conditional natural mortality (CM) estimators were calculated using FAMS.

Category	Parameter	Elk River	Richland Creek
Length-weight	Slope (*a*)	2.83	3.12
	Intercept (*b*)	–4.419	–5.183
Growth	Predicted asymptotic max TL (L_{∞}, mm)	484	468
	Brody growth coefficent (*k*)	0.28	0.37
	Theoretical age at length of zero (*t0*, years)	0.36	0.41
Mortality	Total annual mortality (*A*)	0.46	0.45
	Instantaneous total mortality (*Z*)	0.62	0.59
	Conditional fishing mortality (*cf*)	0.24	0.12
CM	Chen and Watanabe (1989)	0.39	0.43
	Cubillos (1999)	0.31	0.39
	Djabali (1993)	0.30	0.34
	Hoenig (1983)	0.37	0.37
	Jensen (1996)	0.34	0.43
	Lorenzen (1996)	0.32	0.32
	Pauly (1980)	0.40	0.46
	Quinn and Deriso (1999)	0.40	0.40
	Mean CM	0.35	0.39

ble 1). Relative weights were similar between Elk River and Richland Creek populations and averaged 87 for both rivers ($X^2 = 0.38$, df = 1, $P = 0.535$). Relative weights were significantly different among size classes in Elk River ($X^2 = 27.1$, df = 3, $P < 0.001$, Figure 2) and Richland Creek ($X^2 = 7.68$, df = 3, $P = 0.053$, Figure 2). For example, PSD-size fish had higher *Wr* than PSD-p and PSD-M in Elk River.

Smallmouth bass ages ranged from 2 to 9 in Elk River and from 1 to 11 in Richland Creek (Table 2). From the Elk River, 74 fish were aged by otolith, 26 fish were aged by age length key, and 2 fish were censored because they were the only individuals captured at their age. From Richland Creek, 63 fish were aged by otolith, 17 fish were aged by age length key, and 2 fish were censored because they were the only individuals captured at their age (Figure 1). Likelihood ratio tests indicated individual length-at-age models for each river was more appropriate than pooling data across rivers. For example, the asymptotic length was 468 mm at Richland Creek and 484 mm at the Elk River, thus suggesting growth accumulation differences and potential for MLL to have differing effects between rivers (Table 3). Growth comparisons identified length infinity as significantly different between rivers as indicated by AIC relative to other models (Table 4). Smallmouth bass entered the fishery (254 mm TL) at 2.9 years in the Elk River and 2.6 years in Richland Creek.

Chapman-Robson estimates of *Z* were -0.62 in the Elk River and -0.59 in Richland Creek (Table 3). Estimates of *M* ranged from 0.30–0.40 and averaged 0.35 for fish in the Elk River. Estimates of *M* ranged from 0.25–0.46 and averaged 0.38 for fish in Richland Creek. Using the mean value for *M*, exploitation of smallmouth bass in the Elk River and Richland Creek was estimated at 0.2 and 0.1, respectively (Table 3).

For both systems, as *cm* increased, yield varied less over the range of exploitation and simulated effects from MLL became less distinguishable. In the Elk River, YPR models predicted that implementation of a 305-mm MLL would decrease yield only 10% at a *cm* of 0.3 and *cf* of 0.14, but a 355-mm MLL would decrease yield 31% with a *cm* and *cf* at those levels (Figure 3). Likewise, YPR models predicted a 305-mm MLL in Richland Creek would

