# Long-Term Response of a Largemouth Bass Population to a Protected Slot Limit Regulation in a West Virginia Small Impoundment

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*Abstract:* The largemouth bass (*Micropterus salmoides*) population in South Mill Creek Lake, a centrarchid-dominated, eutrophic small impoundment in West Virginia, was managed under a 305-mm minimum-length limit until 2007. Under this regulation the population was typified by consistently low proportional size distribution (PSD) values, low quality-length CPUE, excessive juvenile recruitment, and poor length structure. Therefore, in 2007 a protected slot limit (PSL) regulation (305–406 mm) was implemented to shift the size structure of the fishery. Spring (May) boat electrofishing surveys were conducted pre- and post-regulation (2003–2022) to evaluate fishery response under both regulatory regimes. The largemouth bass population of a similar system, Kimsey Run Lake, was sampled using the same methods over the same time periods. Relative abundance of quality-length fish, PSD, length structure, and growth rate increased for largemouth bass at South Mill Creek Lake under the PSL, while during this period Kimsey Run Lake population characteristics stayed relatively stable under a catch-and-release regulation. Annual mortality rate estimates at South Mill Creek Lake declined from 44.3% to 32.9%, although the change was not statistically significant. Creel surveys during the PSL period indicated angler approval and willingness to harvest sub-quality fish. Our results suggest that angler compliance with the new regulation has enhanced the quality of the South Mill Creek Lake population. Largemouth bass at Kimsey Run Lake continued to experience low growth rates and low annual mortality throughout the study. The protected slot limit regulation was considered successful and could be applied to other West Virginia small impoundment fisheries where largemouth bass populations exhibit poor length structure.

*Key words*: length distribution, small impoundment management, *Micropterus salmoides*

Journal of the Southeastern Association of Fish and Wildlife Agencies 10:76–84

Many small impoundments (<200 ha) managed for public fishing have adequate proportions of littoral zone habitat, are densely vegetated and eutrophic, and have a high density of centrarchids (Lindgren and Willis 1990, Olson 1996, Paukert and Willis 2004). For largemouth bass (*Micropterus salmoides*), these ideal conditions for reproduction can combine with fishing pressure to cause undesired population alterations (Penne 2007, Meneau 2008, Eades and Lang 2012, Wright and Kraft 2012). High recruitment rates and inhibited predation of juvenile largemouth bass are likely to occur in small impoundments possessing abundant aquatic vegetation (Savino and Stein 1982, Durocher et al.1984). Excessive juvenile largemouth bass recruitment, coupled with angler exploitation focused on quality-length individuals, can result in largemouth bass population length distributions that are skewed towards small individuals (Beckman 1941, Novinger and Legler 1978).

Historically, minimum-length limits (MLL) have been implemented to protect early cohorts of sport fish during the establishment phase of a fish community (Eder 1984) or in instances of poor recruitment (Isermann and Paukert 2010). Once densities of black bass (*Micropterus* spp.) reach carrying capacity, protection of sub-quality fish often becomes unnecessary, and MLL regulations may generate populations that are over-crowded, slow-growing, and have undesirable size structures (Farabee 1974, Rasmussen and Michaelson 1974, Eder 1984, Novinger 1990, Wilde 1997, Buynak and Mitchell 2002). Protected-slot limits (PSL) have often been used to redirect harvest away from quality-sized adults in black bass fisheries and reduce numbers of smaller fish (Eder 1984, Summers 1988, Wynne et al. 1993, Neumann et al. 1994, Buynak and Mitchell 2002). However, black bass populations have often shown unsatisfactory responses following PSL regulation due to low angler effort and harvest, environmental stochasticity, and variable recruitment (Gabelhouse 1984b, Novinger 1990, Martin 1995, Parks and Seidensticker 1998, Buynak and Mitchell 2002, Bonds et al. 2008, Fox and Neal 2011).

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The largemouth bass population in South Mill Creek Lake, West Virginia, was regulated with a 305-mm MLL from the onset of the fishery in 1995 until 2007. The intent was to provide protection for the initial, 1995 largemouth bass year class. In 2004 a tagging study indicated that this lake had a harvest rate of 18%, which was the highest among 12 small impoundments surveyed by the West Virginia Division of Natural Resources between 2003 and 2005 (O'Bara 2009). Assuming reasonable estimates of angler non-reporting and tag loss (35% and 50%; Slipke et al. 2003, Slipke and Maceina 2000), angler exploitation may have been as high as 25%, with returned-tag correspondence indicating that after completion of tagging in March 2004, angler catches mostly occurred prior to the end of September 2004. Moreover, due to high fishing effort expended on this small impoundment, the likelihood exists for multiple angler-catches of a considerable proportion of fish, which can also cause an underestimation of harvest. High largemouth bass catch rates in small impoundments have been well documented elsewhere (Hickman and Congdon 1974, Burkett et al. 1986, Lindgren and Willis 1990).

