**Length Limits Fail to Restructure a Largemouth Bass Population:**

**A 28-year Case History**

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*Abstract*

Length limits have been implemented by fisheries management agencies to achieve population density, size structure, and angler satisfaction objectives. By redirecting harvest towards or away from particular length or age groups, length limits rely on harvest by anglers to maintain a population at or near a desired state. The fish population changes that follow the implementation of harvest regulations may take several years to manifest, so long-term monitoring may be needed to adequately evaluate length limits. We used an innovative application of cluster analysis to facilitate evaluation of the effects of three consecutive length limits on a Largemouth Bass *Micropterus salmoides* population over a 28-year period in Ross Barnett Reservoir, Mississippi. A 13-16-in protected slot length limit (10 years), followed by a 15-in minimum length limit (11 years), followed by a 12-in minimum length limit (7 years) failed to restructure the Largemouth Bass population due to what we suggest was expansion of voluntary catch-and-release attitude that started in the first decade of the study period. Various population metrics shifted towards values expected in an unharvested population, and the observed shifts can be attributed to a harvest deficit created by the prevailing catch-and-release attitude. Largemouth Bass harvest regulations may no longer be relevant in many waters. The utility of regulations for restructuring Largemouth Bass populations is largely dependent on harvesting attitudes that vary geographically depending on cultural characteristics and demographics.

Output controls are the most frequently applied approach to regulate harvest, prevent biological overfishing, and conserve inland freshwater fisheries (Isermann and Paukert 2010). Length-limit restrictions are a common output control for many sport fish, including Largemouth Bass *Micropterus salmoides*, providing managers a way to limit harvest. Regulating harvest by length is relatively easy to implement and enforce, relative to input controls (e.g., effort restrictions). In theory, length-limit restrictions may be used to influence population density and size structure. For example, increasing a minimum length limit (MLL) should increase the abundance of fish below the MLL by protecting those fish from harvest (Oele et al. 2016). Similarly, a protected-slot length limit (SLL) should increase the number of fish in a population by restricting harvest to fish within the SLL. However, using length restrictions to meet management objectives for fish populations (e.g., increase numbers, alter size structure, protect spawners) assumes anglers will harvest fish and comply with regulations.

Length-limit regulations are also implemented to satisfy anglers, which is another fundamental agency objective. Diverse angler types (e.g., subsistence, recreational, trophy, tournament) present a challenge to managing with a system-level length limit. For example, subsistence or harvest-oriented recreational anglers may be satisfied by high catch and harvest of average-sized fish. Alternatively, trophy anglers may be satisfied with lower catches if those fish are of relatively large size. Well-organized angler groups can exert pressure on fisheries management agencies to modify length limits based on perceived gains in catch or size structure (Wright 1992; Thurow and Schill 1994). Organizational pressure may extend to lobbying state fish and wildlife commissioners to vote in a particular way on proposed length-limit changes (Allen and Miranda 1997).

Regardless of whether length limits are implemented to meet biological objectives, angler satisfaction objectives, or both, a population response to the change in harvest is expected. Temporal and spatial differences in anglers’ preferences for harvest or catch and release may interact with population responses to length limits (Myers et al. 2008; Allen et al. 2008; Isermann et al. 2013). Additionally, decreases or increases in overall effort on a system over time due to changing angler demographics may limit expected population responses. Nevertheless, length limits continue to be used to meet fishery and angler satisfaction objectives. Therefore, empirical measurement of how fish populations respond to length limits is needed, especially given changes in angler effort and harvest rates over time.

Length-limit regulations can potentially influence many aspects of a fish population. This includes, but is not limited to, changes in population size structure, relative abundance, and relationship of length and weight. Evaluating these potential changes presents a challenge because changes in population metrics may take several years to manifest (Oele et al. 2016). Therefore, long-time series of population metrics are needed to evaluate the influence of length-limit changes. The objective of this study was to evaluate the effect of three consecutive length limits on a Largemouth Bass population over a 28-year interval. We hypothesized that population metrics would change with each successive regulation.