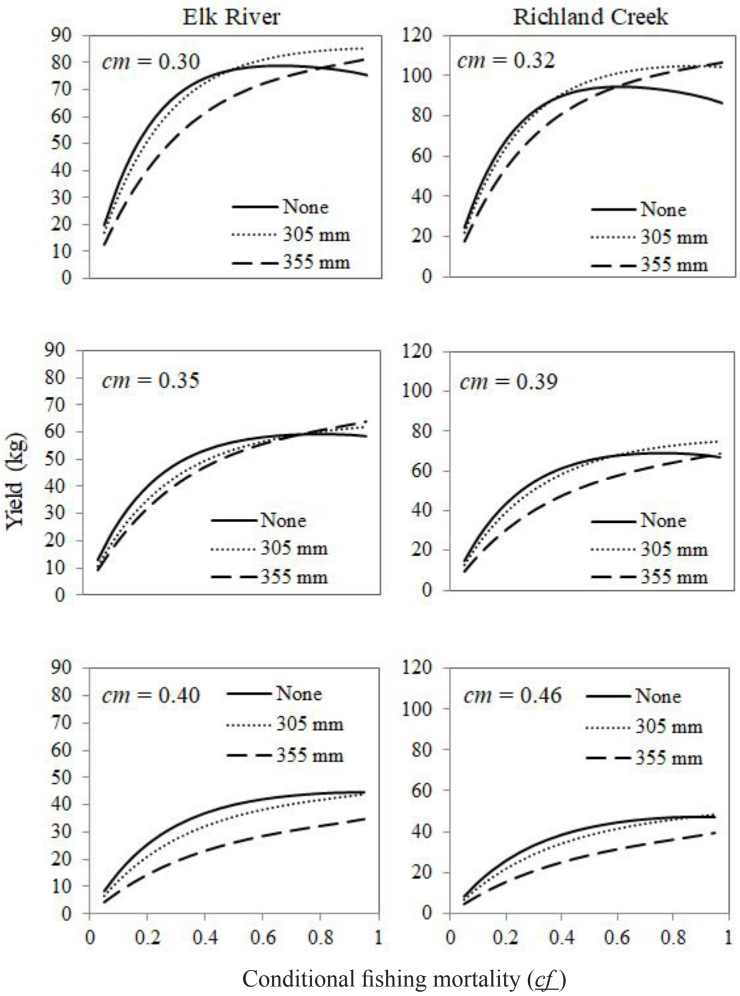

Figure 3. Predicted yield (kg per 1000 recruits) for smallmouth bass under an array of conditional fishing mortality rates (*cf*) with conditional natural mortality rates (CM) of 0.30, 0.35, and 0.40 in Elk River and CM of 0.32, 0.39, and 0.46 in Richland Creek, Tennessee. Models were conducted for no regulation (harvest begins at 254 mm TL), a 305-mm minimum length limit, and 355-mm minimum length limit.

Table 4. Von Bertalanffy growth models were compared with least-squares model of Akaike's information criterion (AIC, Akaike 1973) for smallmouth bass in Elk River and Richland Creek, Tennessee. Differences in asymptotic length (L_∞), Brody growth coefficient (*k*), and theoretical age at which length equals zero (t0) were compared. The general model consists of separate parameter estimates for each river, whereas the common model has the same parameter estimates for each river.

	df	AIC
General model	7	1748.612
$L_\infty 1$	6	1746.718
$L_\infty 2$	6	1747.969
*k*1	6	1747.500
*k*2	5	1756.249
t01	5	1746.518
t02	5	1746.451
Common model	4	1790.723

Figure 3. Predicted yield (kg per 1000 recruits) for smallmouth bass under an array of conditional fishing mortality rates (*cf*) with conditional natural mortality rates (CM) of 0.30, 0.35, and 0.40 in Elk River and CM of 0.32, 0.39, and 0.46 in Richland Creek, Tennessee. Models were conducted for no regulation (harvest begins at 254 mm TL), a 305-mm minimum length limit, and 355-mm minimum length limit.

decrease yield only 8% at a *cm* of 0.38 and *cf* of 0.08, but a 355-mm MLL would decrease yield 26% at those levels of *cm* and *cf*. At a *cm* of 0.26, growth overfishing was predicted to occur in the Elk River if *cf* exceeded 0.55 with no MLL but would not occur under any *cf* with any MLL (Figure 3). With a *cm* of 0.22, growth overfishing was predicted to occur in Richland Creek if *cf* exceeded 0.5 with no MLL or exceeded 0.65 with a 305-MLL. In the Elk River, at the average estimate of *cm* = 0.35, growth overfishing was predicted to occur when *cf* exceeded 0.85 with no MLL but would never occur with any MLL (Figure 3). In Richland Creek, at the average estimate of *cm* = 0.39, growth overfishing was predicted to occur when *cf* exceeded 0.75 with no MLL but would never occur with any MLL (Figure 3). For both rivers, growth overfishing was possible at the lowest estimates of *cm* if *cf* exceeded 0.7.