The South Mill Creek largemouth bass population was characterized by high levels of annual juvenile recruitment, total annual mortality, and length-specific exploitation that produced consistently truncated length distributions under the MSL. In 2007, a 305–406-mm PSL was implemented to regulate this population with the goal of protecting quality-sized fish and reducing density of smaller fish to alleviate density-dependent growth suppression. The objectives of this study were to examine changes in size structure, relative abundance, growth, and mortality following regulation change in South Mill Creek Lake. We used a nearby, similar-sized impoundment where no regulation change occurred as a control (Wilde 1997, Chestnut-Faull et al. 2022) so as to be able to separate effects of changes in environmental variables vs. regulation change.

## Study Area

South Mill Creek Lake is a 16.2-ha impoundment in the Potomac River basin of West Virginia. Impounded in 1994, the reservoir has a maximum depth of 10.7 m, mean depth of 5.3 m, and lake surface elevation of 396 m above sea level; it exhibits little fluctuation in water level throughout the year. Habitat features include flooded timber, a high proportion of littoral zone habitat, and abundant submerged aquatic vegetation (~50% of surface area), with the upstream watershed dominated by agricultural land use and forest. The impoundment contains black crappie (*Pomoxis nigromaculatus*), white crappie (*P. annularis*), bluegill (*Lepomis macrochirus*), brown bullhead (*Ameiurus nebulosus*), green sunfish (*Lepomis cyanellus*), and white sucker (*Catostomus commersonii*). Channel catfish (*Ictalurus punctatus*) are maintained through annual stocking efforts and hatchery-reared, catchable-size rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*) are stocked twice a month from February–April and once in May to support a seasonal put-and-take trout fishery.

Kimsey Run Lake is a 19-ha impoundment constructed in 1996. Located 32.7 km from South Mill Creek Lake, Kimsey Run Lake is also in the Potomac River basin and was selected as a control for this study. Kimsey Run Lake has a maximum depth of 7 m, a mean depth of 3 m, a lake surface elevation of 432 m above sea level, and little annual fluctuation in water levels. Habitat features are similar to those of South Mill Creek Lake, including flooded timber, abundant littoral zone habitat, and abundant submerged aquatic vegetation (~49% of surface area); land use in the upstream watershed is also similar. Both impoundments support similar fish communities, including stocked channel catfish and trout; however, Kimsey Run Lake also has redear sunfish (*Lepomis microlophus*) and muskellunge (*Esox masquinongy*, introduced in 2012). Largemouth bass in Kimsey Run Lake have been managed with a catch-and-release regulation since impoundment, thus harvest is negligible.

## Methods

### Relative Abundance and Size Distribution

Of particular interest throughout this study were the comparative population characteristics of these lakes before and after the regulation change at South Mill Creek Lake. These timeframes spanned years where the South Mill Creek Lake population was stable under the MLL (before 2007) and the PSL regulation (2012 and later), which were determined from observations of general quality-length catch and distribution trends. Boat electrofishing surveys were generally conducted during a single night each May from 2003–2022. Six 10-min transects were fixed throughout the study and used for each yearly sample when possible. All largemouth bass were collected and measured (TL; mm), and CPUE was calculated as fish $h^{-1}$ for stock (200 mm TL) and quality (300 mm TL) (Anderson 1976). We calculated CPUE-SQ (200–299 mm TL) and CPUE-Q (>300 mm TL) for each population to investigate long-term regulatory influences on the relative abundance of these size categories. Repeated measures ANOVA were conducted on $\log(1+x)$-transformed CPUE-Q and CPUE-SQ for the fixed transects using the lme4 package in R (R Core Team 2013, Bates et al. 2015), where data were pooled within regulatory periods. The nlme package in R (Pinheiro et al. 2013) was used to test for pairwise differences between means of within-lake regulatory periods, as determined by Tukey contrasts after Bonferroni *P*-value adjustments.

