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## Population Characteristics of Three Black Bass Species in the Upper Ohio River Drainage

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**POPULATION CHARACTERISTICS OF THREE BLACK BASS SPECIES IN THE  
UPPER OHIO RIVER DRAINAGE**

**Levi F. Brown**

**A thesis submitted to the  
Davis College of Agriculture, Natural Resources, and Design  
At West Virginia University**

**In partial fulfillment for the degree of**

**Master of Science**

**in**

**Wildlife and Fisheries Resources**

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**Division of Forestry and Natural Resources**

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## ABSTRACT

### **Population characteristics of black bass species in West Virginia's large, navigable river systems**

Levi F. Brown

This thesis describes the population characteristics of Largemouth (*Micropterus salmoides*), Smallmouth (*M. dolomieu*), and Spotted Bass (*M. punctulatus*) in West Virginia's navigable river systems: the Kanawha, Monongahela, and Ohio rivers. The first chapter serves as an introduction to the study, remarking on the biology, ecology, and life history of black bass *Micropterus spp.*, with emphasis on the species found in West Virginia, in addition to describing the large river systems of West Virginia and recreational fishing and management in general. The second chapter describes the size structure, age, growth, and mortality of the black bass species in each of the study systems. Lastly, the third chapter examines the simulated effects of different length-limit scenarios on Largemouth and Smallmouth bass fishery yield and size structure using yield-per-recruit modeling.

In West Virginia, species of black bass are economically and ecologically important and support popular fisheries. In the state's large, navigable river systems, however, recent information suggests that anglers consider these fisheries diminished relative to their historic stocks. This study sought to describe the population characteristics of Largemouth, Smallmouth, and Spotted Bass in the upper Ohio River drainage. A sample of 2,380 black bass were collected in fall 2019, spring 2020, and fall 2020, with 1,739 individuals retained for aging. Low relative abundances coupled with poor growth estimates for Largemouth and Spotted Bass suggests that a suite of environmental and anthropogenic factors may be reducing the quality of their recreational fisheries. Conversely, estimates produced for Smallmouth Bass are average relative to rangewide estimates, suggesting that this species may be better suited for these habitats. This study provides a unique opportunity to study three, sympatric black bass species in navigable rivers of central Appalachia and will help inform regional fisheries managers. Future research should be aimed towards determining the factors contributing to the perceived reduced quality of black bass fisheries in the upper Ohio River drainage.

Currently, the only minimum length limit (MLL) for these systems exists on the Ohio River (12" MLL); however, a contemporary evaluation of this regulation regarding its effectiveness has yet to be conducted. In order to evaluate current length limit regulations, length, weight, and age information were collected from Smallmouth and Largemouth Bass in 2019 and 2020 from these rivers. These data were integrated into yield-per-recruit models to assess the impacts of growth overfishing under varying rates of exploitation and across several common length-limits: no MLL, 10", 12" and 14". Data suggests that both Largemouth and Smallmouth fisheries in these systems are at risk when no length-limit is present, while yield is generally maximized under a 305-mm (12") MLL under moderate rates (0.1-0.4) of conditional fishing mortality. Results from this study should be taken into consideration when enacting future length-limit regulations in these systems, although more precise estimates of mortality for Largemouth and Smallmouth Bass should be collected first.

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## ***Chapter 1: Introduction and Literature Review***

### **West Virginia's Navigable River Systems: the Ohio, Kanawha, and Monongahela Rivers**

Throughout the world and in North America especially, large river systems have been highly altered by humans for flow regulation and rarely resemble their natural states (Dynesius and Nilsson 1994). One such system, the Ohio River, has been heavily influenced by human activity along its 1,579-kilometer (981 mi.) course from Pittsburgh, PA to its confluence with the Mississippi River in Cairo, IL. Along the way, it drains approximately 528,360 km<sup>2</sup> (204,000 mi<sup>2</sup>), an area that contains nearly 10% of the entire US population (Applegate et al. 2007). Two of its major tributaries, the Monongahela and Kanawha rivers, have also been modified by locks and dams, affecting their combined 31,540 km<sup>2</sup> drainage (Paukert and Galat 2010). These systems are vital natural resources in Central Appalachia and the Midwest, as the Ohio River alone provides drinking water to roughly 5 million people (Ohio River Valley Sanitation Commission [ORSANCO] 2017). On top of their role as water supplies, these rivers also hold high recreational value, as Duda et al. (2009) estimated that over 3 million people kayak, swim, dive, and participate in other forms of outdoor recreation on the Ohio River each year. Ecologically speaking, the Ohio River basin is home to more species of fishes, freshwater mussels, and crayfishes than any other river drainage in the United States, including the highest number of endangered species (White et al. 2005).

In addition to their ecological and recreational value, these three systems are economic corridors from Central Appalachia to the Mississippi River. In order to allow for commerce, each system has been heavily modified in the past by a series of locks and dams to allow for large vessel navigation and are deemed “navigable rivers”. According to the U.S. Army Corps of Engineers, inland navigable waterways are defined as waters of the United States that at some point in the past, present, or future, have been used or have the potential to be used for the

transport of interstate or foreign commerce (U.S. Department of the Army Civilian (USDAC) 2014). The determination of navigability for rivers relies upon the physical capability for large vessels, such as barges, to utilize the system. For the three aforementioned rivers, navigability has been achieved through a system of locks and dams, maintained by the U.S. Army Corps of Engineers, that control the water at constant levels to allow for large vessels to pass upstream, creating distinct “pools” that are named after their downstream lock and dam. Historically, these rivers have been managed for commerce to maintain a minimum navigable channel of nine feet (2.74 meters). Each year, approximately 250 million tons of cargo are transported along the navigable waterway (Emery et al. 2003), so economic importance dictates that these systems be managed first and foremost for their roles in commerce.

Due to anthropogenic alteration to achieve navigability, these rivers have unique stressors, such as channel homogenization and artificial water level management, that may influence the quality of the fishery and affect species inhabiting these systems. Habitat loss occurs as channelization eliminates side-channels and decreases backwaters, leading to lower overall habitat diversity (Niles and Hartman 2009). Argent and Kimmel (2011) suggested that serial lock and dam facilities can also disrupt individual movement and affect fish communities. Surveys on the Allegheny River, which joins with the Monongahela River to form the Ohio River, revealed dissimilar fish communities above and below lock and dam facilities. Conversely, similar fish assemblages were found throughout the Monongahela River, which experiences double the yearly lockages of the Allegheny, suggesting that idle lock facilities further disconnect fish communities. Lacustrine conditions created behind each dam also act to disrupt riverine communities and lead to serial discontinuities regarding fish assemblages in navigable rivers (Miranda and Dembkowski 2016). The intensity of navigation on river systems

can also have detrimental effects on fish populations, as increases in the number of sport boats, passenger boats, and cargo ship have been shown to decrease species richness in navigable waterways as well as decrease juvenile fish abundances (Zajicek and Wolter 2019; Schludermann et al. 2013). Wakes produced from large vessels also have the potential to strand larval fishes (Adams et al. 1999) as well as the ability to contribute to shoreline habitat degradation through erosion (Bilkovic et al. 2019). Despite these additional stressors, dams can benefit riverine fisheries, as downstream tailwater habitat provides aquatic species with important spawning areas and thermal refugia during critical summer periods; the congregation of fish in these areas make them popular fishing destinations for anglers (Sammons et al. 2021). Though they are highly altered and no longer resemble their natural states, the navigable river systems of West Virginia remain highly diverse aquatic ecosystems that boast high economic and recreational value.