Simulations showed that increasing the MLL was effective at improving size structure for both systems when *cm* and *cf* were at average values (Table 1). A 305-mm MLL was predicted to increase PSD-P of smallmouth bass by 14% in the Elk River and 6% in Richland Creek over that observed with no MLL (Table 1). A 355-mm MLL was predicted to increase PSD-P of smallmouth bass by 29% in the Elk River and 12% in Richland Creek over that observed with no MLL (Table 1). In the Elk River, total number of fish harvested would decrease 32% with a 305-mm MLL and 60% with a 355-mm MLL compared to no MLL. Yield decreased 14% with a 305-mm MLL and 36% with a 355-mm MLL compared to no MLL. The total number of fish exceeding 430 mm TL would increase by 15% and 34% with a 305-mm and 355-mm MLL, respectively, compared to conditions with no MLL. In Richland Creek, the total number of fish harvested would decrease 30% with a 305-mm MLL and 57% with a 355-mm MLL compared to no MLL. Yield decreased 12% with a 305-mm MLL and 33% with a 355-MLL compared to no MLL. The total number of fish exceeding 430 mm TL would increase by 6% and 14% with a 305-mm and 355-mm MLL, respectively.

Discussion

Both the Elk River and Richland Creek are currently managed with no MLL and a five black bass daily harvest limit. Population characteristics and size structure of both rivers were similar to or exceeded Tennessee riverine smallmouth bass averages (Fiss et al. 2001). Smallmouth bass in Richland Creek were larger on average, and yet, had similar *A* as those in the in the Elk River. Several of the natural mortality estimators used *k* to derive *M*, thus resulting in a higher estimate of *cf* for smallmouth bass in the Elk River than Richland Creek. Because *cf* in the Elk River was a higher proportion of *A*, implementation of a MLL was predicted to benefit Elk River smallmouth bass more than Richland Creek. Exploitation rates during this study were estimated and not measured. Prior to the rise in popularity of paddlesports and kayak angling, Condo and Bettoli (2000) observed a harvest rate of 6% for tagged smallmouth bass in the Duck River, Tennessee, with 83% of black bass released. Based on our results, fishing mortality is a greater factor in these populations than what Condo and Bettoli (2000) found in the Duck River, albeit much less so than natural mortality (Ricker 1975).

Sample size for both Elk River and Richland Creek were low and fell short of population age structure benchmarks (500 and 200) proposed by Coggins et al. (2013) and Miranda and Bettoli (2007). Indeed, the number of samples required to describe age structure and growth depend on variability in length at age, subsample length bin sizes, and species longevity. Bias from low sample sizes is derived from the "flattening" of the von Bertalanffy curve from older fish, and thus, making it difficult to model length increases at younger ages. In order to reduce bias, age-classes with less than one fish were censored (only a single age-8 and age-11 fish were observed). The sample sizes from this study likely underestimated asymptotic length and the Brody growth coefficient (Coggins et al. 2013). The Brody growth coefficient is already higher than many other streams so an under estimation is less harmful than an overestimate considering the goals of this study to evaluate the needs and effects of implementing new regulations.

Although similarities exist between smallmouth bass from Elk River and Richland Creek and these systems are adjacent, these populations were modeled separately for yield-per recruit and dynamic-pool models. Other studies have demonstrated extensive movements of stream centrachids (VanArnum et al. 2004, Sammons 2015) and otolith microchemistry work has also demonstrated the interconnectivity of mainstem and tributary smallmouth bass populations (Humston et al. 2010), but the statistical differences (e.g., growth) between the two populations in our study indicated they should be modeled separately and yield-model estimates verified the approach at medium to high exploitation rates.