**METHODS**

*Study site*.—Ross Barnett Reservoir is a 33,000-ac impoundment of the Pearl River northeast of Jackson, Mississippi (32.404597, -90.064977). The reservoir is managed by the Pearl River Valley Water Supply District as a water supply source for the Jackson metropolitan area andfor recreation. Filling began in 1962, and by January 1965 the reservoir impounded water 35 miles upstream. Mean depth is 11 ft and water level fluctuations normally range <1.5 ft. Centrarchidae, Ictaluridae, and Moronidae provide most of the recreational fisheries; shads *Dorosoma* spp. and sunfishes *Lepomis* spp. provide essential prey for the fish assemblage. Roving creel surveys conducted in 1986-1996 estimated total annual fishing effort ranged from 7.4 to 20.3 h/ac. Since 1974 Florida Largemouth Bass (*M. salmoides floridanus*) have been stocked in about 60% of the years at rates averaging 2.7/ac (range = <1-6/ac) with fish averaging 2.1-in total length (range = 1 to 9 in).

*Harvest regulations*.—Length-limit regulations to manage black bass *Micropterus* spp. populations have been used on a near continuous basis in Ross Barnett Reservoir since 1988. Aside from a 15-20-in SLL in 1980, a bag limit was the only harvest restriction through 1987. In early 1988 a 13-16-in SLL was implemented. Except for 1993, when the SLL was temporarily lifted, this length limit lasted through 1997. Beginning in 1998 the SLL was replaced with a 15-in MLL, which lasted 11 years until a 12-in MLL replaced it in February 2009. The 12-in MLL was in place through 2015. A bag limit of seven fish complemented the length limits throughout the 28-year period between 1988 and 2015. Appeals from angler groups and tournament organizers were often catalysts for regulation changes. Nevertheless, in crafting regulations the agency balanced requests from special-interests groups with the need to maintain healthy fish populations and satisfy the needs of the entire angling community.

*Fish population surveys and metrics*.—The Mississippi Department of Wildlife, Fisheries and Parks has been conducting standardized electrofishing monitoring in Ross Barnett Reservoir since 1989. Electrofishing surveys are conducted in fall following methods described in Miranda (2005) and Miranda and Boxrucker (2009). There have been changes in electrofishing equipment and personnel, but electrofishing protocols and sampling design have remained consistent over the study period. Multiple samples lasting 0.25-0.5 h each were taken in fall along the reservoir shorelines at sites selected with systematic random sampling throughout the perimeter of the reservoir. All Largemouth Bass collected were measured for total length and weight.

Fish length, weight, and count data were organized into 16 correlated metrics descriptive of Largemouth Bass population status including population density, size structure, and body condition. Despite predictable redundancies in metrics, we considered the full set to avoid the need for choosing metrics, but accounted for correlation among metrics in our analyses (more in Data analysis section). Population density metrics included catch per hour of fish <8 in, 8-11.9 in, 12-14.9 in, and >15 in. These length groups correspond to those conventionally applied to length-structure analysis of Largemouth Bass populations (Neumann et al. 2012). Size structure metrics included median length of fish <12 in, median length of fish >12 in, median length of the largest 10% of the catch, and percentage of fish <8 in, 8-11.9 in, 12-14.9 in, and >15 in. Body condition metrics included relative condition index of fish <8 in, 8-11.9 in, 12-14.0 in, >15 in, and the slope (*b*) of the logarithmic weight-length regression. The relative condition index (*Kn*) was computed as the observed individual weight divided by the expected weight estimated with weight-length equations fitted separately to all of the Largemouth Bass and Spotted Bass collected during the 28-year period. Separation of relative abundance, size structure, and body condition into size classes within the Largemouth Bass length range was expected to enhance our ability to discriminate among years by providing a more detailed description of the population.

*Fishery surveys and metrics*.—Creel surveys were implemented in 1986-2015, except 1997, 2000, and 2002 during randomly selected time periods. Roving creel surveys were implemented in 1986-1996, and access creel surveys in 1998-2015. Roving and access creel survey procedures, and estimation of metrics, followed the methodology described by Jones and Pollock (2012). Data collected included fishing effort (hours fished x number in party), aggregate weight harvested, number harvested, and number of fish released by major taxa groups. The number of fish released was an estimate made by the party when solicited by the creel clerk. Creel surveys combined Largemouth Bass and Spotted Bass *M. punctulatus* because when querying anglers about black bass released it was impractical to segregate by species. In Ross Barnett Reservoir, Largemouth Bass have represented 84% of the black bass collected by electrofishing since 1989, so we assumed that the majority of the catch was Largemouth Bass.