### **Biology, Ecology, and Life History of Black Bass *Micropterus spp.***

One group of endemic species that helps to shape fish communities of the Ohio River and its tributaries are the black basses, which not only boast high economic value as sport fishes but can also be considered keystone species for their role as a top aquatic predator (Birdsong et al. 2015). Black bass are a group of centrarchid fishes in the genus *Micropterus* that were first described in North America by B. G. E. Lacépède in 1802 (Kassler et al. 2002). Interestingly, the name *Micropterus*, which translates to “small fin”, was given to the genus by Lacépède after observing a Smallmouth Bass specimen with a torn dorsal fin (Taylor et al. 2019). Since description, the phylogenetic classification of the genus has been debated, though advances in molecular genetics, meristics, and morphometry have contributed to the description and classification of nine taxonomic forms since 1998 (Brewer and Long 2015; Long et al. 2015).

Currently, there are seventeen species, one subspecies, and one genetically distinct lineage recognized within *Micropterus* (Taylor et al. 2019).

Despite the diversity within *Micropterus*, there are certain physical traits that are typical of all black basses. Morphologically, black bass have an elongate yet slightly compressed form with large mouths, maxilla that extend at least to the center of the eye olive-yellow fins, ctenoid scales, and an elongate dorsal fin that is two connected sections of spines and rays (Warren 2009). Originally, black basses were found in both lentic and lotic habitats throughout the United States and Canada east of the Rocky Mountains, but populations have been established in South America, Europe, Asia, and Africa through artificial stocking events, leading to their status as invasive species in certain areas (Van Der Walt 2016). Although certain species have restricted ranges and may be considered habitat specialists, such as the Redeye Bass *M. coosae* and Guadalupe Bass *M. treculii*, which are typically designated as stream specialists (Leitner and Earley 2015; Curtis et al 2015), other species are fairly adaptable and able to inhabit a broad range of habitats (Shaw 2015). Generally, species with more restricted ranges are derived forms of other members of the same genus with general ecological preferences or requirements, such as the Alabama Bass *M. henshalli*, a recently elevated species confined to the Mobile River watershed in Alabama that was once thought to be a subspecies of Spotted Bass *M. punctulatus* (Rider and Maceina 2015).

In terms of reproduction, *Micropterus* species typically spawn in the spring after water temperatures have risen between 15 to 25° C (Carlander 1977). As primary piscivores, reproduction for black basses must be timed so that offspring have ample time to develop before taking advantage of the seasonal patterns of prey fish emergence, leading to a one-month window of time where most reproduction occurs (Aday et al. 2009). Although the shortened

spawning season encourages development of larvae, it also allows for abiotic conditions, such as sudden shifts in water temperature or flow, to have extremely detrimental effects across an entire year-class (Parkos and Wahl 2002). Black bass have developed reproductive strategies that emphasize quality over quantity when it comes to offspring, with a high premium on parental care. Males establish territories, construct nests, and if successful, fan and guard the eggs from nest predators, including cannibalistic basses and other members of Centrarchidae (Post et al. 1998). Larval black basses begin exogenous feeding on zooplanktons following yolk-sac depletion, followed by a switch to feeding on littoral macroinvertebrates, and finally the onset to piscivory occurs between age-1 and age-2 in most species (Devries et al 2009).

The shift to piscivory is a critical period for black basses, as studies have shown that juvenile growth rate is important for first-year survival (Ludson and DeVries 1997) and piscivorous young-of-year appear to grow faster than their invertebrate-feeding counterparts (Olson 1996). However, some species of black bass exhibit more opportunistic foraging strategies rather than strict piscivorous diets. Smallmouth Bass *M. dolomieu* in small streams, for example, consume large proportions of crayfish, which may make up nearly 50% of their overall diet (Rabeni 1992; Roell and Orth 1993). This species has developed unique behaviors, such as suction, that make them ideal benthic predators relative to other congenics, allowing them to remain deeper in the water column (Rankin 1986; Winemiller and Taylor 1987). Largemouth Bass *M. salmoides* are another black bass species that exhibits opportunistic foraging behaviors, with only gape-related limitations to their prey selectivity (Hambright 1991). Typically, black bass species are categorized as visual predators relying on their sight to identify prey, but they also utilize their sense of smell and vibrations detected by their lateral lines to forage as well (Claussen 2015). As such, species such as Spotted Bass feed primarily in daylight but have been

observed feeding at all hours (Churchill and Bettoli 2015); species such as Largemouth tend to feed most often at dawn and dusk (Claussen 2015).

In West Virginia, anglers can target three of the most popular black bass species: Largemouth, Smallmouth, and Spotted Bass. Although Largemouth Bass tend to prefer more lentic environments, such as lakes, ponds, and reservoirs (Stuber et al. 1982), all three species have broad habitat tolerances and can thrive in a variety of habitats, such as large river systems like the Ohio River (Shaw 2015). Within large river systems, these black bass species benefit from the matrix of pool and run habitat that rivers provide. There is still some habitat partitioning among members of *Micropterus*, though, as Smallmouth Bass prefer cooler, rockier, and better-oxygenated portions of these river systems (Brewer and Orth 2015), while Largemouth Bass thrive in warmer, eutrophic backwaters with plenty of submerged aquatic vegetation (Claussen 2015); Spotted Bass seem to occupy habitat that is intermediate between their congeners (Churchill and Bettoli 2015). Although all three species are well-studied, regional gaps in the literature exist regarding their population characteristics in Central Appalachia and more generally in large, impounded river systems. Additionally, anecdotal angler information suggests that their populations have become diminished relative to their historic stocks.

### **Freshwater Recreational & Tournament Angling**

Recreational angling is both an economically and culturally important activity in the United States and is arguably the single most profitable component of the outdoor recreation industry in North America (American Sportfishing Association [ASA] 2015). The U.S. Fish and Wildlife Service (2016) estimates 30 million anglers fish freshwater systems each year, excluding the Great Lakes, combining to spend \$27.5 billion annually in fishing-related expenses. Estimates also show the number of anglers in the U.S. has increased by approximately



8% from 2011 to 2016, while the population of hunters decreased by 16% in the same time span, suggesting a positive trend for the freshwater angling economy relative to other industries in wildlife-related recreation. With the financial potential that recreational angling offers, it is important for federal, state, and local agencies to work alongside stakeholders to ensure healthy fisheries for posterity and conserve a highly utilized resource.

States such as West Virginia benefit immensely from the economic input of recreational angling. Each year, over 300,000 people purchase a license to fish in the state and combine to add approximately \$429 million to the state economy (U.S. Fish & Wildlife Service [USFWS] 2011). Although the state offers fishing opportunities in headwater streams and reservoirs, most anglers prefer to fish in larger river systems such as the Ohio and Kanawha River (Duda et al. 2005). According to Wellman and Smith (2020), 93% of all catfish and 28% of all bass tournaments in West Virginia during 2020 were located on either the Kanawha, Monongahela, or Ohio rivers. Across all of West Virginia's fisheries, including the three aforementioned rivers, the four most-targeted species or groups of species in the state were trout, panfish, catfish, and black bass (USFWS 2011). Of those species, West Virginia anglers target black bass the most (43% of all anglers) and spent a disproportionate amount of time fishing (58% of all angler hours) for the three species (USFWS 2011). Additionally, the majority of fishing tournaments in West Virginia are geared towards targeting black bass. In 2020, 511 fishing tournaments were held in the state and of those, 466 were held targeting black bass (Wellman and Smith 2020). Black bass tournaments on West Virginia's navigable rivers comprised roughly 27% (n = 129) of all bass tournaments held within the state, second only to the number of tournaments held on reservoir fisheries (n = 267).

