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Largemouth Bass in the Upper Mississippi River: An Evaluation of Management Strategies and Understanding Potential Factors Influencing Dynamic Rate Functions

Kylie Beth Sterling
Missouri State University, Kylie6@live.missouristate.edu

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LARGEMOUTH BASS IN THE UPPER MISSISSIPPI RIVER: AN EVALUATION OF

MANAGEMENT STRATEGIES AND UNDERSTANDING POTENTIAL FACTORS

INFLUENCING DYNAMIC RATE FUNCTIONS

A Master's Thesis

Presented to

The Graduate College Of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Biology

By

Kylie Beth Sterling

May 2022

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Biology

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Master of Science

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ABSTRACT

The Upper Mississippi River (UMR) supports ecologically and economically important commercial and recreational fisheries. One recreational fishery in the UMR is the Largemouth Bass fishery. Recreational fisheries can be effectively managed using information on population dynamics, though little is known about Largemouth Bass population dynamics in large river ecosystems. Therefore, the objectives of this study were to 1) evaluate recruitment, growth, and mortality of three Largemouth Bass populations in the UMR, specifically within Pools 4, 8, and 13, and 2) to use those estimates of recruitment, growth and mortality to inform exploitation models to evaluate best management practices for each study population. To quantify population dynamics, we studied Largemouth Bass sampled via standard electrofishing as part of the Long Term Resource Monitoring Element (LTRM) of the Upper Mississippi River Restoration Program. From these samples, we collected sagittal otoliths for ageing, and collected length and weight information from each individual. Using the empirical data collected from each fish, we were able to model recruitment, growth, and mortality. Recruitment variability index (RVI) values showed that Largemouth Bass recruitment in Pool 4 (RVI = 0.51) was more variable than that of Pool 8 (RVI = 0.81) and Pool 13 (0.73). However, growth and mortality estimates were varied somewhat among the three study populations. Furthermore, using the dynamic rate estimates as inputs into Fisheries Analysis and Modeling Simulator (FAMS), we developed Yield-per-recruit (YPR) models and models of preferred size fish. YPR models suggest that a more liberal length limit of 279 mm, as opposed to the current 356 mm minimum Length limit, would maximize yield in each pool. Additionally, number of preferred-size fish models suggest that the current 356 mm minimum length limit considerably increased the number of preferred-size fish in each pool under exploitation rates of 20-40%. This information could benefit managers' decision-making by providing them with information on the Largemouth Bass populations in these recreational fishing areas of interest.

KEYWORDS: recruitment, growth, mortality, pool, minimum length limit (MLL)

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Approved:

Quinton E. Phelps, Ph.D., Thesis Committee Chair

Alicia S. Mathis, Ph.D., Thesis Committee Member

Debra S. Finn, Ph. D., Thesis Committee Member

Kristen L. Bouska, Ph. D., Thesis Committee Member

Julie Masterson, Ph.D., Dean of the Graduate College

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INTRODUCTION

The Upper Mississippi River (UMR) begins at its headwaters located at Lake Itasca in northern Minnesota and ends at the confluence of the Ohio River near Cairo, IL. The United States' Congress has declared the Upper Mississippi River System to be both a nationally significant ecosystem and commercial navigation system (Water Resources Development Act of 1986, 33 U.S.C. §§ 652). Given the ecological and economic importance of the UMR, effective monitoring of the resources within are paramount. In order to effectively monitor the status and trends of the ecological resources in this large river system, a standardized sampling program was created in part by the Upper Mississippi River Restoration Program. This program is titled, "The Long Term Resource Monitoring Element (LTRM)" and was developed by the United States Army Corps of Engineers and U.S. Geological Survey. The LTRM is implemented by state and federal natural resource agencies to provide necessary long-term ecological data resources to managers and researchers of the Mississippi River and Illinois River. The LTRM fish component has conducted standard sampling efforts in five study reaches of the Mississippi River and one study reach on the Illinois River since 1993. The stratified random sampling design of the LTRM is considered to be one of the most effective ways to study such a large complex river system (Ickes et al. 2014).

The UMR supports a vital barge transportation economy, an important commercial fishing economy, and many high-quality recreational fisheries. Anglers, commercial and recreational, rely on proper management of the fisheries within the UMR to provide high-quality harvest and recreational angling opportunities. Recreational anglers often target sportfish (e.g., centrarchid spp.) for trophy and harvest fishing opportunities (Cooke and Philipp 2009). One

commonly sought-after sportfish in the UMR and throughout the United States is the Largemouth Bass *Micropterus salmoides* (USFWS 2011). Whether it be for harvest or recreation, most anglers are intent on improved size structure of their recreational fisheries (Dotson et al. 2013). Improved size structure (i.e., greater proportion of larger individuals) not only provides higher yield for harvest anglers and "trophy" fisheries for catch-and-release anglers, but also provides stable sportfish populations because larger fish have higher fecundity ratios (Dotson et al. 2013).

In order to appropriately manage Largemouth Bass populations in the UMR, a comprehensive understanding of their population dynamics (i.e., recruitment, growth and mortality) is necessary. Accurate measures of population dynamics (also known as dynamic rate functions) can be used to predict how anthropogenic disturbances (e.g., harvest, dam implementation, flow alterations, etc.) may be affecting Largemouth Bass populations (Sterling et al. 2019). The importance of these dynamic rate functions is compounded in a highly modified river system such as the UMR. Dams and training structures (i.e., dikes) have likely fragmented Largemouth Bass populations in the UMR, which could affect the dynamic rate functions of these potentially isolated populations, compelling researchers to evaluate them separately because of differing temporal trends and habitat structure (e.g., submersed aquatic vegetation) among pools.

In large river systems, such as the UMR, fish population dynamics are driven by abiotic factors (e.g., temperature and water flow), and biotic factors (e.g., food and competition) (Maceina and Bettoli 1998; Van Den Avyle and Hayward 1999). It is also important to understand how spatial and temporal patterns affect the vital rates of these species. Additionally, we know that latitudinal trends affect growth in fish populations due to temporal shifts

coinciding with latitude. Latitudinal trends in widely distributed species tend to follow

environmental gradients, thus resulting in temperature being the main driver of dynamic rate

functions (Abner and Phelps 2018). According to Bergman's Rule, animal body size correlates

positively with latitude and negatively with temperature (McNab 1971). However, fish tend to

follow the converse of Bergmann's Rule because warm water fish (e.g., Largemouth Bass) tend

to grow slower and reach relatively old ages in northern latitudes, whereas fish in southern

latitudes tend to exhibit accelerated growth rates and generally live shorter lives than their

northern counterparts (Rypel et al. 2014). Though they are generally shorter lived, Garvey and

Marschall (2003) found that Largemouth Bass inhabiting southern latitudes of North America

tend to reach larger body sizes than their northern counterparts. This phenomenon is a result of

fish in northern latitudes living longer but having reduced growth rates to compensate for the

shorter growing periods and colder climates (Conover 1990; Conover & Present 1990).

However, it is unclear whether temperature can produce differences in dynamic rate functions

within various areas along a relatively small latitudinal scale (i.e., 3 degrees). This said, it is not

clear if Largemouth Bass populations in the UMR exhibit specific differences in growth rates

and overall body size. Thus, differences in growth, if existent, may be subtle and require proper

assessment to detect.

To properly assess any fish population, estimates of dynamic rate functions must be

obtained (Buckmeier and Howells 2003; Sterling et al. 2019). Dynamic rate functions are often

obtained by collecting age and growth information which can be used to evaluate how

exploitation is affecting dynamic rates (Devries and Frie 1996). Reliable ageing structures, such

as sagittal otoliths in centrarchids, are vital in quantifying population parameters (i.e., age and

growth) of any fish population to avoid improper management regulations that could result in

overexploitation of a fishery (Beamish and McFarlane 1987; Maceina and Sammons 2006; Sterling et al. 2019).

Largemouth Bass have been studied extensively in ponds, lakes, and reservoirs, but little is known about Largemouth Bass population dynamics in large river ecosystems, such as the Mississippi River (Raibley et al. 1997). Therefore, the objectives of this study were to 1) evaluate and assess recruitment, growth, and mortality of three Largemouth Bass populations in the UMR over a two-year sample (2019-2020); 2) use dynamic rate estimates to inform exploitation models which allow us to evaluate the relationship between various harvest scenarios and management regulations using the fisheries analysis and modeling simulator (FAMS) (Slipke and Maceina 2010); 3) to recommend regulations to provide sustainability and enhancement of Largemouth Bass fisheries in the UMR; and 4) to elucidate potential abiotic and/or biotic factors driving the dynamic rate functions of these Largemouth Bass populations.

METHODS

This study did not require approval by the Institutional Review Board/Institutional Animal Care and Use Committee/Biosafety Committee (See Appendix).