Fishery metrics focused on three ratios expected to be compatible between the two creel survey designs (Lockwood 2004). Catch rate was estimated as number harvested plus number released divided by fishing effort of anglers targeting black bass. Average weight was estimated as the aggregate weight divided by the number harvested regardless of whether anglers were targeting black bass. The proportion of the black bass released was estimated as the count of black bass returned to the water divided by all black bass caught whether kept or released and expressed as a percentage. Because surveys were conducted during randomly selected periods, all ratios were computed with the raw survey data unadjusted for potential temporal differences.

*Data analysis*.—We focused our data analysis on testing our expectations that population and fishery metrics would differ among regulations and that a change in population status would be detectable after a regulation change. The population metrics (i.e., relative abundance, size structure, body condition) and the fishery metrics (i.e., catch rate, average weight, portion released) were analyzed separately because the fishery metrics had three missing years. Thus, one analysis considered the set of 16 population metrics in relation to year and length-limit regulations, and a second analysis considered the set of three fishery metrics.

We applied a single factor (i.e., length-limit regulation) multivariate analysis of variance implemented with a permutation procedure (perMANOVA) to test for differences in metrics among the three length-limit periods. With years as replicates, the perMANOVA relied on 9,999 permutations to assess statistical significance with a pseudo-*F* test and *P* < 0.05. This distance-based procedure is analogous to conventional parametric multivariate analysis of variance, but does not make assumptions about data distribution (e.g., normality). Also, perMANOVA is not affected by temporal correlation in the data (e.g., metric values in year *y* influence those in year *y*+1) because randomly permuting the years removes any inherent temporal correlation (Anderson 2001). If the perMANOVA detected differences in population metrics among the three length limits, pairwise comparisons were performed to identify where the differences occurred. A Bonferroni adjustment for multiple comparisons was included to maintain an overall α = 0.05.

We analyzed metric scores relative to year to assess if metrics shifted after a regulation was implemented. To facilitate this analysis, the 16 metrics were clustered into groups of correlated metrics that were statistically indistinguishable within groups but different among groups. Clustering relied on a group average linkage and a similarity profile analysis (SIMPROF; Clarke et al. 2014) to identify variables with long-term trends that were statistically indistinguishable (*P* > 0.05).

The perMANOVA and cluster analysis were applied to similarity matrices constructed with a Euclidean similarity coefficient and a Pearson correlation coefficient, respectively. Prior to computing the similarity coefficients, all metrics were normalized (*z*-scores) to place them in the same scale. The PRIMER-E v7 software (Clarke et al. 2014) was used for all analyses.

**RESULTS**

Over the 28-year period 848 electrofishing samples were taken. The average number of samples per collection (i.e., year) was 30 (range = 8 to 38). Total electrofishing effort varied from 4 to 19 h/collection and averaged 11.9 h. This effort produced a total of 19,274 Largemouth Bass, averaging 714 fish per collection, and varied from 359 to 1,222 fish per collection. In general, catch rate metrics were the most variable among years and condition metrics were the least variable (Table 1).

The perMANOVA applied to the 16 population metrics detected a significant difference among length-limit periods (pseudo-*F* = 3.3, *P* < 0.01). A follow-up analysis with Bonferroni adjusted pairwise tests (Bonferroni adjusted α = 0.02) indicated the population metrics differed significantly between the 13-16-in SLL and the 12-in MLL (*t* = 2.6, *P* < 0.01), the 15-in MLL and the 12-in MLL (*t* = 1.7, *P* = 0.02), but not between the 15-in MLL and the 13-16-in SLL (*t* =1.4, *P* = 0.08).