Recently, catch-and-release fishing has become common practice among recreational fishers, with a high proportion of anglers choosing to release their fish rather than harvest them (Taylor et al. 2019; Sass and Shaw 2020). Pope and Wilde (2004) attributed the shift to fisheries regulations (e.g., restrictive length limits, creel limits) imposed by managers to conserve the fishing viability of populations in the face of increased fishing pressure, as well as the angler perception that catch-and-release fishing maintains fishery quality via decreasing harvest. One major assumption of catch-and-release fishing is that the released fish will survive the angling event; the reality, however, is that released fish experience a multitude of sublethal stressors from angling events and may experience mortality some time afterwards, leading to the assumption that catch-and-release mortality is negligible (Cooke and Suski 2005). The effects of catch-and-release angling have been well-documented for black bass species, as they remain popular targets for amateur anglers and tournament fishers alike. Tournament fishing typically includes additional stressors relative to recreation angling, such as retention in a livewell prior to weigh-in, leading to longer periods of stress (Siepker et al. 2007). Recognized anthropogenic factors that can influence catch-and-release mortality rates include gear type, hooking location (e.g., foul-hooking), the duration of play, angler experience, and the techniques used during handling and release (Bartholomew and Bohnsack 2005). Environmental conditions also play an important part in determining the impacts of angling, as increased water temperature has been shown to coincide with increased injury and mortality of Smallmouth Bass post-angling and during retention (Cooke and Hogle 2000).

Recent studies have also begun to explore the impacts of angling on the tertiary stress response of black basses and how it may impact dynamic rates such as growth, survival, and recruitment (Long et al. 2015). Spring and early summer is a popular time to fish for black bass,

as nest-guarding males can be easily targeted. Removal of males during nest-guarding leaves eggs vulnerable to predation from other species such as Round Goby *Neogobius melanostomus*, which rarely predate on guarded nests but have been estimated to consume all eggs from an unguarded nest in roughly fifteen minutes (Steinhart et al. 2004). Catch-and-release angling can also affect the reproductive success of individuals, as Largemouth Bass subjected to stress similar to what would be experienced during an angling event tended to produce smaller offspring with later swim-up dates (Ostrand et al. 2004). Though certain studies show there is little evidence to suggest that angling has a negative impact on Largemouth Bass growth and weight gain (Cline et al. 2012; Pope and Wilde 2004), Clapp and Clark (1989) noted a negative relationship between Smallmouth Bass growth rate and capture frequency. To compound issues related to angling-induced stress, Phillip et al. (2009) found evidence to suggest that Largemouth Bass that were more likely to be caught by anglers can pass on their vulnerability to angling, a trait that appears to be more correlated with individuals that tended to produce significantly more offspring (Sutter et al. 2015).

### **Black Bass Management**

As a public resource with high economic value, black bass fisheries are highly scrutinized by their stakeholders (e.g., anglers, fishing guides) due to their perceived viability or “trophy” output, leading to push for population management. It can be argued that no other inland fishery has pushed the management paradigm like black bass fisheries, leading to the advancement of many novel management strategies (Taylor et al. 2019). Up until the 1920’s, black bass species were prized not for sport as they are today, but for their commercial value as food fishes (Long et al 2015). This mentality led to many black bass populations being overfished and facing extirpation, which lead Congress to pass the Black Bass Act in 1926, a piece of legislation

modeled after the Lacey Act that attempted to curb the transport of harvested black bass across state lines (Nielsen 1999; Merritt 2012; Long et al. 2015). In response to the Great Depression, new public works projects were developed to combat unemployment, including some specifically targeting water infrastructure. Two pieces of legislation specifically, the Tennessee Valley Authority (TVA) Act of 1933 and the Flood Control Act of 1936, sought to reduce flooding and improve inland waterway navigation through the construction of dams (Long et al. 2015), but also inadvertently increased lentic habitat (i.e., reservoirs) that quickly supported nearly 25% of all freshwater recreational angling by 1965 (Jenkins 1970). In addition to the nearly 100-fold increase in farm ponds following the Dust Bowl (Swingle 1970), these newly created fisheries became ideal for black bass, leading to advancements in their propagation, management, and changes to angling regulations surrounding their fisheries.

As angling opportunities increased for black bass nationwide, regulation and management of these bolstering fisheries soon came to the forefront state management agencies' agendas. As black bass fishing increased in popularity, evidence suggested that overfishing, due in part to liberal regulations, had diminished the black bass fisheries nationwide (Fox 1975). Fishing mortality seemed to be a large factor in this, as it wasn't unusual for exploitation rates to exceed 40% in individual fisheries (Redmond 1974), which Allen et al. (2008) suggested is high enough to severely truncate both age and size structure within a bass population. To alleviate this, management agencies implemented a variety of regulatory actions to combat overharvest, including creel limits, closed seasons, and enacting or altering length limits, which were non-existent in nearly 34 states as of 1974 (Fox 1975). These newly adopted regulations also coincided with a change in angler behavior, with professional organizations such as the Bass Angler Sportsman Society (B.A.S.S.) adopting a catch-and-release format for their tournaments

as early as 1972 (Long et al. 2015); Myers et al. (2008) also saw an increase in recreational catch-and-release fishing in select lakes from 20-40% in the 1970's to nearly 90% by the early 2000's.

New descriptive management techniques were also developed to quantify and compare the quality of bass fisheries and individual bass within them. Wege and Anderson (1978) introduced relative weight as a means for assessing Largemouth Bass condition, a metric that was intended to make condition standardized and comparable between populations and has been expanded to include several other fish species (Blackwell et al. 2000). Johnson and Anderson (1974) developed metrics to assess Largemouth Bass and Bluegill *Lepomis macrochirus* size-structure using length-frequency data; this method would be further refined through the years into what is now known as proportional size distribution (PSD), a size-structure metric that is used to compare populations of a variety of fishes to one another throughout their ranges (Gabelhouse 1984; Guy et al. 2007). Currently, these metrics are still widely used by fisheries managers to assess black bass stocks and inform management decisions. However, metrics and models are only as good as the information you put into them, making it important to continue to collect length, abundance, weight, and growth data from populations who have yet to be assessed, or to update knowledge on populations that have been assessed in the past.

### **Thesis Objectives**

The goal of this thesis is to provide baseline demographic information from populations of Largemouth, Smallmouth, and Spotted Bass inhabiting West Virginia's navigable river systems. Information collected from these species on the Monongahela, Kanawha, and Ohio rivers will fill in gaps in the regional knowledge, allow for study of these species in relatively understudied systems (large, impounded rivers), and help guide future management decisions for

black bass. Specific objectives include: 1) collecting length-stratified samples of all three species from the upper Ohio River drainage; 2) utilizing age, length and weight data to estimate population characteristic (sex ratio, size structure, etc.) and dynamic rate (growth, mortality) information; and 3) incorporate estimates in different length-limit scenarios in yield-per-recruit simulations in order to quantify the effects of altering minimum length limits in these systems.