Differences in length structure between treatments were examined using Kolmogorov-Smirnov tests on length-frequency distributions pooled across regulatory periods for each lake. This entailed a compact execution of all pairwise tests and a Bonferroni correction for *P*-value adjustments (Ogle 2016). Proportional size distribution (PSD) of largemouth bass was calculated using pooled data from each lake's regulatory period (Gabelhouse 1984a). We also calculated the proportion of fish with TL longer than the upper length threshold of the protected slot (406 mm TL, $PSD_{406}$) to investigate changes in proportions of larger individuals. Chi-square tests for equality of proportions were conducted to determine if differences in PSD or $PSD_{406}$ occurred between regulatory periods for South Mill Creek and Kimsey Run lakes (Newcombe 1998, Ogle 2016). A pairwise comparison of proportions with Holm's *P*-value correction was used to identify statistical differences.

## Growth

Largemouth bass were collected from each reservoir while South Mill Creek Lake was regulated by a MLL (50 and 53 fish from South Mill Creek and Kimsey Run lakes, respectively, during 2005–2006) and while the South Mill Creek Lake population was stabilized under the PSL. During the PSL period we increased fish collections for aging, with 80 fish (2013 and 2016) and 95 fish (2017 and 2019) collected from South Mill Creek and Kimsey Run lakes, respectively. Approximately 25 fish were collected randomly within <200, 200–299, and ≥300-mm TL categories in 2005 and 2006. Collection quotas for age assessment structures were increased to approximately 40 fish each year within the same TL categories at both lakes during the PSL period.

Using otolith-obtained ages and resulting length-at-age data from each lake, age-length keys were developed for largemouth bass by regulation period for each lake. Length categories for the age-length keys were set at 25-mm intervals. Age-length keys were used to predict ages for unknown-age fish by using the semi-random assignment method described in Isermann and Knight (2005). We then examined differences in growth of bass age >1 between regulatory periods for each lake using ANCOVA (R package emmeans, Russell 2022) to compare the slopes of TL to $\log_{10}$ age regressions (Bartlett et al. 1984). The von Bertalanffy (1938) model parameterization was used to describe largemouth bass growth during regulatory periods for each impoundment.

## Mortality Rate

Weighted catch-curve regression was employed to establish estimates of *Z* (Maceina and Bettoli 1998) from data pooled by lake and regulation period. Catch frequencies were $\log_e$ transformed and correlated with ages >1 using the FSA package in R (Ogle 2016). We used the same age assignments and otolith-obtained age data that were used for growth analyses. Catch curve slopes between treatment and control timeframes were tested using ANCOVA (Miranda and Bettoli 2007) with the emmeans package in R. For this test we set $\alpha = 0.10$ due to the severe reduction of test power resulting in binning hundreds of individual fish into summed counts by age. Annual mortality (*A*) was calculated for each regulation timeframe and lake (Ricker 1975) for ease of interpretation.

## Creel and Angler Opinion Survey

An angler questionnaire was developed for South Mill Creek Lake and was administered in-person by a creel clerk throughout the fishing season in 2016. The creel clerk worked shifts of half-day surveys from 14 May through 29 October. Surveys either lasted from 09:00–13:00 (mornings) or from 15:00–19:00 (evenings). Morning and evening shifts alternated for weekdays and weekend days, separately. Saturday and Sunday shifts alternated by week, while weekday survey patterns alternated throughout the fishing season in the following manner: Mon. and Weds., Tues. and Thurs., and Fri. only. The creel clerk either collected contact information of anglers to obtain creel results or remained on site towards the end of shifts to complete surveys of anglers who were not yet off the water.

Largemouth bass anglers were asked if they were aware of the PSL regulation and if they were interested in the harvest of largemouth bass. Angler effort for, catch of, and harvest of largemouth bass were recorded. Individual anglers were asked to rank (0–4; very poor to very good) their acceptance of the PSL, and subsequently we calculated the percentage of anglers replying with assessment ranks ≥3. Fishing effort, catch, and harvest calculations were summarized for collected data, and resulting weekday and weekend averages were extrapolated to incorporate the hours of the fishing season that were not assessed and to incorporate incomplete surveys from anglers that would not or could not be assessed. Estimated total fishing effort, total catch, angler CPUE-Q and -SQ (angler-caught fish $h^{-1}$), total harvest, harvest per ha, angler PSL awareness (%), angler interest in largemouth bass harvest (%), and PSL acceptance (%) were calculated for the 2016 warmwater fishing season. Angler effort and harvest from November through April were considered negligible.