The cluster analysis applied to the 16 metrics recognized six statistically different groups of metrics (*P* < 0.05; Figure 1). Each group portrayed unique patterns over the 28-year study period, but metrics within each group followed similar patterns. Metrics in clusters 1 and 2 decreased over time, suggesting that median length of fish larger than 12 in and representation of fish smaller than 8 in decreased over the study years (Figure 2). Metrics in clusters 3 and 4 fluctuated but showed no clear temporal trends, although cluster 4 showed some of the lowest condition levels during the 15-in MLL period, which is predictable if the MLL is in fact reducing mortality and food supply becomes limited. Metrics in cluster 5 showed their lowest values during the first two years that regulations were in effect (i.e., 1989 and 1990), suggesting that the 13-16-in SLL, after a lag period, could have caused an increase of fish 12-15-in and >15-in long. Metrics in cluster 6 experienced a long-term increase, suggesting a greater representation of large fish in the population, as well as greater median length of fish smaller than 12 in. Nevertheless, while temporal trends were apparent, and multivariate tests identified statistically significant differences among length-limit intervals, the line plots of the population metrics did not show convincing shifts linked directly to length limits, other than the initial increases specified for cluster 5.

*Fishery metrics*.—In all, 19,853 anglers in 12,207 parties were interviewed during 1986-2015. Mean annual catch rate during the study period averaged 0.61 fish/h (min-max, 0.25-0.90), mean annual average weight 1.88 lb (1.26-2.70), and fish released 82% (35-98).

The perMANOVA detected a significant difference in the fishery metrics among the three length-limit periods (pseudo-*F* = 20.1, *P* < 0.01). A follow up analysis with Bonferroni adjusted pairwise tests (Bonferroni adjusted α = 0.02) indicated the fishery characteristics differed between the 13-16-in SLL (1988-1997) and the 12-in MLL (2009-2015) (*t* = 4.5, *P* < 0.01), the 15-in MLL (1998-2008) and the 12-in MLL (*t* = 2.6, *P* = 0.02), and the 15-in MLL and the 13-16-in SLL (*t* =5.3, *P* < 0.01).

Plots of the fishery metrics, relative to year, fluctuated but exhibited identifiable patterns (Figure 3). The catch per hour of black bass increased following implementation of the SLL (mean during SLL period = 0.46, SE = 0.036), and reached a plateau when the 15-in MLL was in effect (mean starting in 1999 = 0.75, SE = 0.048). Average weight of fish harvested followed a similar pattern with the lowest values occurring during the SLL period (mean during period = 1.5 lb, SE = 0.045) highest values with the 15-in MLL (mean = 2.4 lb, SE = 0.196), and intermediate average weights with the 12-in MLL (mean = 1.9 lb, SE = 0.099). Conversely, the percentage of fish released increased from rates observed in the two years preceding 1988 (mean 1986-1987 = 43, SE = 9.5). The percentage of fish released increased when the SLL was implemented (mean during period = 75, SE = 5.7), peaked with the 15-in MLL (mean = 94, SE = 1.3), and remained high under the 12-in MLL (mean = 92, SE = 1.4).

**DISCUSSION**

Length6

Our long-term data revealed some differences in population and fishery metrics, as well as various temporal trends. We suggest these trends can only be partially attributed to output controls exercised through length-limit regulations. In 1988 the SLL required anglers to release fish within the protected slot, prompting an increase in the percentage of fish released. In the two years preceding 1988 release rate averaged less than 50% but by the late 1990s release rate was 90% or higher. The regulation was designed to promote the release of 13-16-in fish, but it coincided with a period when there was a shift in harvest attitudes in black bass recreational fishing away from harvesting and towards releasing the catch (Quinn 1996). Similar shifts matching in time with our observations have been reported for other black bass fisheries in Florida and Texas (Myers et al. 2008), Wisconsin (Hansen et al. 2015), and other locations in the United States (Quinn 1996). Thus, while harvest regulations promote involuntary release, voluntary release or self-imposed length limits (Chizinski et al. 2014) in some recreational fisheries may have increased to a level that may make length-limit regulations ineffective for influencing population density and size structure, except in fisheries that receive very high effort. In high-effort fisheries, restricting harvest by even small percentages could potentially produce consequential reductions in the number of fish harvested.