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## ***Chapter 2: Population Characteristics of Black Bass Species in the Upper Ohio River Drainage***

### **ABSTRACT**

In West Virginia, navigable river systems provide unique fishing opportunities for some of the most important game species, including black bass *Micropterus spp.* Anecdotal angler information suggests that black bass fisheries in the Ohio, Kanawha, and Monongahela rivers have diminished relative to historic stocks. To ensure the conservation of this fishery, this study sought to establish baseline fishery characteristic information for each of the three black bass species residing in these systems. Largemouth *M. salmoides*, Smallmouth *M. dolomieu.*, and Spotted Bass *M. punctulatus* were sampled using boat electrofishing surveys in 2019 and 2020. Somatic measurements were used along with age information collected from sagittal otoliths to produce estimates for size structure, condition, mortality, and growth for each species on each river. Data from 2,380 black bass were collected, with age information collected from 731 Largemouth, 641 Smallmouth, and 367 Spotted Bass. Low relative abundances coupled with poor growth estimates for Largemouth and Spotted Bass suggests that a suite of environmental and anthropogenic factors may be reducing the quality of their recreational fisheries. Conversely, estimates produced for Smallmouth Bass are average relative to range-wide estimates, suggesting that this species may be better suited for these habitats. This study provides a unique opportunity to study three, sympatric black bass species in navigable rivers of central Appalachia and will help inform regional fisheries managers. Future research should be aimed towards determining the factors contributing to the perceived reduced quality of black bass fisheries in West Virginia's navigable river systems.

## INTRODUCTION

Recreational angling is an economically and culturally important activity that is considered the single most profitable component of the outdoor recreation industry in North America (ASA 2015). The U.S. Fish and Wildlife Service (USFWS) estimates 30 million anglers fish freshwater systems (excluding the Great Lakes) each year, combining to spend \$27.5 billion annually in fishing-related expenses (USFWS 2016). Estimates also show the number of anglers in the U.S. has increased by approximately 8% from 2011 to 2016, while the population of hunters decreased by 16% in the same time span, suggesting a positive trend for the fishing economy relative to other industries in wildlife-related recreation. With the financial potential that recreational angling offers, it is important for federal, state, and local agencies to work alongside stakeholders to ensure healthy fisheries for posterity and conserve a highly utilized resource.

States such as West Virginia benefit immensely from the economic input of recreational angling. Each year, over 300,000 people purchase a license to fish in the state and combine to add approximately \$429 million to the state economy (USFWS 2011). Although the state offers fishing opportunities in headwater streams, lakes, ponds, and reservoirs, most anglers prefer to fish in larger river systems such as the Ohio and Kanawha River (Duda et al. 2005). The four most-targeted species or groups of species in the state are trout, panfish, catfish, and black bass (USFWS 2011). Of those species, West Virginia anglers fish for black bass the most (43%) and spend a disproportionate amount of time (58% of all angler hours) targeting the three native species (USFWS 2011).

When considering freshwater fishing in North America, no other recreational fishery surpasses the economic scale of black bass fishing, as Largemouth Bass *Micropterus salmoides*

and Smallmouth Bass *Micropterus dolomieu* are two of the most sought-after and valuable freshwater fish species (Cooke and Philipp 2009). The name “black bass” refers to species within the genus *Micropterus*, a group of centrarchid fishes. In addition to their economic value as sport fishes, black bass are also considered to be keystone species within their respective ecosystems due to their role as top predator species (Taylor et al. 2019). Recent shifts in angling culture have seen an increase in catch-and-release fishing with only mild harvest pressure on black bass in some systems (Long et al. 2015). Though harvest mortality is lower with black bass relative to other freshwater fishes, individuals can still experience indirect mortality from catch-and-release angling (Kerns et al. 2016) as well as lowered reproductive success because of male bass being removed from nest guarding during the spawning season (Hargrove et al. 2018).

In West Virginia, rivers and streams provide fishing opportunities for a variety of freshwater species, including black bass. Three rivers that are popular black bass fisheries, the Monongahela, Kanawha, and Ohio rivers, have been highly modified to allow for commercial boat traffic to travel upstream farther than the natural conditions would normally allow. Alteration to allow for commercial transport as well as the hydraulic forces resulting from large vessel traffic imparts unique stressors onto the fish community when compared to natural systems. In addition to the forces imparted upon the system by boat traffic, water level management within pools can affect recruitment of young-of-year. Kohler et al (1993) found that hatching success of Largemouth Bass in Illinois reservoirs was influenced by water level, as hatching success decreased during times of rapid water level fluctuation, and that hatching success was highest when water levels remained relatively stable. Since pools within navigable rivers are similar to reservoirs in the sense that water levels and flow are controlled by man-made structures, water management within these units undoubtedly affects the fisheries they sustain.

Fisheries management decisions have far reaching impacts, as angler satisfaction regarding a particular fishery directly influences fishing participation in an area, which can in turn affect local economies and small business owners (Allen and Hightower 2010). Due to this, it is imperative that management decisions are backed by sound science and that all available information pertaining to the affected species is collected before additional rules and regulations, which may affect average angler opinion and satisfaction, are put in place. Understanding the basic dynamic rates of a population, such as growth, mortality, and recruitment, can further justify the use of supplementary fishing regulations (e.g., length limits, seasonal closures, etc.) and inform biologists whether they will be effective *a priori*. For instance, Allen et al. (2002) found that minimum length limits for Largemouth Bass in Florida waters were only effective if growth in a given water body was relatively fast and natural mortality was low. In these situations, imposing a minimum length limit increased catch numbers and harvest potential for Largemouth Bass in their respective systems. Of the three study rivers that will be focused on in this project, only the Ohio River has length-based regulations (12-inch minimum length limit) for black bass species.

The focal species of this project, Largemouth Bass, Smallmouth Bass, and Spotted Bass *Micropterus punctulatus*, are all native to the Ohio River drainage in West Virginia and able to persist in a variety of aquatic systems, including lakes, reservoirs, rivers, and streams, although Largemouth and Smallmouth prefer lentic habitats (Stuber et al. 1982; Edwards et al. 1983; McMahon et al. 1984). These species represent popular target species of West Virginia anglers as well as ecologically important members of their respective fish communities. Recent anecdotal information suggests that anglers consider these black bass fisheries diminished relative to their historic stocks (Dave Wellman, personal communication), but biological



information has yet to confirm these claims. The high economic and ecological value of Black Bass fisheries in the state of West Virginia lend justification for studying the population characteristics of the three Black Bass species that inhabit the upper Ohio River drainage. This research seeks to describe population characteristics of these species in systems where they are understudied yet intrinsically important to their ecosystems in addition to local economies. By estimating baseline demographic rates for these populations, we hope to determine if alternative management strategies, such as supplemental stockings or length-limit regulations, could help ensure a robust fishery moving forward. Therefore, the objective for this chapter was to collect somatic (i.e., total length and weight) and age information from a length-stratified collection of Largemouth, Smallmouth, and Spotted Bass from West Virginia's navigable river systems. Using this information, demographic (sex ratio, size structure, condition, etc.) and dynamic rate (growth and mortality) estimates were produced in order to describe the populations of these three species in the river systems of interest.

## **METHODS**

### **Study Area**

The three rivers of interest in this study are the Monongahela, Kanawha, and Ohio rivers, with specific focus on navigable pools in West Virginia's jurisdiction (Fig. 1). The Ohio River, which flows 1,579 kilometers (981 mi.) from Pittsburgh, PA to Cairo, IL, where it empties into the Mississippi River, drains approximately 528,360 km<sup>2</sup> (204,000 mi<sup>2</sup>), an area that contains nearly 10% of the entire US population (ORSANCO 1994). The Ohio River and its tributaries are popular fishing destinations and are home to a diverse fish assemblage, as lock rotenone surveys from 1957 to 2001 yielded approximately 116 taxa across 19 families (Thomas et al. 2005). Two such major tributaries, the Monongahela and Kanawha rivers, run through the state

of West Virginia and drain a combined area of approximately 31,540 km<sup>2</sup> (19,600 mi<sup>2</sup>), with the entirety of the Kanawha River residing within the state (ORSANCO 1994).