## Results

### Relative Abundance and Size Distribution

Largemouth bass CPUE-Q in South Mill Creek Lake increased following implementation of the PSL in 2007 (Figure 1). Repeated measures ANOVA indicated significant differences ($F_{3,15} = 38.94$, $P < 0.001$) in mean CPUE-Q between regulation timeframe × lake treatment combinations, except between South Mill Creek and Kimsey Run Lakes during the stable PSL timeframe ($P = 0.557$). Largemouth bass CPUE-Q rate was lowest overall at South Mill Creek Lake during the MLL period but increased there throughout the study until rates became similar to those at Kimsey Run Lake (Figure 1). Mean CPUE-Q for South Mill Creek Lake increased from 13.59 fish $h^{-1}$ (95% CI = 7.58–23.78) during the MLL timeframe to 95.54 fish $h^{-1}$ (83.77–108.95) during the PSL timeframe ($P < 0.001$). Mean CPUE-Q in Kimsey Run Lake also increased from 37.86 fish $h^{-1}$ (95% CI = 19.70–71.24) during the MLL timeframe to 126.74 fish $h^{-1}$ (105.70–151.93) in the PSL timeframe ($P < 0.001$). Generally, annual CPUE-Q at South Mill Creek Lake followed a sigmoid pattern, where rates were low during the MLL, rose through a transitional phase, and stabilized at higher catches during the PSL (Figure 1). Annual CPUE-Q of largemouth bass rose gradually throughout the study at Kimsey Run Lake, but mean CPUE-Q was still greater than that observed for South Mill Creek Lake during the MLL timeframe ($P < 0.002$).

Largemouth bass CPUE-SQ were generally similar between lakes and regulatory timeframes (Figure 1). Repeated measures ANOVA ($F_{3,15} = 38.94$, $P = 0.012$) and pairwise contrast ($P < 0.001$) indicated a significant increase in CPUE-SQ between MLL and PSL timeframes at Kimsey Run Lake. No significant differences were detected between South Mill Creek Lake CPUE-SQ rates or those obtained from Kimsey Run Lake in the MLL timeframe ($P > 0.05$). CPUE-SQ means for South Mill Creek Lake during the MLL and PSL timeframes were 112.30 (95% CI = 74.94–168.02) and 116.92 (100.49–137.38) $fish^{-1}$. CPUE-SQ means for Kimsey Run Lake during the MLL and PSL timeframes were 61.80 (95% CI = 37.47–103.58) and 131.95 (102.54–169.72) $fish^{-1}$.

Largemouth bass size structure differed among regulation timeframe × lake groups ($P < 0.0001$; Figure 2). Mean TL of largemouth bass pooled within the regulation timeframes were 213.44 mm (95% CI = 208.34–218.55; MLL) and 258.96 mm (255.53–262.40; PSL) for South Mill Creek Lake, compared to 243.50 mm (95% CI = 236.97–250.02; MLL) and 273.37 mm (270.05–276.70; PSL) for Kimsey Run Lake. Largemouth bass TL distribution increased from MLL to PSL timeframes at South Mill Creek Lake ($D = 0.29$, $P < 0.0001$) and Kimsey Run Lake ($D = 0.19$, $P < 0.0001$). The TL distribution of largemouth bass at Kimsey Run Lake during the