Study Areas

A pool in the UMR is defined as an area of the river that separates navigation dams (USGS 2018). Dams create slack-water pools for navigation during periods of low and medium flows. Three pools of the UMR were selected as study sites. Pool 4 located in Lake City, MN (58.6 miles long); Pool 8 located in La Crosse, WI (23.5 miles long); and Pool 13 located in in

Bellevue, IA (34.2 miles long; Figure 1). Interestingly, Pool 4 encompasses Lake Pepin, a 21-mile-long, naturally occurring lake within the Mississippi River. These three pools span approximately 3 degrees in latitude. These study pools were selected in part of on-going LTRM monitoring activities, and also because of their high recreational angler use (Ratcliff et al. 2014).

Collection

During 2019, LTRM biologists collected Largemouth Bass via daytime electrofishing using standardized LTRM protocols (Ratcliff et al. 2014). In 2020 due to the circumstances of the COVID-19 pandemic, Largemouth Bass were collected without standardized LTRM electrofishing protocols (e.g., one person netting fish, fewer sample runs and fewer samples per run). However, modified protocols for collection in 2020 were standardized. Upon collection, total length (mm) and weight (g) were recorded for each individual caught per LTRM protocol. A sub-sample of 10 individuals per 10 mm length category were kept and frozen for later processing for ageing purposes.

Sample Processing

After collection, we removed sagittal otoliths for age analyses. Following removal, otoliths were dried, submerged in glycerol, and viewed beneath a dissecting microscope with low magnification (6-50x). Otoliths were read whole with two independent readers. Any otoliths that appeared to have annuli crowded at the margins or were unclear were fractured on the transverse plane, mounted in clay, submerged in glycerol, and viewed using illumination from a fiber optic light (Buckmeier and Howells 2003). In the event of a disagreement between readers, we used a third reader to resolve discrepancies (Maceina and Sammons 2006). Obtaining reliable age

estimates and total length measurements allowed us to quantify recruitment, growth, and mortality for Largemouth Bass. From the aged fish, pool-specific age-length keys were created to assign ages to unaged fish from the 2019 and 2020 samples using the Fisheries Analysis and Modeling Simulator (FAMS) (Slipke and Maceina 2014).

Data Analyses

To quantify the stability of interannual recruitment, we used a recruitment variability index (Guy and Willis 1995). The index is defined as:

$$RVI = \left[\frac{S_n}{(N_m + N_p)} \right] - \frac{N_m}{N_p}$$

here S_n represents cumulative relative frequencies across year-classes in the sample, N_m is the number of year-classes missing from the sample, and N_p is the number of year-classes present in the sample. The Recruitment Variability Index values can range from -1 to 1, with values closer to 1 representing relatively stable recruitment (Iserman et al. 2002, Guy and Willis 1995). From this model, we evaluated recruitment variability of each study population in pools 4, 8, and 13 of the UMR. Complimentary to the Recruitment Variability Index, the Recruitment Coefficient of Determination (RCD) was also used to quantify the stability of interannual recruitment (Isermann et al. 2002). RCD is the goodness of fit value (R^2) derived from the catch-curve (linear regression) mortality estimate. We cross-correlated the relative strength or weakness of year classes (R^2) from the catch-curve regression of each Largemouth Bass population. R^2 values also range from -1 to 1, with values closer to 1 representing strong year classes and -1 representing weak year classes. This allowed us to determine if recruitment patterns were similar among pools 4, 8, and 13.

We estimated growth for Largemouth Bass in each pool by determining the mean length-at-age. Mean-length-at-age were determined by averaging individual lengths of each age class. Mean length-at-age data was incorporated into Fisheries Analysis and Modeling Simulator (Slipke and Maceina 2014) and were used to model growth using a von Bertalanffy model. The von Bertalanffy growth model is generated using the equation

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where Length infinity (L∞) is the theoretical maximum length that a fish can achieve, K is the Brody Growth Coefficient which is the growth constant or rate at which a fish reaches the theoretical maximum length, and t_0 is the theoretical age at length zero (Von Bertalanffy 1938). We used the individual parameters of the von Bertalanffy model to descriptively compare locations. Specifically, we compared theoretical maximum length, and the Brody growth coefficient among sites.

A catch-curve mortality estimate was used to quantify mortality for each Largemouth Bass population (Ricker 1975). Catch-curve regressions were generated by summing the number of fish caught per age class in each individual pool. These data allowed us to develop individual regression models to estimate instantaneous mortality.

$$A = 1 - (e^{-z})$$

Here, Z is Instantaneous mortality rate and A is total annual mortality for selected fishes from each river reach. Conditional natural mortality (CM) was estimated by averaging the combined mortality estimators' values derived in FAMS in the absence of fishing.

After obtaining estimates of the dynamic rate functions for each Largemouth Bass population, we explored various management regulations for each pool. To do this we used FAMS software to create a Yield Per Recruit (YPR) model. By analyzing the effects of various

exploitation rates at multiple minimum length limits (i.e., 254 mm, 279 mm, 305 mm, 330 mm,

356 mm and 381 mm) we predicted how each population's yield will respond to various

exploitation scenarios.

To model yield, we employed the Beverton and Holt yield-per-recruit model (1957). The

model can be expressed as

$$Y/_R = FW_\infty \left[\frac{1}{Z} - \frac{3e^{-kr}1}{Z+K} + \frac{3e^{-2kr}1}{Z+2K} - \frac{e^{-3kr}1}{Z+3K} \right]$$

where Z (=F+M), F and M are the instantaneous rates of total fishing and natural mortality,

respectively; $r_1 = t_e - t_0$; and W_∞, K and t_0 are the parameters of the von Bertalanffy growth

equation (Beverton and Holt 1957).

Given that Largemouth Bass are a highly sought-after sportfish, we anticipated that a

model of number of preferred-size fish would provide insight to those who manage these pools.

The preferred length for Largemouth Bass is 371-455 mm (14.6-17.9 inches) and is categorized

as "somewhat bigger" than the quality length (297-338 mm; 11.7-13.3 inches) that most anglers

prefer to catch (Gabelhouse 1984). This model is used to depict how many preferred-sized

Largemouth Bass could be produced under various minimum length limit scenarios as well as

various exploitation estimates in a theoretical cohort of 1000 recruits. We used the growth

parameters and natural mortality estimates to predict the number of Largemouth Bass in the

preferred length category in each pool using FAMS (Slipke and Maceina 2014).

RESULTS

In total, 3,178 Largemouth Bass were sampled during 2019 and 2020 via daytime

electrofishing in Pools 4, 8, and 13 by LTRM field station personnel. As previously mentioned,

due to the COVID-19 pandemic, the 2020 sample was obtained using modified LTRM protocols. Counts for each pool for 2019 and 2020 combined were as follows: 666 from Pool 4, 1602 from Pool 8, and 927 from Pool 13. We aged 211 individuals in Pool 4, 619 individuals in Pool 8, and 593 individuals in Pool 13. Fish that were not kept for ageing purposes were assigned ages based on the age-length key.

As is typical of most fishes, both length frequency and age frequency distributions for Largemouth Bass depicted a high number of smaller, younger fish sampled in each pool. Length frequency among the pools shared a similar, positively skewed, distribution (Figure 2). Age frequency of Largemouth Bass in all three pools exhibited similar distributions as well (Figure 3). Notably, Pool 4 had the least number of samples, and contained missing age classes (Figure 3). Mean lengths varied across pools somewhat, ranging from 113.75 mm in Pool 4 to 181.54 mm in Pool 13 (Table 1), but overall body size of Largemouth Bass among Pools 4, 8, and 13 are comparable given the similar length-weight relationships for each pool (Figure 4).

Recruitment

Recruitment varied somewhat among sample pools. Pool 4 exhibited the most variable recruitment (RVI=0.51) in relation to Pools 8 (RVI=0.81) and 13 (RVI=0.73) (Table 1). RCD values (R^2) from the catch-curve regression provided insight on recruitment success among each Largemouth Bass population. RCD values varied somewhat among pools as well. Pool 4 had the lowest value (RCD=0.63) in relation to Pool 8 (RCD=0.91) and Pool 13 (RCD=0.94), exhibiting relatively variable recruitment in Pool 4 and stable recruitment in Pools 8 and 13. Using both recruitment metrics (RVI and RCD), we determined that Largemouth Bass have somewhat variable recruitment in Pool 4, and stable recruitment in Pools 8 and 13.