These three systems have been heavily modified in the past to be made suitable for large vessel commerce and have been designated as “navigable”. According to the U.S. Army Corps of Engineers, inland navigable waterways are defined as waters of the United States that at some point in the past, present, or future, have been used or have the potential to be used for the transport of interstate or foreign commerce (USDAC 2014). The determination of navigability for rivers relies upon the physical capability for large vessels, such as barges, to utilize the system. For the three aforementioned rivers, navigability has been achieved through a system of locks and dams, maintained by the U.S. Army Corps of Engineers, that control the water at constant levels to allow for large vessels to pass upstream, creating distinct “pools” that are named after their downstream lock and dam. Historically, these rivers have been managed for commerce to maintain a minimum navigable channel of nine feet (2.74 meters). Due to anthropogenic alteration to achieve navigability, these rivers have unique stressors, such as channel homogenization and artificial water level management, that may influence the quality of the fishery.

Altogether, black bass were sampled from eight navigation pools on the Ohio River, three on the Monongahela River (MON), and two on the Kanawha River (KAN) (Table 1). The decision was made to split the Ohio River into an Upper (UOR) and Lower (LOR) reach based upon the results of a non-metric multidimensional scaling (NMDS) analysis, which showed a significant change in proportional catch numbers of black bass species above and below Willow Island Lock and Dam (Fig. S-1). This suggests that habitat composition might shift from the upper reaches of the Ohio relative to its downstream areas, as Xenakis (2005) noted that habitat

in the upper Ohio River is better suited for Smallmouth Bass due to a higher gradient and faster current, whereas downstream sections featured slower flows with higher proportions of slack water areas, which seem to be the preferred riverine habitat of Largemouth Bass. Thus, calculating population characteristics for populations of black bass in the upper portions of West Virginia's jurisdictional waters (upstream of Willow Island Lock and Dam) in addition to its downstream reaches may provide additional information relevant to the management of the three species in the Ohio River. Hereafter, each of the four study river segments will be referred to as reaches.

### **Fish Collection & Processing**

Black bass were collected from the four study reaches in order to gather length, weight, and age information that were applied to develop age-length keys as well as estimate relative abundance, growth, mortality, and other fisheries metrics. Sampling for black bass was conducted in conjunction with West Virginia Division of Natural Resources (WVDNR) and Ohio Department of Natural Resources (ODNR) fish community sampling. Fish were sampled using night-time, pulsed DC-mounted boat electrofishing, with crews consisting of two netters and the vessel operator. At each of the thirteen navigational pools, four to six sites were chosen that were representative of each river reach (e.g., tributary mouths, embayments, and dam tailwaters). At each site, sampling consisted of ten to fifteen-minute transects, with transect duration altered depending on the amount of sampleable habitat at each site. Our goal was to collect and retain at least 100 individuals of each black bass species from each study reach. Collections were stratified by 25-mm length bins, stratified from 50 to 525 mm total length with a goal of retaining five individuals in each length bin for aging. Primary black bass collections occurred between 25 September - 30 October 2019; and 30 September - 17 November 2020.

Supplemental sampling occurred in the spring of 2020 between 5 May - 28 May, with additional individuals collected as by-catch from ancillary WVDNR surveys. During Spring and Fall 2020 sampling, individuals that fell within a completed length bin were released after being weighed and measured.

After each electrofishing transect, individuals to be retained for aging were separated by species, placed in labelled bags which were placed on ice, and then frozen at the lab. In the lab, fish were thawed and individuals were given a unique ID, measured to the nearest mm total length, and weighed to the nearest tenth of a gram. Sagittal otoliths were then removed from the cranial cavity, cleaned of tissue, allowed to dry, and then stored in microcentrifuge tubes. Otoliths were then placed in labelled coin envelopes that also contained several scales collected from behind the left pectoral fin that served as ancillary aging structures in the case of disagreement when using otoliths.

To maximize information gained from collected individuals, digestive systems and genetic information were also collected for possible future analysis. An incision was made anterior to the vent that continued along the ventral side of the fish to the clavicle. From there, the gill arch was gripped and removed from the cavity, allowing for the intact removal of the esophagus, stomach, and remaining gastrointestinal (GI) tract to be preserved as one structure. GI tracts were then placed in appropriately sized Whirl-Paks and stored for future processing. In the process of GI tract removal, individuals were sexed based upon gonadal inspection. Lastly, a clip was collected from each individual's left pectoral fin and stored dry in a coin envelope for future genetic purposes.

## Otolith Aging and Image Analysis

Ages-at-capture were assigned to each retained individual by means of incremental otolith microstructure analysis. Methods for otolith preparation and reading followed Buckmeier and Howells (2003) and were standardized with protocols used by Ohio Department of Natural Resources personnel. A depression was made in black modelling clay, in which single, dried whole otoliths were placed and immersed in water. Otoliths were examined using an Amscope variable-power, trinocular dissecting microscope (3.5-180x) fixed with a 10-MP digital camera.

Photographs were taken of the whole otolith, concave side up. Those with no visible annuli were aged whole (i.e. whole-view) and designated as age-0 fish, whereas all others (> 1 visible annuli) were aged by inspection of a transverse section, as Hoyer et al. (1985) observed that at least one annulus may be obscured in whole-view otoliths as early as age-2. All otoliths aged by a transverse section were “burned” using a hot plate to elucidate annuli. Otoliths were placed concave-side down and allowed to darken for 20-30 seconds, or until the otolith stopped getting any darker. After burning, otoliths were placed convex side down on a flat surface and cracked near the nucleus by applying pressure with a finger. The exposed surface was then sanded with 400-grit automotive sandpaper and then polished with incrementally finer-grit sandpaper (up to 2,500-grit). For those sampled in WVDNR surveys, multiple pictures were then taken using the microscope camera, making sure to include whole-view images of the entire transverse section in addition to zoomed-in portions to add additional clarity to age estimates assigned.

Two readers independently assigned age estimates to each bass by independently reviewing images. If readers disagreed on the age of an individual fish, the image was reviewed in concert until a consensus was reached. Further measures taken to resolve disagreements

include photograph retakes followed by double-blind image reviews. If a consensus could not be reached, the individual was excluded from further analysis. For fish collected in the spring, the outer edge of the otolith was counted as an annulus, as peak annulus formation for fishes in temperate latitudes tends to occur from April to June (Beckman and Wilson 1995), when supplemental sampling occurred. Age information provided by ODNR was collected using the same protocols. Fish that were assigned age estimates older than 16 (one individual) were excluded from further analysis using age data, as this method of aging has only been validated on known-aged Largemouth Bass up to 16 years (Buckmeier and Howells 2003). Age and length data collected from otolith aging was used to construct age-length keys, at 25-mm increments, for each study reach. Keys were subsequently used to assign age estimates to un-aged individuals with length measurements.

Radial measurement information was also collected on otoliths from fish collected by WVDNR and a subsample of fish collected from ODNR. Following a transect adjacent to the sulcus, the R package RFishBC (Ogle 2020) was used to measure the distance, in pixels, from the otolith nucleus to each annulus and the outer edge. Using these radial measurements in addition to the individual's total length (mm) at capture, back-calculated lengths at age were estimated using the Dahl-Lea direct proportion method, one of the most common back-calculation methods applied by fish and wildlife agencies (Maceina et al. 2007; Klumb et al. 1999).

## **Population Characteristics**

### *Relative Abundance*

Catch numbers from standardized sampling events were used to calculate Catch Per Unit Effort (CPUE), an index of relative abundance, for each species at each river reach (Hubert and

Quist 2010). The total number of individuals for each species (C) were divided by the sample effort (f; measured in hours) to calculate a metric for relative abundance comparisons among populations.