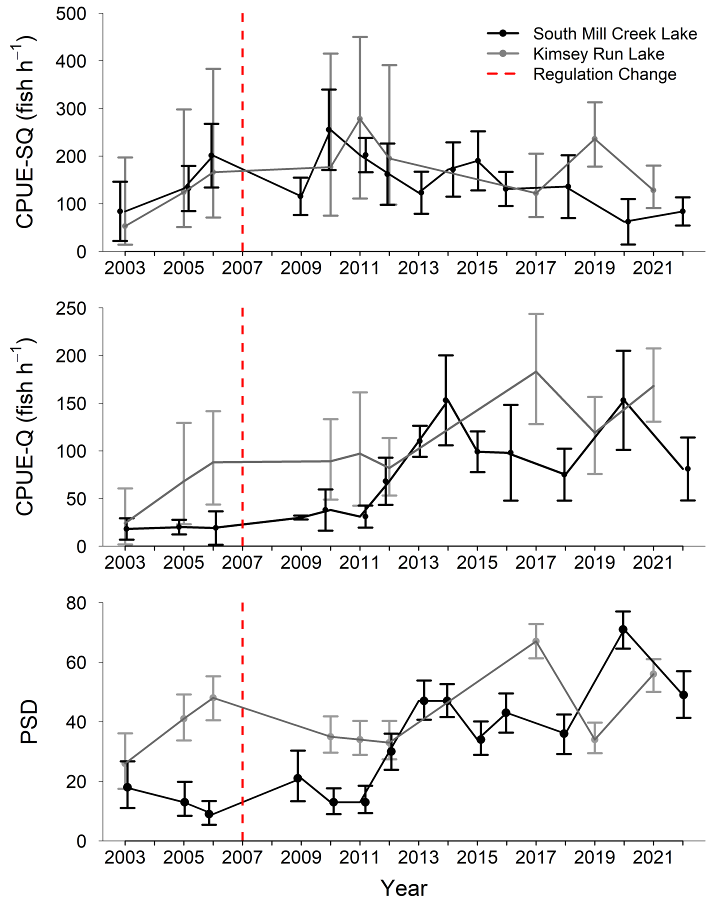


**Figure 1.** Annual sub-quality stock-size CPUE (CPUE-SQ, 200–299 mm TL), quality-size CPUE (CPUE-Q, ≥300 mm TL), and proportional size distribution (PSD) of largemouth bass at South Mill Creek and Kimsey Run lakes, West Virginia. Vertical line denotes the implementation of a 305–406-mm protected-slot limit on South Mill Creek Lake. Error bars depict 95% CI.

PSL timeframe was the greatest observed, including differing from that of South Mill Creek Lake during the stable PSL timeframe ($D = 0.14$, $P < 0.0001$). Size structure indices showed similar trends. Largemouth bass PSD increased from the MLL to PSL timeframes in South Mill Creek Lake ($P < 0.0001$); whereas PSD was similar between timeframes in Kimsey Run Lake ($P > 0.05$; Figures 1 and 2). Largemouth bass PSD during the MLL timeframe at South Mill Creek Lake was the lowest among all lake-timeframe combinations ($\chi^2 = 192.4$, $P < 0.001$). Although PSD at Kimsey Run Lake gradually increased across survey years, South Mill Creek Lake PSD, as with that seen for CPUE-Q, followed a sigmoid pattern, where stable-population MLL and PSL timeframes were separated by a period of transition (Figure 1). Largemouth bass $PSD_{406}$ differed ($\chi^2 = 9.70$, $P = 0.021$) only between the PSL timeframe at Kimsey Run Lake (0.94; 95% CI = 0.50–1.73) and South Mill Creek Lake (2.42; 1.80–3.25).

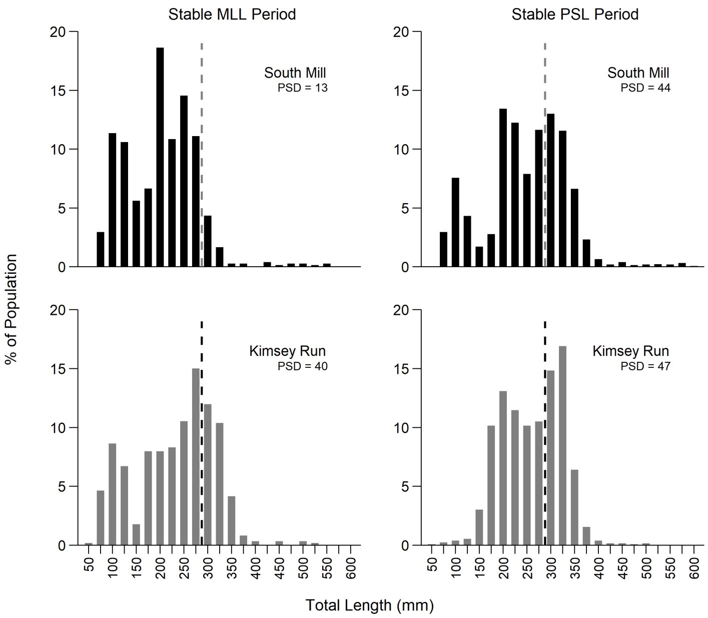


**Figure 2.** Length-frequency histograms (25-mm bins) for largemouth bass from South Mill Creek Lake and Kimsey Run Lake, West Virginia, collected during May boat electrofishing surveys. Left: population length structures for both lakes during the 305-mm minimum-length limit (MLL, years 2003–2006); right: length structure for both lakes under the 305–406-mm protected-slot limit once population stabilization was reached under this regulation at South Mill Creek Lake (PSL, years 2012–2022). Vertical lines indicate sub-quality- and quality-length thresholds. Proportional size distribution (PSD) is also provided for aid in comparison.