Growth

   Mean length-at-age across Pools 4, 8, and 13 appear to be similar (Table 2). The von
Bertalanffy growth coefficients depict some variation between pools (Figure 5). The theoretical
maximum lengths (L∞) for each pool ranged from 448 mm (Pool 4) to 478 mm (Pool 13; Table
1). The Brody growth coefficient (K), also known as the rate at which an individual reaches
theoretical maximum length, varied most between Pool 4 (K = 0.34) and Pool 13 (K = 0.29), and
was most similar between Pool 8 (K = 0.31) and pool 13 (K = 0.29; Table 1). These metrics
depict that Pool 13 has the highest growth potential (L∞=478mm) and Pool 4 has the highest rate
at which theoretical maximum length is met (K=0.34).

Mortality

   Catch-curve analyses showed mortality estimates were similar for all three pools (Figure
6). Pool 4 had a 37% mortality rate and Pools 8 and 13 had a 38% mortality rate (Table 1).
Conditional natural mortality rates derived from multiple mortality estimators in FAMS show
Pool 4 to have a 33% mortality rate in the absence of fishing and Pools 8 and 13 had 31%
mortality rate in the absence of fishing (Table 1).

Yield-Per-Recruit

   YPR models depicted that a 254 mm minimum length limit (MLL) would subject all 3
pools to growth overfishing under high exploitation rates (> 60%, Figure 7). Conversely, a 381
mm MLL would not result in growth overfishing for any pool under extreme exploitation rates
(Figure 7). However, a 381 mm MLL would reduce yield to anglers (Figure 7). For Pools 4, 8,

and 13 it appears that under reasonable exploitation rates (20-40%) observed in many recreational Largemouth Bass fisheries (Allen et al. 1998; Miranda et al. 2002; Allen et al. 2008) a 279mm MLL would produce the highest yield to anglers and maintain populations safe from growth overfishing (Figure 7).

Model of Preferred-Size Fish

Due to L∞ not reaching the memorable-size length category (488-528 mm; Gabelhouse 1984), we created a model of preferred-size fish (371-455 mm; Gabelhouse 1984). The models of preferred-size Largemouth Bass depict that a 381 mm MLL in Pool 13 could produce ~105 (233%) more preferred-size individuals than a 254 mm MLL at exploitation rates of 20-40% (Allen et al. 1998; Miranda et al. 2002; Allen et al. 2008; Figure 8). At the current 356 mm MLL for Pool 13 under 20-40% exploitation, the number of preferred-size individuals is 120, which is 30 (25%) fewer individuals than the 381 mm MLL (Figure 8). Pool 4 and Pool 8 exhibit very similar trends in this model. For both pools, a 381 mm MLL would produce ~80 (200%) more preferred-size individuals than a 254 MLL, and a 356 mm MLL would produce ~40 (50%) fewer preferred-size individuals than a 381 mm MLL (Figure 8).

DISCUSSION

Our results suggest there are variations in recruitment and growth rates among Pools 4, 8, and 13 of the UMR. Variations in recruitment and growth produced differences in our models of yield and number of preferred-size fish in each pool, thus, allowing us to provide management recommendations for each pool. Variations in dynamic rates among Largemouth Bass

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populations in the study pools could be a result from a variety of biotic and abiotic factors within the pools themselves (e.g., temperature, turbidity, flood events, geographic range, submersed aquatic vegetation etc.). Largemouth Bass are a relatively slow-growing species in the northern latitudes of the United States (Beamesderfer and North 1995). Beamesderfer and North (1995) concluded that growth, productivity and natural mortality of Black Bass (ssp.) are positively correlated with temperature when they observed northern populations exhibit slower growth rates and lower natural mortality rates than that of southern Largemouth Bass populations in the U.S.

Air temperature directly influences water temperature, which directly affects recruitment in many fish species, including Largemouth Bass (Beamesderfer and North 1995; Fullerton et al. 2000). The northern-most part of the United States, including Pool 4, sometimes endures harsh winter extremes, which could negatively affect recruitment success for Pool 4 and other surrounding waterbodies (Fullerton et al. 2000). Though temperature has shown to produce differences in dynamic rate functions among Largemouth Bass along a broad latitudinal scale, our evidence does not support temperature as the main driver in the differences observed among the three pools because their annual water temperatures show only slight differences (Figure 9). Therefore, exploring other potential abiotic or biotic factors that could be driving the higher variation in recruitment of the Pool 4 Largemouth Bass population may be more informative.

As assessed by USGS (2020), the portion of Pool 4 upstream of Lake Pepin generally exhibits higher turbidity than that of the other two study pools. Turbidity has been observed to affect overall nest success in *Micropterus spp*. by increasing sediment loads in nests and forcing the males to abandon nest sites (Lukas and Orth 1995). Furthermore, turbidity has been linked to

decreased growth in Largemouth Bass (Wolfe et al. 2009). Thus, the increased turbidity in Pool 4 could be a factor affecting reduced growth and variable recruitment of Largemouth Bass.

Parkos and Wahl (2010) determined that variation in recruitment strength of intrapopulation species within a community were associated with either production of age-0 fish from the parental care stage or prey fish (e.g., Bluegill *Lepomis macrochirus*) abundance. With these results in mind, Parkos and Wahl (2010) suggest that Largemouth Bass management should focus on actions designed to promote nesting success, as well as communities that support the growth and production of prey fish species to ensure food availability for Largemouth Bass recruitment success. However, a study on synchrony between Black Bass ssp. and Crappie ssp. recruitment in Missouri reservoirs suggests that management to improve recruitment of one species may not enhance the recruitment of another one (Michaletz and Siepker 2013), as synchrony was not observed between these fishes' recruitment patterns. Therefore, it may be beneficial for managers to conduct community assessments within Pool 4 to help explicate the main drivers for variable recruitment. Managers should also keep in mind the potential effects on other species' recruitment variability when implementing any strategies to improve recruitment of any specific species.

The Flood Pulse Concept idealized by Junk et al. (1989) states that fish use the floodplain to gain access to optimal nursery habitat and spawning grounds (Galat and Zweimüller 2001). Floodplain connectivity has been linked to recruitment success. The impounded UMR has maintained off-channel connectivity (De Jager and Rohweder 2011), thus, it is unlikely that lack of floodplain connectivity is influencing the somewhat variable recruitment in Pool 4. However, enhancing floodplain connectivity in Pool 4 could improve recruitment success by providing crucial nursery habitat.

Bergmann's Rule states that body size correlates positively with latitude and negatively with temperature (McNab 1971). However, the converse of Bergmann's Rule has been observed in warmwater fish species inhabiting freshwaters because body size correlates negatively with latitude and positively with temperature (Rypel 2014). Therefore, we expected Pool 13 to exhibit increased growth rates and larger individual body size in relation to Pools 4 and 8 due to its lowest position of the three pools on the latitudinal gradient (Figure 1), and its likely higher water temperatures (Figure 9) in relation to the other pools. Our models confirmed the converse of Bergmann's Rule concept by showing that Pool 13 has the highest growth potential ($L\infty = 478$ mm), depicting that overall growth potential for the Largemouth Bass population in Pool 13 is greater than that of the populations in Pools 4 ($L\infty = 448$ mm) and 8 ($L\infty = 453$ mm).

The thermal requirement for optimum growth in Largemouth Bass is 24°C (Whitledge et al. 2002). Furthermore, in order to survive the effects of winter, Largemouth Bass must seek thermal refuge from extreme, cold temperatures (Torgersen et al. 2012; Westhoff et al. 2016). During periods of time when the river water temperature is colder than the groundwater or spring inflow temperature, Centrarchid ssp. will migrate to those inflow locations to thermoregulate and overwinter (Westhoff et al. 2016). Due to the typical harsh winter temperatures within the study area, a study on thermal refuge availability may be useful to managers when determining potential avenues to decrease recruitment variability in Largemouth Bass, especially in Pool 4 where we observed recruitment to be the most variable among the three study pools.

Monthly mean temperatures of each study pool were plotted to depict trends within and between each pool (Figure 9). Mean monthly temperatures were derived from temperatures recorded during LTRM stratified random water quality sampling efforts. Stratified random sampling only occurs quarterly throughout the year, therefore, only seven months (i.e., January,

February, April, May, July, August and October) out of the year are depictive of actual mean monthly temperatures. For the other five months we analyzed fixed site temperatures recorded to depict an interpool temperature trend. The values for the fixed site averages should not be interpreted as accurate temperature observations, but rather an indication of trends to bridge the gap between months with accurate temperature recordings. As expected, the mean monthly temperatures of the study pools follow a latitudinal trend (Figure 9; McNab 1971). Water temperatures of all three pools allow for a brief period of optimum growth temperatures between June and August (Figure 9). However, due to the short period of annual optimal growth temperatures in relation to populations in the southern United States, growth potential is likely reduced (Conover 1990; Whitledge et al. 2002). These three Largemouth Bass populations are growing at a slower rate than their southern counterparts that sustain longer growing seasons with optimal temperatures to produce trophy Largemouth Bass. Therefore, temperature could be the main driver of growth potential (McCormick and Wegner 1981; Modde and Scalet 1985; Conover 1990). Consequently, the reduced growth potentials observed in these populations will likely never support trophy Largemouth Bass fisheries in any of the study pools.