### Size structure

The size structure of each population was evaluated using length frequency histograms and proportional size distributions (PSD) of each species in each river reach (Guy et al. 2007; Gabelhouse 1984). Length categories from Gabelhouse (1984) (Table 2) were used to estimate the PSD for each species in each river reach. PSD<sub>Q</sub>, otherwise known as PSD, was calculated using the following equation:

$$PSD = \frac{\text{Number of fish} \geq \text{quality length}}{\text{Number of fish} \geq \text{stock length}} \times 100$$

This is a useful metric of comparison among populations, as quality-size has been thought of as the minimum size that most recreational anglers will target for a given species (Anderson 1978). Size-classes were also used to compare growth rates between the three populations, as Beamesderfer and North (1995) demonstrated that the time it takes for a species to reach a certain size class (e.g., quality-sized) can be a useful metric when comparing the quality of fisheries among systems.

### Condition

Fish condition, or the assessment of “plumpness,” was evaluated using the Relative Weight ( $W_r$ ) Index (Wege and Anderson 1978) using the equation:

$$W_r = \frac{W}{W_s} \times 100$$

where  $W$  is the measured weight in grams of a given individual,  $W_s$  is the standard weight for an individual of that given total length (mm), and  $W_r$  is the calculated relative weight for that

individual. Murphy et al. (1990) proposed that standard weights be estimated from calculations of the 75th-regression-line-percentile (RLP) technique using the equation:

$$\log_{10}(W_r) = a' + (b \times \log_{10}(TL))$$

to develop species-specific intercepts ( $a'$ ) and slope-coefficients ( $b$ ) (Pope and Kruse 2007). The following equations were used in this study for Largemouth Bass [1], Smallmouth Bass [2], and Spotted Bass [3]:

$$[1] \log_{10}(W_r) = -5.528 + (3.273 \times \log_{10}(TL)) \text{ (Henson 1991)}$$

$$[2] \log_{10}(W_r) = -5.329 + (3.200 \times \log_{10}(TL)) \text{ (Kolander et al. 1993)}$$

$$[3] \log_{10}(W_r) = -5.392 + (3.215 \times \log_{10}(TL)) \text{ (Wiens et al. 1996)}$$

It is recommended that Largemouth and Smallmouth Bass below 150 mm TL and Spotted Bass below 100 mm TL be excluded from relative weight analyses (Blackwell et al. 2000), so all individuals below these length suggestions were excluded from further condition analyses. For comparison's sake, only fish collected in the Fall of 2019 and 2020 were included when assessing condition, as the relative weight of individuals expressing fully formed gonads may be artificially inflated. Average  $W_r$  for populations of each species found in the study reaches were compared against one another using Analysis of Variance (ANOVA) followed by an *a posteriori* multiple comparison procedure, Tukey's honestly significant difference (HSD) test, to determine if there were any significant differences in condition. Additionally,  $W_r$  was also calculated within Gabelhouse (1984) size categories to determine if there were any relationships between length and condition for all species within a reach. Least-squares regression was used to see whether size (total length in mm) had a significant effect on condition ( $W_r$ ) for a given species within a study reach. Values were considered significant at  $\alpha < 0.05$ .



## **Dynamic Rates**

### *Mortality & Year-class Strength*

Mortality estimates for the individual species in each population were derived using a catch-curve approach (Ricker 1975). The linear decline of fish caught at each age was found by plotting the natural logarithm of catch (y-axis) by age (x-axis). Using these data, individual-regression models were developed to estimate the slope of the descending right limb, which represents the ages at which fish are fully recruited to the sampling gear. The negative slope of this line can be thought of as the instantaneous total mortality ( $Z$ ), which was then be used to estimate the total annual mortality ( $A$ ) for each species in each river using the equation:

$$A = 1 - e^{-Z}$$

Only data collected from standardized sampling techniques where all fish are retained were used to estimate mortality. Miranda and Bettoli (2007) suggested that data collected from subsequent years be pooled for catch-curve analysis to dampen the effect of erratic recruitment, so data collected from 2019 and 2020 were aggregated for each species in each study reach.

It has been suggested that residuals from catch-curve regressions can represent yearly recruitment variability in fish populations (Maceina 1997). Since catch-curve models in this study utilized pooled data from 2019 and 2020, new models using only 2020 data were created in order to estimate year-class strength. Studentized residuals from the aforementioned catch-curve were calculated and used to quantify the relative strength or weakness of each year class. Maceina (1997) suggests that positive residual values correspond to relatively strong year classes, with negative residuals indicating weaker year classes.

### *Recruitment Variability*

Recruitment variability for each species was measured by the recruitment variability index (*RVI*), which was developed by Guy and Willis (1995) in order to quantify Black Crappie *Poxomis nigromaculatus* recruitment in South Dakota. This index utilizes the equation:

$$RVI = \frac{S_N}{N_M + N_P} - \frac{N_M}{N_P}$$

where  $S_N$  is the sum of the relative frequencies across year-classes,  $N_M$  is the number of year-classes missing from the sample, and  $N_P$  is the number of year-classes present in the sample.

Index values can range from -1 to 1, with values closer to 1 representing stable recruitment (Isermann et al. 2002). Quist (2007) found that averaged *RVI* values from multiple years of data were highly correlated with empirical estimates of Walleye *Stizostedion vitreus* recruitment variability. Therefore, *RVI* values from catch information from 2019 and 2020 were averaged for all species from all river reaches.

### Growth

Growth was estimated for all species in each reach by using back calculated length-at-age data from retained individuals. These data were then incorporated to model growth using the von Bertalanffy equation, which uses length-at-age data to describe growth that slows with age using the equation:

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

where  $L_t$  is the total length at age  $t$ ,  $L_\infty$  is a theoretical average maximum length,  $K$  is the Brody growth coefficient, and  $t_0$  is the theoretical time at which the fish was at size “0” (Allen and Hightower 2010).  $L_\infty$  and  $K$  have been used as indicators of fish growth that can be compared across populations. To preserve sample size, information collected from males, females, and unsexed individuals were aggregated for growth estimation. While female Largemouth Bass tend to obtain significantly larger maximum sizes (Claussen 2015), studies that have estimated sex-

specific growth have shown no significant differences in both  $L_{\infty}$  and  $K$  between males and females in certain Largemouth populations (Rodriguez-Sánchez et al. 2009). Additionally, male and female Smallmouth Bass tend to grow similarly (Brewer and Orth 2015). Bootstrapped growth curve parameters were obtained using nonlinear least-squares (NLS) regression from functions within the stats (R Core Team 2021) and boot (Canty and Ripley 2021) packages in R. Procedures for estimating growth followed the methods in Ogle (2016) as well as Eggleton and Peacock (2020).

Length-at-age estimates for Largemouth and Smallmouth Bass were also compared to standard growth models. Jackson et al. (2008) compiled data from across species' ranges to estimate standard growth for nine North American fish species, including Largemouth Bass, while Starks and Rodger (2020) developed a standard growth equation for lotic Smallmouth Bass using only otoliths-based data. To compare with the data with standard growth models, the relative growth index (RGI) equation:

$$RGI = \frac{L_t}{L_s} \times 100$$

was used, where  $L_s$  was the length at a given age estimated from the standard growth equations and  $L_t$  was length estimated at a given annuli from back-calculation. An RGI value of 100 corresponds to standard, or average, growth, whereas values that fall above and below 100 represent strong and weak growth, respectively. In the two standard growth studies, standard growth was only estimated for Largemouth and Smallmouth, so no comparison was made for Spotted Bass in this study.