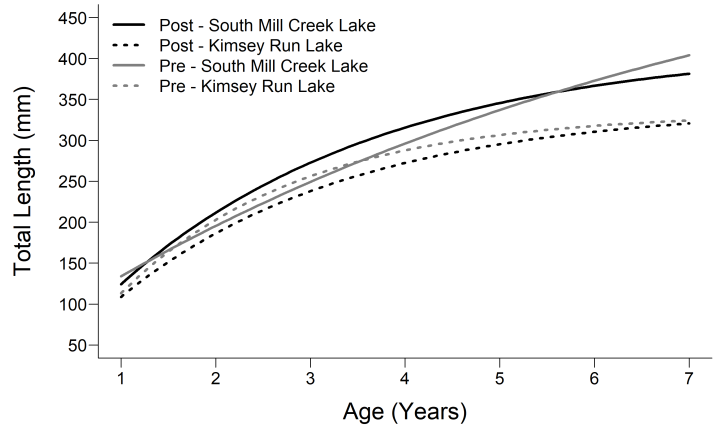


**Figure 3.** Typical von Bertalanffy growth curves for largemouth bass populations of South Mill Creek Lake and Kimsey Run Lake, West Virginia. Separate curves were constructed for each lake during the 305-mm-TL minimum-length limit regulation ($n = 50$ fish; 2003–2006) and during the timeframe where the South Mill Creek Lake population stabilized under the 305–406-mm-TL protected-slot limit ($n = 80$ fish; 2012–2016).

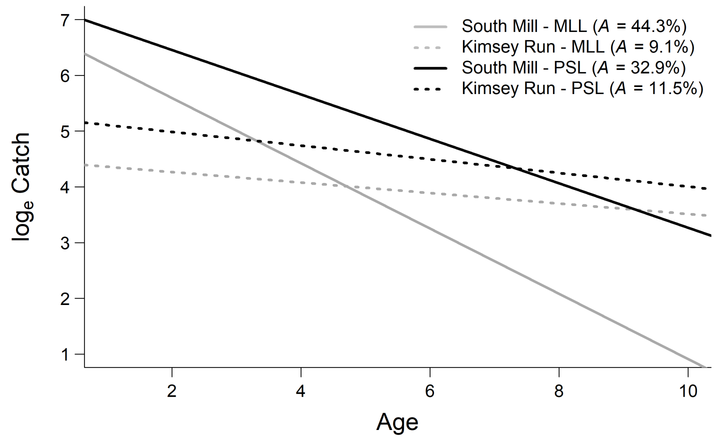


**Figure 4.** Log-linear weighted catch-curve-regression lines and calculated annual mortalities ($A$) generated for age distributions of largemouth bass collected during the 305-mm-TL minimum-size limit (MLL; before 2007) and the stabilized 305–406-mm-TL protected-slot-limit timeframes (PSL; beginning in 2012).

## Growth and Mortality Rate

Differences in largemouth bass growth rate slopes were detected among regulation timeframes and lakes ($F_{3, 5115} = 389.30$, $P < 0.0001$). Growth rate slopes of TL vs. $\log_{10}$ age for South Mill Creek Lake were 278.32 (95% CI = 192.33–204.01) for the MLL timeframe and 313.55 (309.42–317.67) for the PSL timeframe. Growth rate slopes for Kimsey Run Lake were 232.89 (95% CI = 225.49–240.30) for the MLL timeframe and 198.17 (192.33–204.01) for the PSL timeframe. Largemouth bass at South Mill Creek Lake grew faster than those from Kimsey Run Lake, regardless of regulation timeframe (Figure 3). The growth rate for South Mill Creek Lake during the PSL timeframe was greater than any other combination ($P < 0.0001$). Conversely, Kimsey Run Lake largemouth bass grew significantly slower during the PSL timeframe compared to the other three timeframe × lake combinations (P < 0.0001).

Mortality slopes of largemouth bass differed among study timeframes × lake combinations ($F_{2, 23} = 2.61$, $P = 0.076$; Figure 4). Estimates of $A$ for South Mill Creek Lake were 44.30% (95% CI = 32.88–53.77) during the MLL timeframe and 32.85% (11.60–48.73) during the PSL timeframe. Estimates of $A$ for Kimsey Run Lake were 9.07% (95% CI = 0–30.37) during the MLL timeframe and 11.55% (0–27.99) during the PSL timeframe. The mortality rate for the South Mill Creek Lake population during the MLL regulation was significantly greater than that of Kimsey Run Lake during either timeframe ($P = 0.040$ and $P = 0.036$ for MLL and PSL, respectively; Figure 4). The mortality rate during the South Mill Creek Lake PSL was not significantly greater than that calculated for the MLL timeframe at South Mill Creek Lake or from either timeframe at Kimsey Run Lake ($P > 0.05$). Estimated $A$ during the PSL decreased by 11.45% from that of the MLL timeframe in South Mill Creek Lake but remained 21.30% higher than that of Kimsey Run Lake.