In 1989, Wisconsin adapted new management strategies for Black Bass ssp., altering their length limits (254 mm to 356 mm), reduced aggregate bag limits (15 fish/day to 5 fish/day), and implemented a catch-and-release-only season during the spring. In the northern one-third of Wisconsin, where the greatest density of lakes occurs, Hansen et al. (2015) tested trends in Largemouth Bass relative abundance, growth, and angler catch and harvest rates in relation to management policies spanning from 1990 to 2001. They found that when the statewide 356 mm minimum length limit was implemented, angler catch rates as well as electrofishing catch per unit effort (CPUE) increased from 0.09 fish/hr. to 0.61 fish/hr. Likewise, Carlson and Isermann

(2011) also found that CPUE of Largemouth Bass ≥ 381 mm also improved after more conservative regulations were implemented in six Minnesota lakes. However, Hansen et al. (2015) noticed that the mean total length of age-6 Largemouth Bass decreased from 370.8 mm to 340.4 mm with the 356 mm MLL. Both Carlson and Isermann (2011) and Hansen et al. (2015), documented that anglers showed an increase in voluntary release of Largemouth Bass. With these results in mind, we could assume that anglers in Pools 4, 8 and 13 are adopting similar ethics as anglers in nearby Wisconsin and Minnesota lakes by voluntarily releasing fish in hopes of attaining a Largemouth Bass fishery with larger individuals. Like these two previous studies, within the study pools, we deduced that the current 356 mm MLL is the optimum regulation at which fish of preferred size for most anglers will be achieved (Figure 8) while maintaining a reasonable amount of harvest (Figure 7). While considering angler habits with regard to Largemouth Bass harvest, or lack-there-of, it is also important to consider the requirements of Largemouth Bass populations that can optimize growth when making appropriate management decisions.

Largemouth Bass are a highly sought-after sportfish in these study locations, creating pressure for managers to provide the best Largemouth Bass fishery possible. A best management practice for obtaining these sought-after fisheries is to consider angler opinion for the fishery (Edison et al. 2006). If the angler community wishes to have a maximized size structure (e.g., greater proportion of larger individuals) a conservative MLL, such as the current 356 mm MLL would be appropriate. Conversely, if the angler community wishes to maximize their yield, a more liberal MLL, such as the 279 mm MLL should be considered. Thus, due to similar maximum length potentials and recruitment, growth, and mortality estimates, management strategies should not differ among the three pools. The current 356 mm MLL appears to provide

a population that will not succumb to growth over-fishing, as observed in Figure 7. Furthermore, the 356 mm MLL allows these populations to reach their maximum growth potential, albeit relatively low, under reasonable exploitation rates from 20-40% (Allen et al. 1998; Miranda et al. 2002; Allen et al. 2008; Figure 7). If the current 356 mm MLL was reduced to the 279 mm MLL, Largemouth Bass anglers in Pools 4, 8, and 13 could see potential increases in yield of 20-43% overall under reasonable exploitation rates of 20-40%. Though a more liberal MLL would likely increase angler yield, size structure and growth potential would likely be hindered.

Largemouth Bass anglers typically exhibit catch-and-release ethics in hopes to improve the size structure of the population they are fishing. Thus, we would assume keeping the current 356 mm MLL would best benefit the anglers and provide the opportunity for these fish to reach their maximum growth potential, while still providing harvest opportunities if so desired. Additionally, the growth coefficients of these three Largemouth Bass populations, as previously mentioned, depict that a trophy fishery (i.e., individuals ≥ 610 mm; Gabelhouse 1984) is not likely due to the relatively low maximum growth potential ($L\infty$) for each population only ranging between 448-478 mm. In order for these populations to become trophy fisheries, $L\infty$ would have to drastically increase from what they are now (448-478 mm) to ≥ 670 mm (Gabelhouse 1984; Dotson et al. 2013). While maintaining current habitat and climatic trends, it is unlikely that these Largemouth Bass fisheries can ever be considered "trophy" fisheries. Therefore, managers should resist pressure from anglers to invoke more restrictive angling regulations as they will likely not produce a trophy fishery in these study pools provided current temperature trends.

However, climate change may have an impact on growth rates of these three northern Largemouth Bass populations in the future. As average annual temperatures continue to rise, Largemouth Bass populations at more northern latitudes could see responses in dynamic rate

functions. If warmer water temperatures occur, it would likely create longer growing seasons for Largemouth Bass in Pools 4, 8, and 13. This, in turn, could allow these populations to see improved size structure and more stable recruitment. Therefore, re-examining these three Largemouth Bass populations as water temperatures increase from a warming climate would be beneficial for managers to gain insight on the response of these populations to climate change. Management recommendations could then be adapted appropriately.

Estimates of recruitment, growth, and mortality in each of these study pools provide novel data regarding Largemouth Bass populations in the UMR. Future efforts evaluating angler harvest could help provide specific exploitation rates to better interpret the exploitation models herein. Continued monitoring of dynamic rates can also provide information on Largemouth Bass response to climate change. Furthermore, elucidating relationships with other variables (e.g., turbidity, aquatic vegetation, habitat improvements, etc.) could provide a basis for developing strategies to make improvements in growth and recruitment in these populations. Demographic rate estimates remain an important part of fisheries science and provide important insight into populations of exploited fisheries. Proper estimates of recruitment, growth, and mortality can provide managers with best management practices to improve the recreational fisheries in the UMR.

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Table 1. Life history parameters of Largemouth Bass captured in each study pool from 2019-2020 via daytime electrofishing conducted by LTRM; RVI are recruitment variability index values, $L\infty$, K, and t_0 are Von Bertalanffy Growth coefficients, and weight and length coefficients are log transformed. Conditional natural mortality is the combined mortality estimators' values in the absence of fishing. Total annual mortality (AM) considers instantaneous mortality and fishing mortality. Length limits (TL) are the current minimum length limits regulated in each pool. Maximum TL was the maximum total length observed and Minimum TL was the minimum total length observed. Mean TL (mm) is the Mean total length in millimeters and are portrayed with SE values.

Parameters	Pool 4	Pool 8	Pool 13
RVI	0.51	0.81	0.73
RCD	0.63	0.91	0.94
$L\infty$	448.38	452.6	478.356
K	0.34	0.312	0.296
t_0	-0.37	-0.40	-0.42
Maximum age (years)	14	16	13
Conditional natural mortality	0.33	0.31	0.31
Total annual mortality	0.369	0.377	0.378
Log_{10}(weight) : Log_{10}(length) coefficients (intercept; slope)	-5.03; 3.09	-5.12; 3.11	-5.31; 3.19
Length limits (TL)	356	356	356
Maximum TL	448	495	530
Minimum TL	45	20	28
Mean TL	113.75 ± 3.05	144.97 ± 2.63	181.54 ± 3.95

Table 2. The mean TL (mm) of Largemouth Bass at various age estimates for each study pool from 2019-2020. Fish were captured via daytime electrofishing conducted by LTRM. The dashes indicate that no individuals of that age were analyzed in this study.