## **RESULTS**

### **Sampling Effort**

Over the course of Fall 2019, Spring 2020, and Fall 2020 sampling, Ohio DNR and West Virginia DNR combined to sample black bass in four navigation pools on the Upper Ohio River and four on the Lower Ohio River. West Virginia DNR also sampled two navigation pools on the Kanawha River and three on the Monongahela River. Electrofishing surveys combined for 63.5 hours of effort across the four study reaches: 11.6 hours in the Kanawha River, 10.0 in the Monongahela River, 17.25 hours on the Upper Ohio River, and 24.6 hours on the Lower Ohio River (Table 1). Although sampling was highest on the two Ohio River reaches, effort per river kilometer was greater in the Kanawha (0.14 hours/km) and Monongahela rivers (0.20 hours/km) relative to the Upper and Lower Ohio River (0.09 hours/km each). Altogether, 2,369 bass were sampled during black bass electrofishing events, with an additional four Smallmouth Bass and seven Spotted Bass collected from the Monongahela River during ancillary WVDNR sampling. Of the 2,380 total black bass sampled, 1,739 were retained for aging; the remaining 641 were released and age-length keys were used to estimate their ages.

### **Aging**

Of the 1,739 black bass that were retained for aging, 777 were aged by WVU personnel and age data for the remaining 962 individuals were provided by ODNR biologists. For fish aged by WVU personnel, overall percent agreement of age was high at 94.47% and ranged from 91.75% (Largemouth Bass) to 95.44% (Smallmouth Bass). This corresponds to an average percent error (APE) of 2.19% and an average coefficient of variation (ACV) of 3.09% across all bass (Table S-1), with both values falling below the precision threshold of 5% suggested by

Campana (2001). Lack of significant P-values for the chi-square tests of symmetry on age-agreement (Table S-2) suggest that there was no bias between the two agers.

### **Largemouth Bass**

In total, 1,008 Largemouth Bass were sampled during 2019 and 2020 surveys, with 731 individuals retained for aging. The number of fish sampled and number retained for aging (in parentheses) from each study reach is as follows: 123 (65) from the Kanawha River, 188 (113) from the Monongahela River, 121 (95) from the Upper Ohio River, and 574 (458) from the Lower Ohio River. Catch-per-unit effort (CPUE) ranged from 7.0 bass/hour on the Upper Ohio River to 23.3 bass/hour on the Lower Ohio River (Table 3). CPUE for Largemouth Bass quality-sized and above was highest in the Monongahela River (4.1 fish/hour) and lowest in the Upper Ohio River (1.2 fish/hour). Sex information was collected from retained individuals and ratios (Female:Male) varied from population to population, with the Monongahela River showing the highest proportion of females (66.7%) and the Lower Ohio River displaying the lowest (47.7%) (Table 3). To see if the sex ratio of any reach differed significantly from 1:1 (50%), a one-proportion z-test was performed using the aforementioned sex ratios. The results of the test showed that only the sex ratio of the Monongahela River population differed significantly from 50% ( $z = 10.01$ ,  $P = 0.002$ ).

Length frequency and size structure varied by study reach (Figure SLMB-1). Mean total length ( $\pm$  SE) was similar for the Monongahela ( $237.2 \pm 6.5$  mm) and Kanawha ( $258.9 \pm 6.7$  mm), while Largemouth sampled from the Upper and Lower Ohio River were observed to be slightly smaller ( $203.7 \pm 7.0$  and  $224.4 \pm 3.2$  mm, respectively) (Table 3). A one-way ANOVA showed a significant difference in mean total length between the populations ( $F_{3, 1002} = 11.46$ ,  $P < 0.001$ ). A Tukey's HSD *post hoc* test suggests that mean total length in the Kanawha River

was significantly higher than all other reaches except for the Monongahela River, and the Monongahela and Lower Ohio reaches had significantly higher mean total lengths than the Upper Ohio River. Proportional size distribution (PSD) ranged from 31.0 in the Kanawha River to 46.5 in the Upper Ohio River. The number of fish observed in Gabelhouse (1984) five-cell length-categories (including substock-sized fish) from each study reach can be found in Table SLMB-1.

Condition was estimated for each population using the relative weight ( $W_r$ ) index. Only fish sampled during fall surveys were included in condition analyses. Average  $W_r$  was high for all populations, ranging from 102.3 in the Kanawha River to 115.4 in the Upper Ohio River. There was a statistically significant difference in condition between reaches as demonstrated by one-way analysis of variance ( $F_{3, 642} = 21.19, P < 0.001$ ). A Tukey's HSD *post hoc* test showed that Largemouth Bass in the Upper Ohio River had higher  $W_r$  values than all other reaches and fish in the Lower Ohio River had higher  $W_r$  than fish in the Kanawha and Monongahela rivers. There was no significant difference between average relative weight estimated from the Kanawha and Monongahela rivers. When relative weight was averaged for individuals within Gabelhouse (1984) size categories, certain populations showed declines in condition as size-class increased (Table SLMB-2). Condition was also regressed on total length at capture (mm) for each population (Fig. SLMB-2). Results of the linear models showed that TL had a significant, negative effect on condition in all Largemouth Bass populations except the Kanawha River ( $t_{109} = -0.921, P = 0.359$ ).

A total of 731 Largemouth Bass were successfully aged using sagittal otoliths in this study, with the remaining 277 individuals assigned age estimates using an age-length key constructed from 25-mm length bins. Age-at-capture estimates ranged from 0 to 12 years. One

individual was estimated at 17 years of age, but since Largemouth Bass age estimates derived from otoliths have been validated to 16 years (Buckmeier and Howells 2003), this individual was excluded from further demographic analysis involving age. Age structure varied by population (Table 3), with mean age-at-capture ranging from 0.9 years (Lower Ohio River) to 2.0 years on the Monongahela River (Table 3). A one-way ANOVA showed a significant difference in mean age at capture between the populations ( $F_{3, 1001} = 26.56, P < 0.001$ ), with Tukey's HSD suggesting that Largemouth Bass sampled from the Monongahela River were older than all other populations and fish sampled from the Kanawha River were older on average than fish sampled from the Upper Ohio River.

Log-transformed catch-at-age data were used to construct weighted catch curves to estimate instantaneous ( $Z$ ) and total annual ( $A$ ) mortality (Fig. SLMB-3). Coefficient of determination ( $R^2$ ) values all exceeded 0.85, suggesting that log-transformed catch data has a strong correlation with age-class. Estimates for  $A$  (with  $Z$  in parentheses) for each study reach is as follows: 63.1% (0.996) on the Kanawha River; 43.9% (0.577) on the Monongahela River; 49.0% (0.673) on the Upper Ohio River; and 51.8% (0.729) on the Lower Ohio River.

Studentized residuals from the weighted catch-curve regression were used to approximate Largemouth Bass year-class strength (Fig. SLMB-4). Residuals above the 80<sup>th</sup> percentile for all age classes represented strong year-classes and those below the 20<sup>th</sup> percentile represented weak year-classes. For Largemouth Bass, the following years, with their corresponding reaches in parentheses, displayed relatively strong year-class: 2010, 2011, 2015, and 2018 (MON); 2012, 2015, and 2020 (UOR); and 2019 (LOR). Weak-year classes were as follows: 2016 (KAN); 2009 and 2017 (MON); 2018 (UOR); and 2018 (LOR). Recruitment variability index ( $RVI$ ) scores

show that recruitment is relatively stable in the Kanawha, Monongahela, and Upper Ohio rivers ( $RVI = 0.72$  to  $0.83$ ), while recruitment on the Lower Ohio River may be less stable ( $RVI = 0.29$ ).