### Creel and Angler Opinion Survey

On-site largemouth bass-angler surveys ($n = 208$) at South Mill Creek Lake during the 2016 fishing season amounted to 252 h of effort. Anglers caught an estimated 3185 largemouth bass over a total of 3273 hours of fishing. Total angler CPUE, CPUE-SQ, and CPUE-Q was 0.76, 0.31, and 0.45 fish $h^{-1}$. Total harvest of the population for the fishing season was 103 fish, and harvest of fish with TL outside of slot protection equated to 8%. Approximately 6.4 fish $ha^{-1}$ were harvested. Most anglers stated that they were fully aware of and understood the PSL regulation (75%) and that they approved of the slot limit (90%). Approximately 24% of anglers indicated interest in harvesting largemouth bass.

## Discussion

Slot limits commonly have been imposed on a variety of populations to improve population size and length structure (Eder 1984, Novinger 1990, Wynne et al. 1993, Luecke et al. 1994, Power and Power 1996). Use of PSL regulations is often successful at restructuring largemouth bass populations formerly under MLLs. For example, Buynak and Mitchell (2002) imposed a 305–406-mm PSL on a riverine smallmouth bass population in Kentucky in hopes of improving poor length structure that evolved under a 305-mm MLL. Increases in CPUE-Q and decreases in CPUE-SQ occurred after the implementation of the PSL, and the authors considered the PSL to be successful at increasing sport fishing quality. However, growth did not improve, and continued length-structure improvement depended to some degree on strong year-classes. Other studies have documented increased growth in conjunction with larger size structure resulting from implementation of slot limits (Eder 1984, Wynne et al. 1993, Neumann et al. 1994).

Wilde (1997) thoroughly reviewed population responses to length regulations placed on lotic largemouth bass fisheries. Although MLL regulations were useful in increasing population size, they failed to alter the number and biomass of fish harvested and proportions of fish that were quality sized and greater. Conversely, PSL regulations increased population size and proportions of fish ≥300 mm TL, but failed to increase angler catch rates or harvest. Bonds et al. (2008) noted that 71% of anglers in Texas lakes indicated that they had not recently harvested or did not want to harvest largemouth bass. However, anglers interviewed at PSL lakes had a better understanding of the rationale behind the encouragement of selected harvest. Gabelhouse (1984b) noted that a 300–380-mm PSL increased the abundance of stock- and quality-sized largemouth bass but the expected improvements in growth and condition did not occur, likely due to inadequate harvest of smaller fish; the regulation performed similarly to a 380-mm MLL. Other efforts where PSL regulations have produced unsatisfactory results appear to be directed towards smaller impoundments or in non-traditional largemouth bass environments. Novinger (1990) conducted a study on 14 small (0.6–2.4 ha) private impoundments in Illinois that received 305–406-mm PSL regulations. Modest results were observed despite liberal harvest of sub-quality fish, and PSD and CPUE-Q only increased in approximately one-third of the impoundments. Overall, PSL regulations were generally unsuccessful, as excess recruitment appeared to hinder efforts to restructure length distributions (Novinger 1990). A high PSL (356–508 mm) was prescribed for a Puerto Rican impoundment that supported a crowded population of Florida largemouth bass primarily ≤350 mm TL (Fox and Neal 2011). Failure of this regulation to improve size structure was believed to be due to a lack of harvest. However, thermal influence on largemouth bass metabolism and possible effects of size-specific forage shortages for bass at crowded TL ranges may also have been confounding factors.

Education and harvest compliance of the angling public have been common outreach goals for agencies attempting to increase the likelihood of success for PSL (Eder 1984, Summers 1988, Martin 1995, Bonds et al. 2008). Martin (1995) described an unsuccessful attempt at increasing largemouth bass size structure in <10-ha impoundments in Delaware, predominantly due to angler disinterest in harvest. Summers (1988) studied a 450-ha Oklahoma impoundment where a 356-mm MLL was replaced with a 300–381-mm PSL to rectify largemouth bass overharvest and poor length distribution. Illegal harvest of largemouth bass waned throughout the study, resulting in increases of PSD and densities of bass >381 mm TL.