Age (years)	Pool 4	Pool 8	Pool 13
0	82.7 ± 0.1	71.4 ± 0.5	74.2 ± 1.1
1	119.7 ± 2.4	137.3 ± 1.7	138.3 ± 1.8
2	223.6 ± 12.5	218.5 ± 3.9	224.3 ± 4.9
3	317.7 ± 14.0	301.8 ± 5.7	319.6 ± 5.9
4	376.8 ± 4.2	360.9 ± 3.2	374.3 ± 4.4
5	410 ± 0	372.8 ± 6.1	385.3 ± 5.3
6	373.5 ± 17.5	382.3 ± 8.4	391.6 ± 10.2
7		405 ± 4.6	418 ± 9.1
8	435 ± 2	430.4 ± 11.8	446.9 ± 6.1
9		439.3 ± 12.7	472 ± 0
10	426 ± 11.0	437.6 ± 8.8	443.8 ± 11.6
11	442 ± 16.0	440.4 ± 15.2	465 ± 65
12		451 ± 0	
13	425 ± 1	454 ± 4	456 ± 0
14	443 ± 0	400 ± 0	
15			
16		460 ± 0	
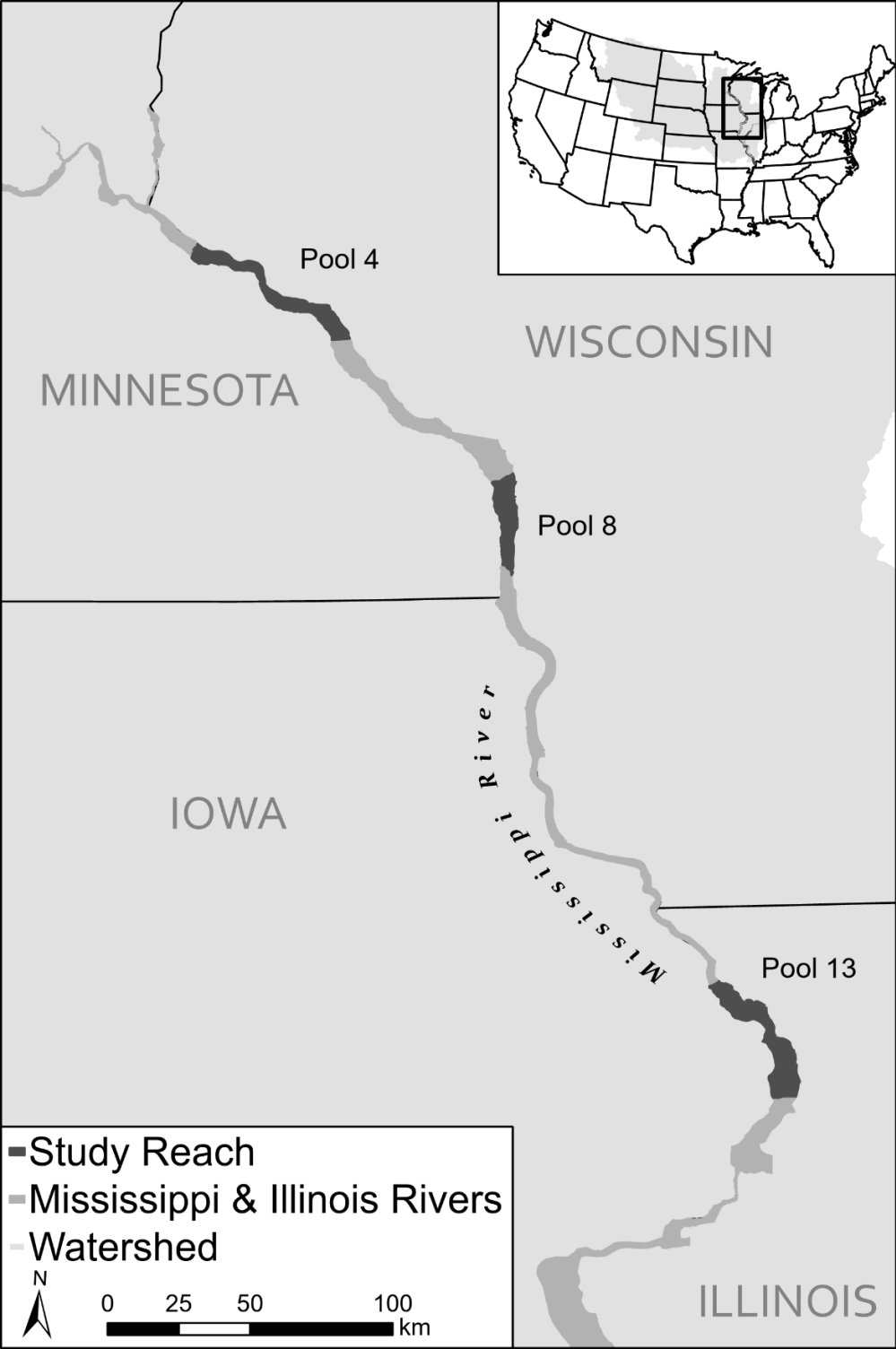
Figure 1. A map of the Upper Mississippi River. Pools 4, 8, and 13 are denoted with dark coloring.