We suspect that the shift in catch-and-release attitude observed at the close of the 20th century had a greater influence on the Largemouth Bass population at Ross Barnett Reservoir than any of the harvest regulations. If length limits are effective, then shifts in metric trajectories following a regulation change are to be expected. For example, in a review of 49 evaluations of largemouth bass population response to length limits published between the 1960s and mid-1990s Wilde (1997) observed that length limits often restructured populations by increasing population size (both MLL and SLL) and the proportion of large fish in the population (SLL only). However, at Ross Barnett Reservoir shifts in population metrics did not correspond with regulations; in particular, the long-term trends observed were generally in one direction, more coherent with a long-term attitudinal change than with well-defined regulation changes. Moreover, in 2009 when harvest was liberalized by lowering the 15-in MLL to 12-in, the rate of release remained high despite the opportunity to harvest more fish, substantiating our interpretation that attitudinal changes regarding harvest were steering population metrics instead of agency-levied harvest regulations. The only metric we could pin directly to regulation changes was average weight of fish harvested. This metric shifted after every regulation change as it directly reflected the fraction of the population available for harvest to a small percentage of harvest-oriented anglers, but possibly also to a segment of anglers that may harvest a small part of their catch.

Many of the observed changes in population metrics can be interpreted in terms of the harvest deficit created by the prevailing catch-and-release attitude. For example, the decline in median TL of fish >12-in documented by cluster 1 is consistent with the accumulation of fish >12-in documented by cluster 6. This accumulation is expected to cause growth reductions (Gabelhouse 1987; Novinger 1987; McHugh 1990; Beamesderfer and North 1995). Also, the decline in fish <8-in documented by cluster 2, and a parallel increase in median TL of fish <12-in documented by cluster 6, reflects the effect that a buildup of larger predators may have through cannibalism (Dong and DeAngelis 1998). Overall, the characteristics of the Largemouth Bass population shifted towards those expected in unharvested populations (Goedde and Coble 1981; Longhurst 2002).

Condition metrics (cluster 4) were expected to show a decreasing trend with the biomass buildup associated with reduced harvest, but no clear trend was apparent. We speculate that long-term trends in eutrophication of the reservoir have allowed increased prey supply and enable the support of a Largemouth Bass population buildup without detectable changes in condition. Eutrophication in Ross Barnett Reservoir has progressed at a relatively fast pace as development associated with the Jackson metropolitan area has engulfed the reservoir, particularly in the lower lake. Total phosphorus and chlorophyll-*a* roughly doubled between 1975 (total phosphorus = 50 ppb, chlorophyll-*a* = 10 ppb; USEPA 1975) and 2004 (total phosphorus = 120 ppb, chlorophyll-*a* = 19 ppb; Mississippi Department of Environmental Quality, unpublished data). The increase in primary productivity has resulted in long-term increases in prey availability composed principally of shads and sunfishes (Figure 4). The observed Largemouth Bass population accumulation attributed to reduced harvest may need to be partly attributed to the effects of eutrophication.

Florida Largemouth Bass have been stocked over the last 40 years in Ross Barnett Reservoir with the goal of increasing large fish in the population. The metric median length of the largest 10% of the electrofishing catch showed an upward trend in cluster 6, suggesting larger fish have become better represented in the population. Nevertheless, it is difficult to attribute this increase conclusively to the Florida Largemouth Bass stocking program. Genetic analyses with DNA fingerprinting in 1993-1995 did indicate low within-population genetic similarity at Ross Barnett Reservoir, suggesting the Florida Largemouth Bass stocking program was influencing the genetic composition of the population (D’Surney et al. 1995). Nevertheless, the increased representation of large fish in the population could also be attributed to increased survival through reduced harvest and increased eutrophication.

Largemouth Bass harvest regulations may still be relevant in some waters (Carlson and Isermann 2010). Nevertheless, their utility for restructuring Largemouth Bass populations is largely dependent on angler willingness to harvest fish and limited to high-effort fisheries. Angler attitudes towards harvesting vary among regions and target species (Myers et al 2008; Isermann et al. 2013; Chizinski et al. 2014) depending on cultural characteristics and demographics, and even within regions depending on user profile (Arlinghaus et al. 2007), and this variability needs to be considered in crafting fishery management plans (Johnston et al. 2010). Moreover, attitudes are not static and can change rapidly within a few decades (Rahel 2016). Establishing successful length-limit fishing regulations for Largemouth Bass fisheries is complicated. No longer can managers craft a regulation based exclusively on a simple yield-per-recruit model (Beamesderfer and North 1995) because these models assume that anglers will harvest fish. Management requires recognition of angler attitudes and that attitudes and motivations can change quickly driven by various factors (Arlinghaus et al. 2007), many not requiring harvest.