Our collections occurred shortly after spawning season, and thus, may have reduced *Wr* values relative to other times of the year (Brown and Murphy 2004). Smallmouth bass were primarily collected in late May from the Elk River and fish over 350 mm had a mean *Wr* of 81. Richland Creek smallmouth bass were collected in early May and fish over 350 mm had a mean *Wr* of 83. Mean *Wr*s for stock-sized fish was 86 and 87 for the Elk River and Richland Creek, respectively. Relative weights of other riverine smallmouth populations in Tennessee are typically between 85 and 90 since sampling typically occurs in late spring or early summer (Tennessee Wildlife Resources Agency, unpublished data). Although smallmouth bass *Wr* was low in both of our study rivers, it is likely safe to assume that it is not related to density-dependent competition but just time of sample.

Black bass variable year class strength can be related to environmental factors such as hydrologic variation and could affect recruitment (Bonvechio and Allen 2005). Recruitment variation of riverine smallmouth bass in Virginia streams was associated with stream discharge (Smith et al. 2005). In other systems, temperature was more important than streamflow to predict of age-0 smallmouth bass abundance in Wisconsin streams (Haglund et al. 2019). The age structure of smallmouth bass populations in the Elk River and Richland Creek suggested that weak year classes for age-4 and age-8 fish in both rivers corresponded with flood events during 2010 and 2014. In 2010, flows during May and June were more than 30-fold and 123-fold higher than average in the Elk River and Richland Creek, respectively. In 2014, flows during this period were more than 16-fold and 45-fold higher than mean flows in the Elk River and Richland Creek, respectively. Conversely, flows were low and more stable during April through June 2012, and strong year classes were detected in both streams.

Yield was estimated to detect potential for growth overfishing and to identify if regulation changes could benefit the fishery. Models indicated that smallmouth bass in the Elk River and Richland Creek are not at risk of overharvest at the current time. Growth overfishing only occurred when natural mortality was low and *cf* was several times higher than current estimates based on simulated models. Any size limit over 305 mm prevented growth overfishing over the range of simulated *cf* rates. At moderate and high levels of conditional natural mortality (CM), yield was constant at *cf* rates above 0.4 since more fish would die of natural causes. Our findings are in accord with those of Beamesderfer and North (1995), who noted that in 409 smallmouth bass populations across North America, yield would not increase after implementation of an MLL in average or slow growing populations.

Smallmouth bass fisheries with high W_r, *k*, and L_∞ are responsive to fishing regulations and can result in increased yield and size structure (Beamesderfer and North 1995, Copeland et al. 2006). Although the Elk River smallmouth bass population size structure would benefit from a 355-mm MLL (up to 29% increase in PSD-P), those in Richland Creek would only marginally improve (12% increase). A 355-mm MLL would increase the number of fish reaching 430 mm TL by 34% and 13% in the Elk River and Richland Creek, respectively. Exploitation rates in this study were consistent with low to moderate estimates (Reed and Rabeni 1989) and *M* was slightly higher than many smallmouth bass populations (Beamesderfer and North 1995). If exploitation rates are close to natural mortality rates, regulations can benefit populations; however, fishery managers should temper expectations of MLL since current amount of *M* is high relative to *F* (Beamesderfer and North 1995, Sammons 2016). The findings of this study suggest there is not biological need for a regulation in order to sustain stocks; instead, anglers and biologists are in a position to develop goals based on angler desires (i.e., catch or size).

As new recreation access points and participation (e.g., kayak fishing) increase, the need for regulations could change. Local state and federal agencies have added multiple public access points in the last several years and further improvements are planned in Tennessee. Elk River access has increased 60% in the last 20 years. Richland Creek access has increased from a single site to two, while a third access will open to the public in 2020. Further, the contribution of private outfitters to fishing pressure is unknown as they utilize both private and public access. Using Condo and Bettoli's (2000) estimate of 6% harvest as a loose proxy and our estimates of *cf*, smallmouth bass fishing mortality may have tripled in the last 20 years in the Elk River and doubled in Richland Creek. Even so, these rates are still low and comparable to recent *cf* estimates to other riverine black bass populations (Middaugh et al. 2016, Sammons 2016). As access and interest increase, biologists should continue to monitor for growth overfishing, evaluate fishing mortality, and work with the public to develop ideal management strategies.

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