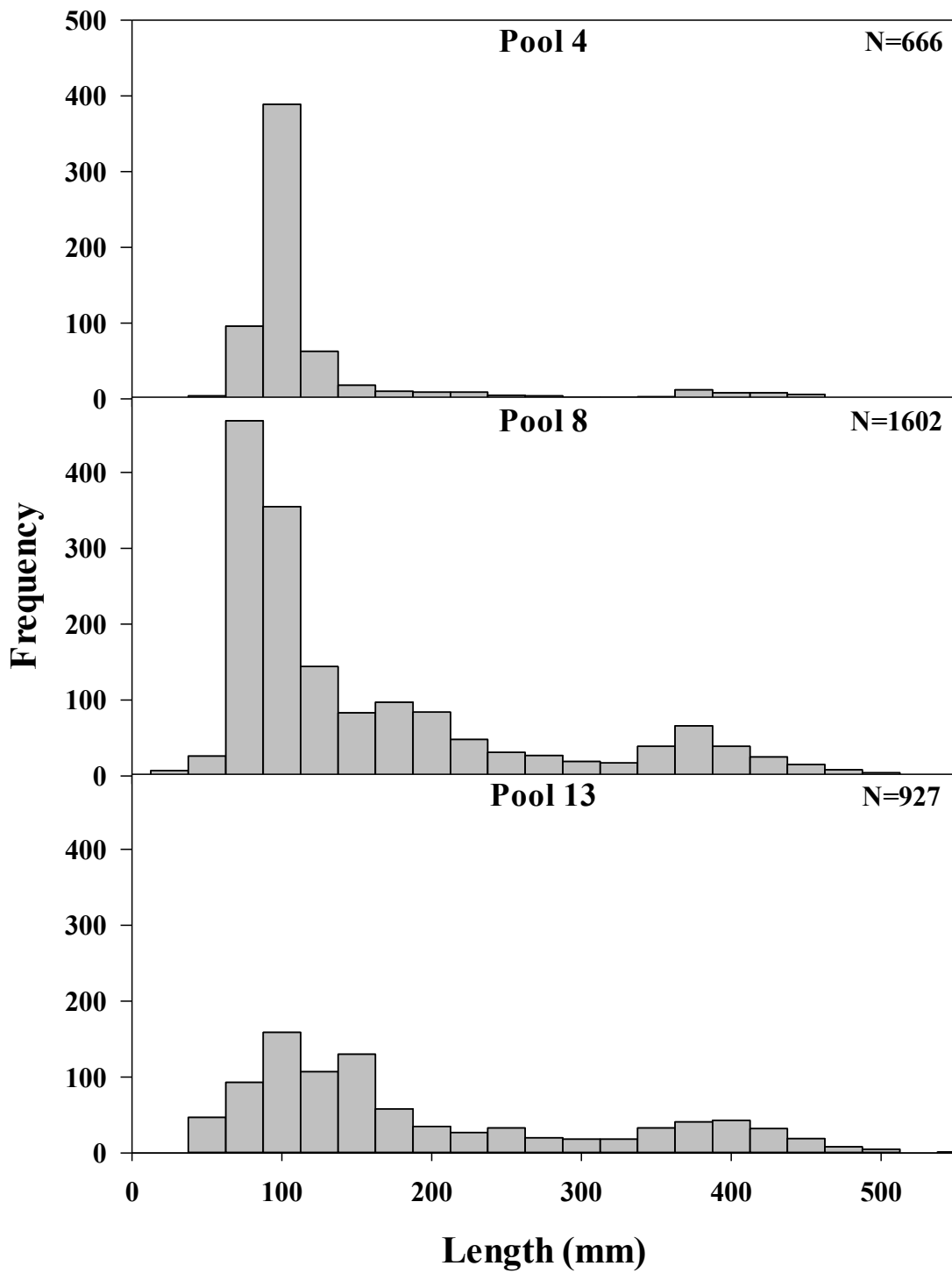
Figure 2. Largemouth Bass TL (mm) frequency distribution from each study pool from 2019-2020. Fish were captured via daytime electrofishing conducted by LTRM.
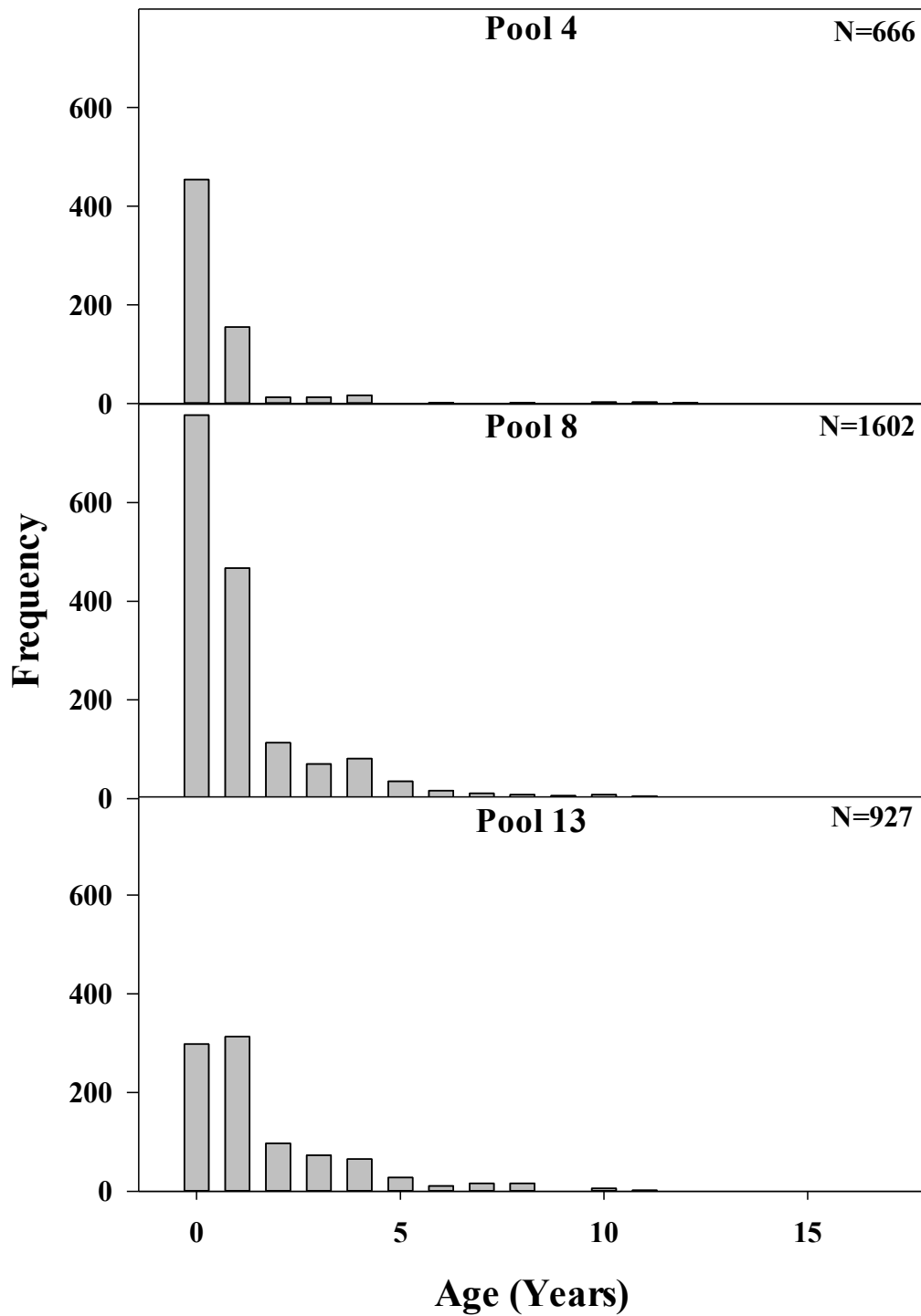
Figure 3. Largemouth Bass age frequency distributions from each study pool from 2019-2020. Fish were captured via daytime electrofishing conducted by LTRM.
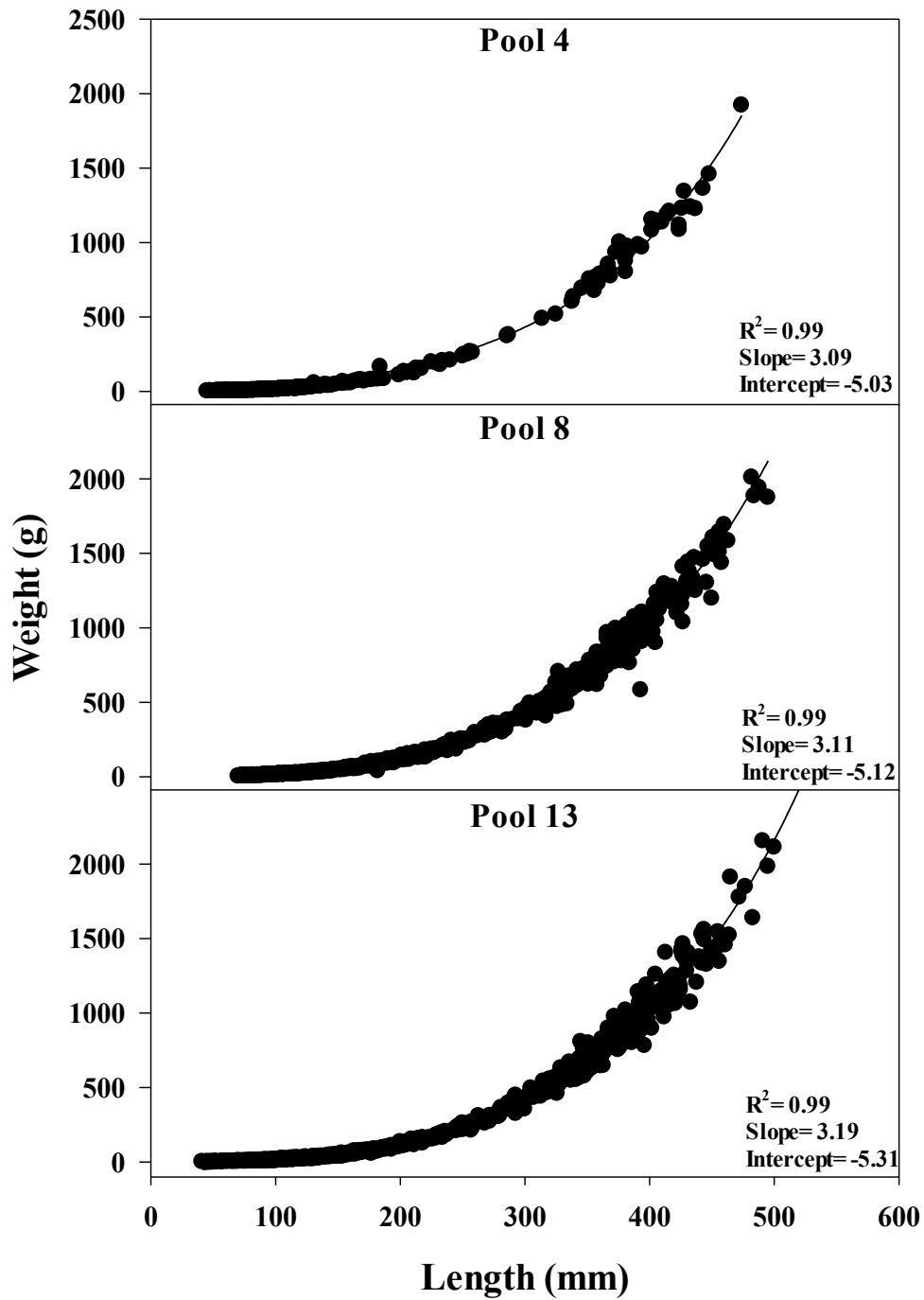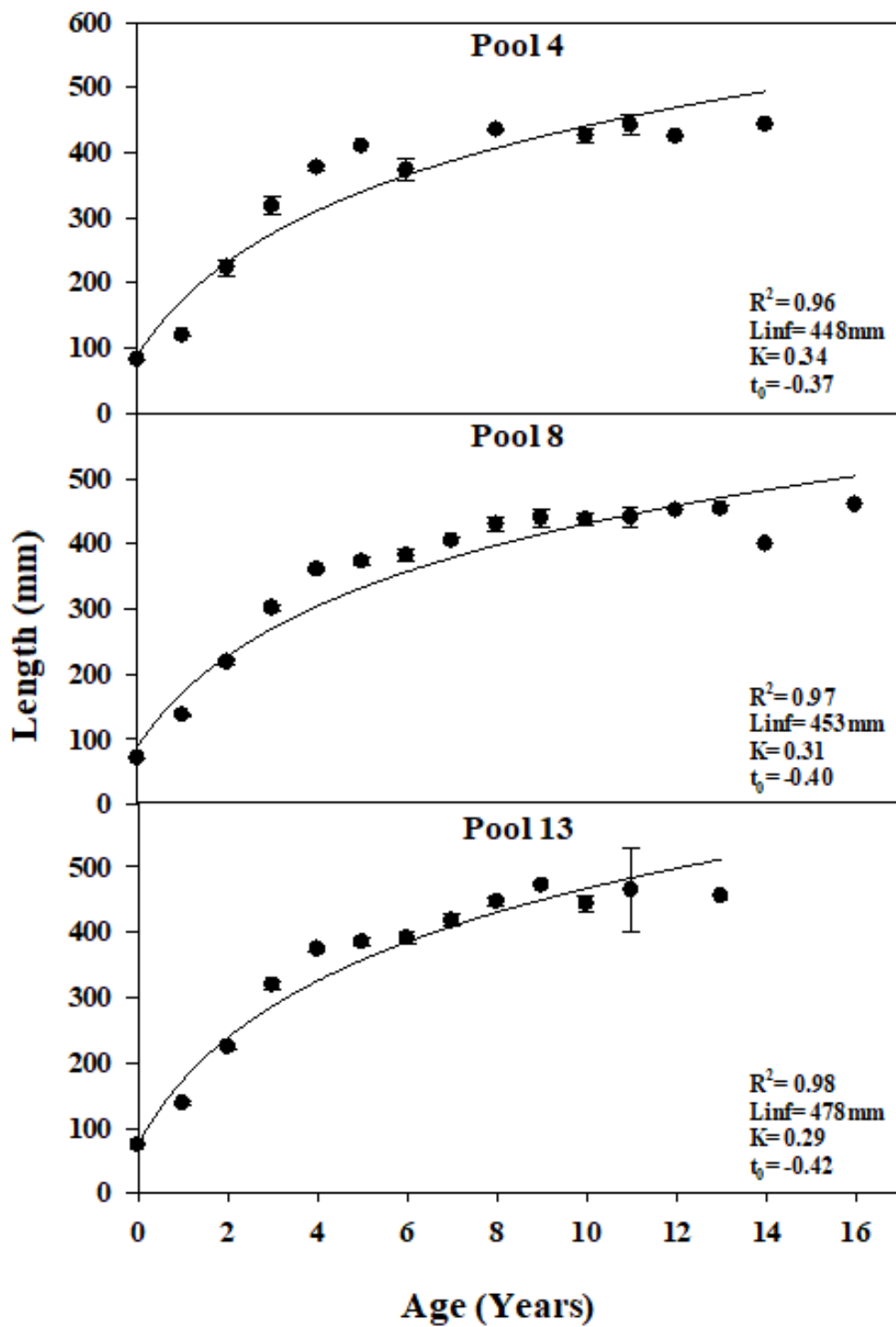
Figure 4. Weight-length distributions of Largemouth Bass from each study pool from 2019-2020. Fish were captured via daytime electrofishing conducted by LTRM.