Our study indicated that modest harvest of largemouth bass below the slot was occurring at South Mill Creek Lake after the imposition of the PSL. Mean largemouth bass CPUE-SQ did not decline between MLL and PSL regulation timeframes at South Mill Creek Lake but increased at Kimsey Run Lake over this same period. Although CPUE-SQ was comparable between PSL and MLL timeframes at South Mill Creek Lake, estimates of CPUE-SQ generally declined after survey year 2010. Survey years 2020 and 2022 experienced two of the three lowest CPUE-SQ values observed for this lake throughout our 20-year study. Still, density-dependent recruitment effects could be allowing densities to remain relatively stable through the compensation of reproductive output or the dampening of the influences of sub-quality fish harvest (Beverton and Holt 1957). Many fish populations show signs of density-dependent regulation as juveniles or young adults, where compensatory survival acts to mitigate against natural or exploitative mortality (Fuiman and Werner 2002). The degree to which compensatory mortality structures natural populations often diminishes through ontogeny, where density-independent sources of natural mortality become more important regulators of abundance of older, larger individuals (Forslund and Pärt 1995, Bonenfant et al. 2009). King et al. (1979) demonstrated that low densities of conspecifics led to high year-class recruitment in largemouth bass in their study of a new impoundment. In our study, the increase in CPUE-SQ during the regulation transition (2009–2011) was likely influenced by the recruitment of the large 2008 year class, the first year class to be spawned by adults protected by the slot limit imposed in 2007.

Harvest of largemouth bass across the 2016 fishing season at South Mill Creek Lake was primarily directed at sub-quality bass, but estimated to be lower at this lake than in several Southeastern studies. Harvest of sub-quality largemouth bass from South Mill Creek Lake was calculated to be approximately one-third of that suggested by Eder (1984; ~19 fish $h^{-1}$) as needed to see improvements in length structure in a Missouri lake. Throughout the creel study, our clerk would occasionally observe visiting vehicles, suspected to be anglers, avoiding the access after observance of agency vehicle and personnel. Furthermore, considering the estimated number of catches during the 2016 fishing season, we suspect a high likelihood of angler catches >1 per individual stock-sized fish in this lake; effects of such multiple catches may lead to underestimation of exploitation rates in tag-return or creel survey studies. Therefore, our harvest estimate should be interpreted as conservative and true harvest at this lake may more closely resemble estimates calculated in other studies of successful PSL regulations. Populations of largemouth bass inhabiting regions that experience shorter growing seasons naturally exhibit slower growth, later maturation, greater longevity, and lower annual mortality (Beamesderfer and North 1995). Thus, lower harvest rates of largemouth bass in these regions may still be able to improve growth, condition, or crowding relative to what would be expected in more southerly areas of North America.

Long-term investigations of PSL regulations and adequate control systems are lacking in literature (Wilde 1997), and many conclude over a shorter duration than the population adjustment phase documented for this study (~5 years). Our study encompassed a 20-year period where significant increases in CPUE-Q, length structure, PSD, and growth rate occurred at South Mill Creek Lake after the replacement of the 305-mm MLL with a 305–406-mm PSL. Significant positive changes to the South Mill Creek Lake population frequently resulted in metrics being no different or greater than those observed at the nearby, catch-and-release-regulated Kimsey Run Lake. CPUE-Q, PSD, and survival (reduced *A*) improved at South Mill Creek Lake until no significant differences existed between its largemouth bass population and that of Kimsey Run Lake. By the end of the study, $PSD_{406}$ was greater at South Mill Creek Lake than at Kimsey Run Lake. Furthermore, growth rates at South Mill Creek Lake increased during the PSL, while declining in the Kimsey Run Lake population. Largemouth bass length structure at Kimsey Run Lake remained greater than that at South Mill Creek Lake, but proportions of largemouth bass <150 and >400 mm TL became comparatively rare during recent surveys at Kimsey Run Lake. This suggests age-1 cohort recruitment and growth of individuals to preferred length may be declining, perhaps due to a lack of directed harvest and negative influences from intraspecific competition. Alternative length-specific regulations should be considered for Kimsey Run Lake largemouth bass moving forward. Future investigations at South Mill Creek Lake should focus on the recruitment of preferred-size largemouth bass recruitment to the fishery, the potential for overcrowding to occur within or above the protected TL range, and longer-term trends in CPUE-SQ.

## Acknowledgments

This study was conducted by the West Virginia Division of Natural Resources and partially funded through Federal Aid in Sport Fish Restoration, Project F-42-R. We thank Dr. Derek Ogle for advice on growth analysis and for creating the helpful Fishery Stock Assessment (FSA) R package. We thank Jim Hedrick for recognizing the potential for special regulations at South Mill Creek Lake. Thanks to Dr. Quinton Phelps for editorial and advisory input, to many field staff members, technicians, and volunteers whose help with field collections made this long-term evaluation possible, and to Dr. Corbin Hilling for statistics assurance and consultation. Finally, we are extremely grateful to Justin Mullenax, who put hundreds of hours of effort into the creel surveys at South Mill Creek Lake.

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