Evaluations of fish populations can be complicated by the need to examine multiple metrics descriptive of various aspects of the population. Fishery managers often rely on multiple indices derived from survey data consisting of fish catch rates, length, and weight to evaluate management practices. Evaluations based on multiple metrics can be complex because of the need to examine and weigh various lines of evidence, often inconsistent, provided by partially correlated metrics that may emphasize different aspects of population demographics. The application of cluster analysis facilitated analyses by classifying multiple metrics into clusters displaying similar temporal patterns, which then allowed a simpler analysis of sets of metrics. This procedure offered a more robust analysis because it was based on the preponderance of evidence provided by multiple metrics rather than single metrics, and at the same time reduced the ambiguity of considering many metrics separately.

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TABLE 1. Summary statistics for 16 population density, size structure, and body condition metrics used to describe the Largemouth Bass population at Ross Barnett Reservoir, Mississippi, 1989-2015 (N = 28 years). Median total length statistics are given in inches. *Kn* is a relative condition index and *b* is the slope of log weight – log length regression.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Metric | Mean | CV | Min | Max |
| Catch rate | | | | |
| Catch per hour <8 in | 13.6 | 55 | 3.6 | 26.2 |
| Catch per hour 8-11.9 in | 16.2 | 29 | 7.1 | 24.8 |
| Catch per hour 12-14.9 in | 15.5 | 27 | 8.1 | 23.0 |
| Catch per hour >15 in | 10.1 | 28 | 5.1 | 15.7 |
| Size structure | | | | |
| Median TL <12 in | 8.0 | 7 | 6.5 | 8.9 |
| Median TL >12 in | 14.3 | 2 | 13.8 | 14.9 |
| Median TL of largest 10% | 453 | 4 | 432 | 497 |
| Percentage <8 in | 23.8 | 44 | 9.6 | 39.1 |
| Percentage 8-11.9 in | 29.2 | 15 | 21.4 | 36.4 |
| Percentage 12-14.9 in | 28.5 | 24 | 18.4 | 40.9 |
| Percentage >15 in | 18.5 | 24 | 11.2 | 27.9 |
| Condition | | | | |
| *b* | 3.217 | 2 | 3.134 | 3.267 |
| *Kn* <8 in | 1 | 5 | 0.91 | 1.17 |
| *Kn*  8-11.9 in | 1 | 4 | 0.93 | 1.10 |
| *Kn* 12-14.9 in | 1 | 4 | 0.92 | 1.07 |
| *Kn* >15 in | 1 | 4 | 0.95 | 1.09 |

FIGURE CAPTIONS

FIGURE 1. Cluster analysis of the 16 Largemouth Bass population metrics. Dashed lines identify metrics found to be statistically indistinguishable. The numbers encircled identify the six statistically different clusters. The lower axis identifies the correlation among metrics and clusters.

FIGURE 2. Long-term trends in the 16 Largemouth Bass population metrics at Ross Barnett Reservoir, Mississippi, 1989-2015. Metrics are organized according to the clusters defined in Figure 1. Metric scores were normalized (*z*-scores) to achieve a common scale. Length-limit periods identified by the shaded regions include a 13-16-in protected slot length limit (13-16 SLL), a 15-in minimum length limit (15 MLL), and a 12-in minimum length limit (15 MLL).

FIGURE 3. Long-term trends in black bass fishery statistics normalized with *z*-scores at Ross Barnett Reservoir, Mississippi, 1986-2015. Length-limit periods identified by the shaded regions include a 13-16-in protected slot length limit (13-16 SLL), a 15-in minimum length limit (15 MLL), and a 12-in minimum length limit (15 MLL).

FIGURE 4. Long-term trends in electrofishing catch rates of shads and sunfishes normalized with *z*-scores at Ross Barnett Reservoir, Mississippi, 1996-2015 (R. Jones, unpublished data).