Figure 5. Von Bertalanffy growth curves of Largemouth Bass from each study pool from 2019-2020 via daytime electrofishing conducted by LTRM; Linf is the theoretical maximum length, K is the Brody growth coefficient, and t_0 is the theoretical age at length 0.
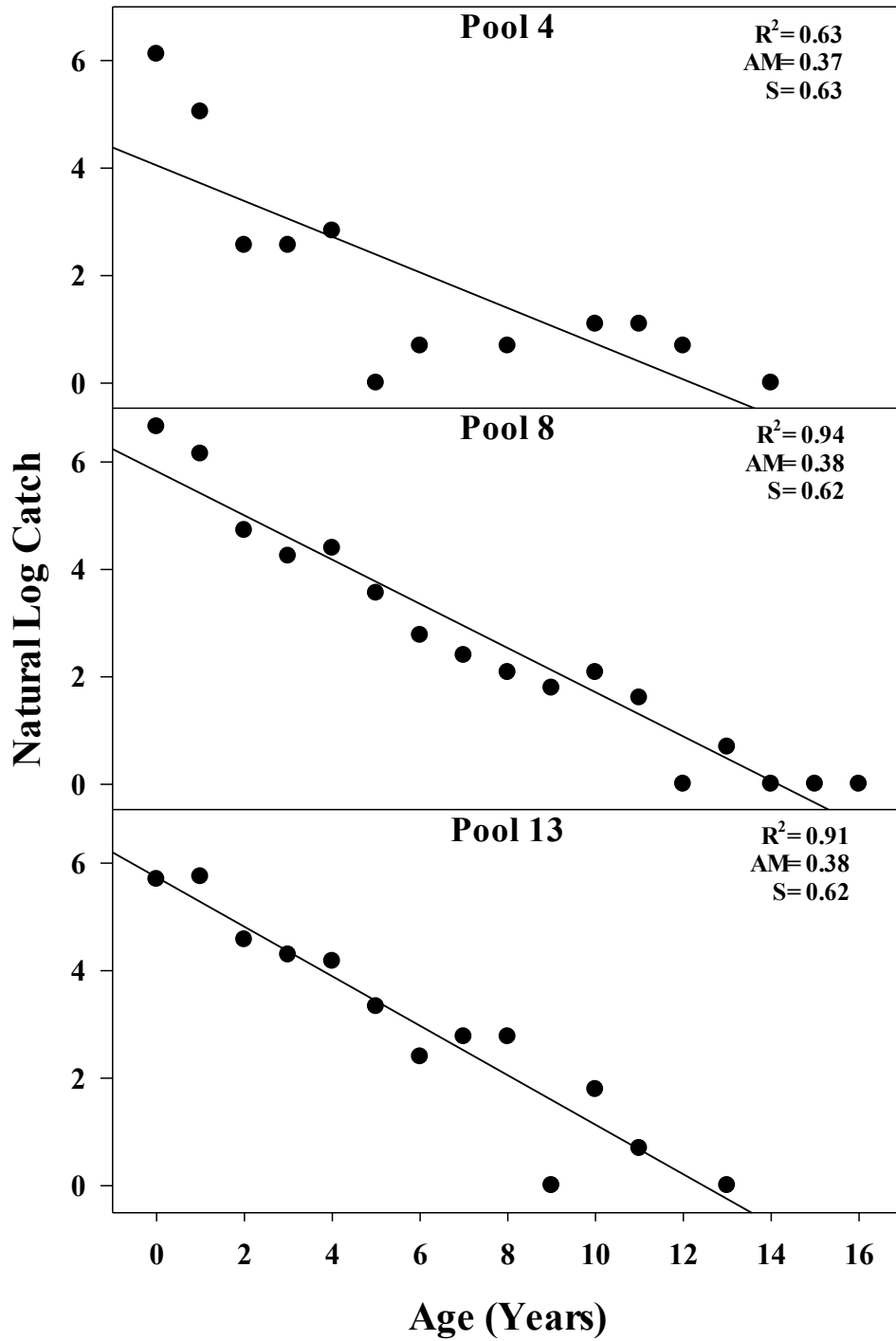
Figure 6. Catch curve mortality estimates of Largemouth Bass from each study pool from 2019-2020 captured via daytime electrofishing conducted by LTRM; AM is the total annual mortality and S is the total annual survival.
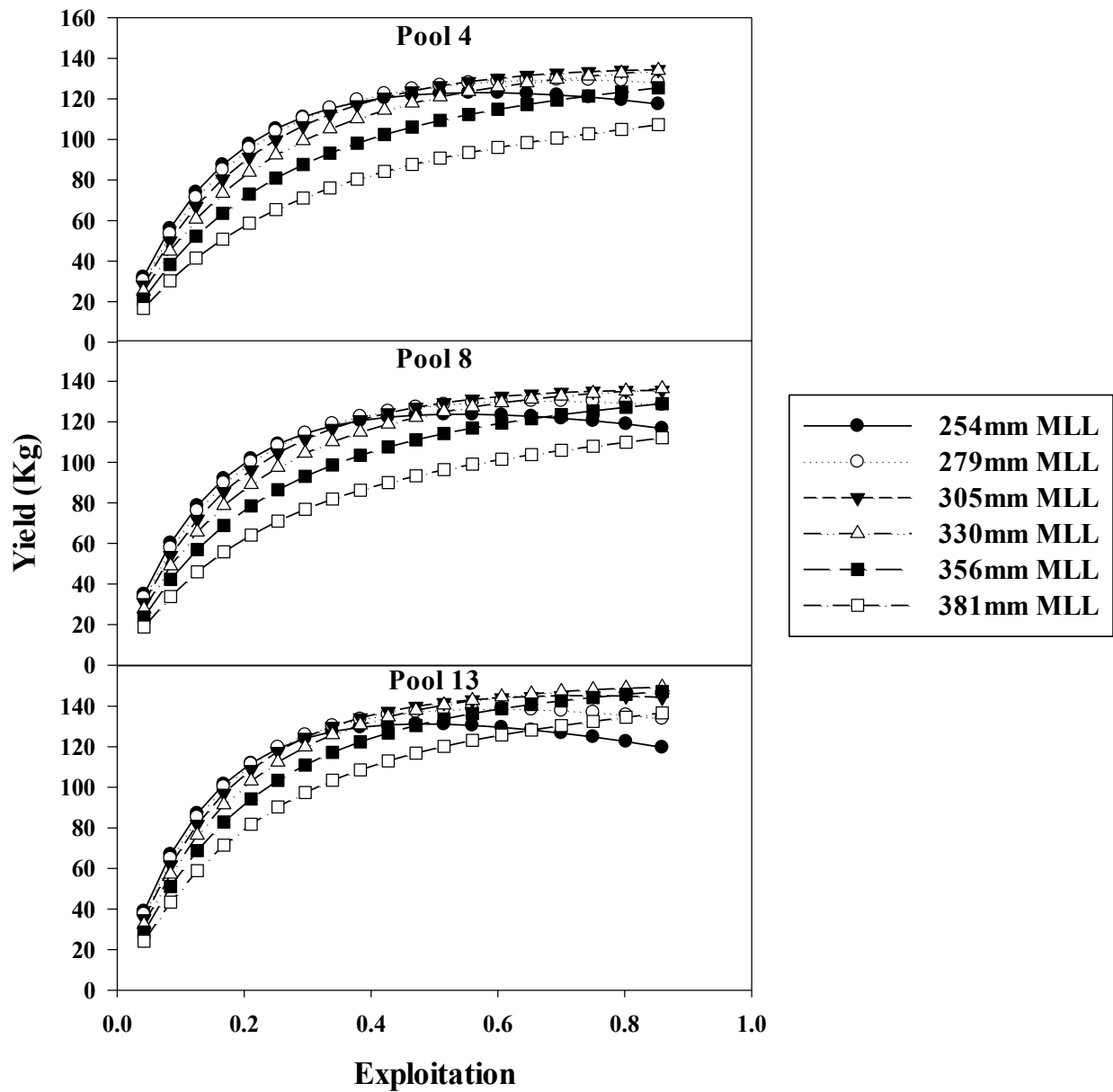
Figure 7. Yield-per-recruit models based on theoretical cohorts of 1,000 fish for each study pool from 2019-2020. Fish were captured via daytime electrofishing conducted by LTRM. MLL = minimum length limit.
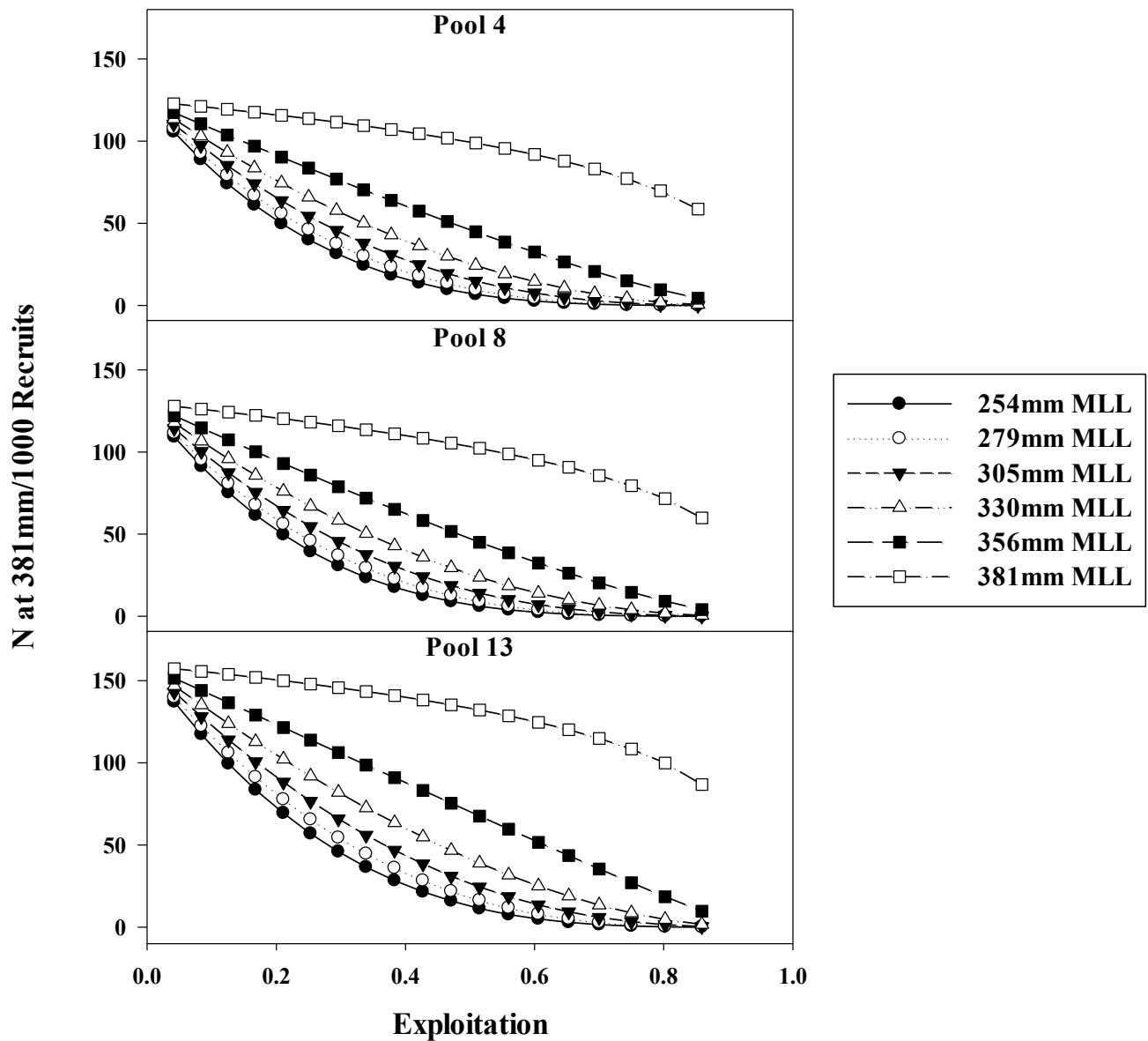
Figure 8. The number of preferred-size (381 mm) Largemouth Bass under varying minimum length limits (MLL) for each study pool using theoretical cohorts of 1,000 fish. Fish were captured via daytime electrofishing conducted by LTRM.
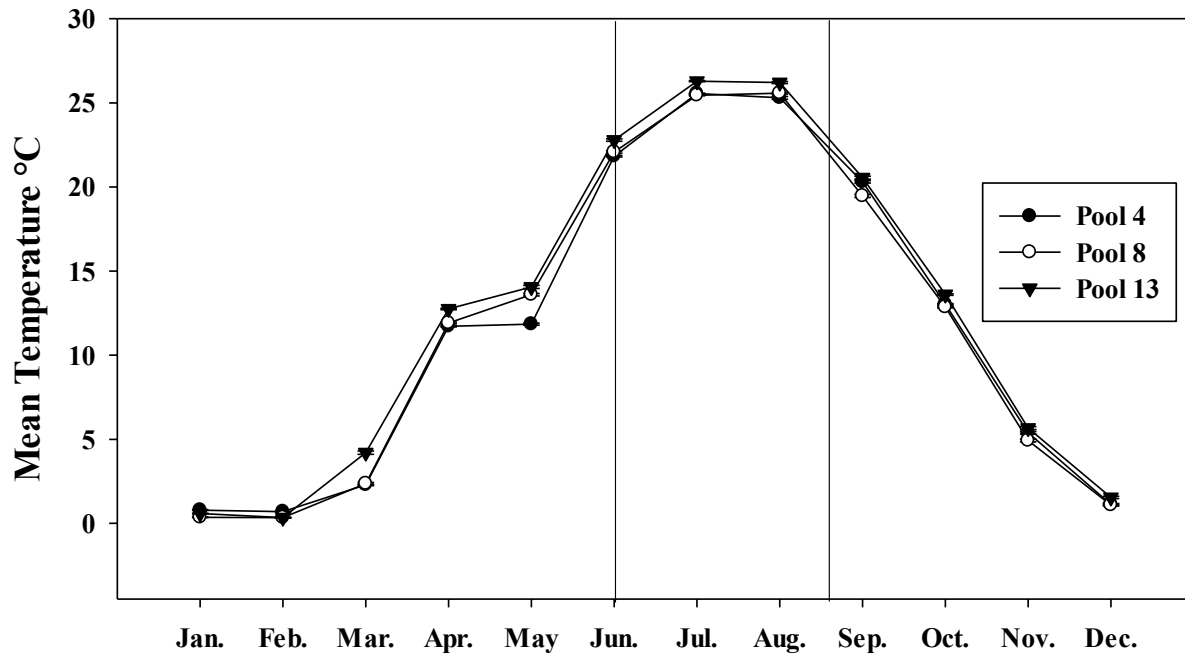
Figure 9. Mean annual water temperature of pools 4, 8, and 13 of the UMR from 1993–2020. Vertical lines depict the Largemouth Bass window of optimal growth in these three pools.

Missouri State
U N I V E R S I T Y

January 28, 2022

RE: IACUC Waiver

Dear Kylie Sterling,

Regarding the recently submitted waiver request from Dr. Quinton Phelps entitled, "Investigating Vital Rates of Upper Mississippi River Fishes", for work conducted in previous semesters, while the committee is unable to approve this retroactively, in reviewing the request, it has been determined that the nature of the work would not have warranted an approved protocol.

Therefore, while the IACUC cannot officially approve the waiver request, we can confirm that permission to conduct the research was not required.

Sincerely,

Brian Greene

Chair,
The IACUC Committee