Back-calculated estimates calculated using the Dahl-Lea direct proportion method were used to fit von Bertalanffy growth curves to length-at-age data (Fig. SLMB-5). Estimates for the average theoretical maximum length obtained by individuals ( $L_{\infty}$ ) in each population ranged from 361.44 mm ( $TL$ ) in the Upper Ohio River to 575.96 mm in the Lower Ohio River. Conversely, the rate at which individuals approached this asymptotic length, or the Brody growth coefficient ( $k$ ), was lowest (0.19) in the Lower Ohio River and highest (0.54) in the Upper Ohio River. Growth equations resulting from each model are:

$$L_t = 409.22(1 - e^{-0.38(t-0.37)}) \text{ [Kanawha River]}$$

$$L_t = 496.00(1 - e^{-0.20(t-0.92)}) \text{ [Monongahela River]}$$

$$L_t = 361.44(1 - e^{-0.54(t-0.14)}) \text{ [Upper Ohio River]}$$

$$L_t = 575.96(1 - e^{-0.19(t-0.76)}) \text{ [Lower Ohio River]}$$

By rearranging the standard parameterization to solve for age at which an individual reached a specified length, age at quality-size ( $A_Q$ ) was calculated for each population and ranged from 3.11 years in the Kanawha and Upper Ohio to 3.64 years in the Monongahela River. Lastly, von Bertalanffy growth models estimated from West Virginia study populations were compared to range-wide growth estimates from Beamesderfer and North (1995) (Figure 2). This comparison shows that relative to rangewide growth estimates, Largemouth Bass in these rivers exhibit above-average growth in early years that slows as fish age, leading to below-average growth rates in older (Age-5+) years.

Length-at-age estimates generated from otolith back-calculations were compared to a standard growth model for Largemouth Bass developed by Jackson et al. (2008). Length-at-age



estimates for all four population models displayed above average growth for age-1 and -2 Largemouth ( $\overline{RGI} = 108.9$  to  $134.2$ ). Estimates for age-3 Largemouth also displayed above average growth in the Kanawha and Upper Ohio rivers. After age-3, however, all populations display below average growth for all subsequent ages ( $\overline{RGI} = 79.6$  to  $98.1$ ), except for age-6 Largemouth on the Lower Ohio River ( $\overline{RGI} = 102.4$ ) (Table 3).

### **Smallmouth Bass**

In total, 883 Smallmouth Bass were sampled in this study, with 641 retained for aging. The number of fish sampled and number retained for aging (in parentheses) from each study reach are as follows: 295 (179) from the Kanawha River, 217 (132) from the Monongahela River, 173 (158) from the Upper Ohio River, and 198 (172) from the Lower Ohio River. Relative abundance (CPUE) was highest in the Kanawha River at 25.4 fish/hour and lowest in the Lower Ohio River at 8.0 fish/hour. CPUE for Smallmouth Bass quality-sized and above was highest in the Upper Ohio River (3.3 fish/hour) and lowest in the Kanawha River (1.7 fish/hour). Sex information was collected from retained individuals and showed that sex ratios ranged from 48.4% (Lower Ohio River) to 63.7% Upper Ohio River (Table 4). To see if the sex ratio of any reach differed significantly from 1:1 (50%), a one-proportion z-test was performed using the aforementioned sex ratios. The results of the test showed that only the sex ratio of Smallmouth Bass in the Upper Ohio River differed significantly from 50% ( $z = 10.41$ ,  $P = 0.001$ ).

Length frequency and size structure varied by study reach (Figure SSMB-1). Mean total length was similar in the Monongahela and Lower Ohio rivers ( $199.9 \pm 4.9$  and  $216.8 \pm 6.9$  mm, respectively) and highest overall in the Upper Ohio River ( $241.3 \pm 7.1$  mm). Lowest overall mean total length was observed to be in Kanawha River ( $173.9 \pm 3.8$ mm) where relative

abundance was also highest. A one-way ANOVA showed a significant difference in mean total length between the populations ( $F_{3, 879} = 28.34, P < 0.001$ ), with Tukey's HSD suggesting mean total length was significantly higher in the Upper Ohio River compared to all others, and that Smallmouth Bass in the Lower Ohio and Monongahela rivers were longer on average than those sampled from the Kanawha. PSD in each study reach ranged from 19.6 in the Kanawha River to 54.4 in the Lower Ohio River. The number of fish observed in Gabelhouse (1984) five-cell length-categories (including substock-sized fish) from each study reach can be found in Table SSMB-1.

Condition was estimated for each population using the relative weight ( $W_r$ ) index. Only fish sampled during fall surveys were included in condition analyses. Average  $W_r$  ranged from 87.8 in the Kanawha River to 106.9 in the Lower Ohio River. There was a statistically significant difference in condition between reaches as demonstrated by one-way ANOVA ( $F_{3, 548} = 81.00, P < 0.001$ ). Results from a Tukey's HSD *post hoc* test showed that there were significant differences in  $W_r$  between all reaches. When relative weight was averaged for individuals within Gabelhouse (1984) size categories, certain populations showed declines in condition as size-class increased (Table SSMB-2). Condition was also regressed on total length at capture (mm) for each population (Fig. SSMB-2). Results of the linear models showed that TL had a significant, negative effect on condition in Smallmouth Bass populations in the Monongahela River ( $t_{125} = -3.146, P = 0.00207$ ) and the Upper Ohio River ( $t_{126} = -4.142, P < 0.001$ ).

A total of 641 Smallmouth Bass were successfully aged using sagittal otoliths in this study, with the remaining 242 individuals assigned age estimates using an age-length key constructed from 25-mm length bins. Age-at-capture estimates ranged from 0 to 11 years. Age structure varied by population, with mean age-at-capture ranging from 0.9 years (Kanawha

River) to 2.1 years on the Monongahela River (Table 4). A one-way ANOVA showed a significant difference in mean age at capture between the populations ( $F_{3, 879} = 26.31$ ,  $P < 0.001$ ), with Tukey's HSD suggesting that Smallmouth Bass sampled from the Monongahela and Upper Ohio rivers were older on average than those sampled from the other reaches.

Log-transformed catch-at-age data were used to construct weighted catch curves to estimate instantaneous ( $Z$ ) and total annual ( $A$ ) mortality (Fig. SSMB-3). Coefficient of determination ( $R^2$ ) values all exceeded 0.82, suggesting that log-transformed catch data has a strong correlation with age-class. Estimates for  $A$  (with  $Z$  in parentheses) for each study reach is as follows: 57.3% (0.851) on the Kanawha River; 50.8% (0.710) on the Monongahela River; 45.5% (0.607) on the Upper Ohio River; and 46.6% (0.627) on the Lower Ohio River (Table 4).

Studentized residuals from the weighted catch-curve regression were used to approximate Smallmouth Bass year-class strength (Fig. SSMB-4). Residuals above the 80<sup>th</sup> percentile for all age classes represented strong year-classes and those below the 20<sup>th</sup> percentile represented weak year-classes. For Smallmouth Bass, the following years, with their corresponding reaches in parentheses, displayed relatively strong year-class: 2014 and 2019 (KAN); 2015 (MON); 2011 and 2016 (UOR); and 2012 and 2020 (LOR). Weak-year classes were as follows: 2017 (KAN); 2014 (MON); 2013 and 2015 (UOR); and 2018 (LOR). Recruitment variability index ( $RVI$ ) scores show that recruitment is relatively stable in all reaches ( $RVI = 0.70 - 0.91$ ).

Back-calculated estimates calculated using the Dahl-Lea direct proportion method were used to fit von Bertalanffy growth curves to length-at-age data (Figure SSMB-5). Estimates for the average theoretical maximum length obtained by individuals ( $L_{\infty}$ ) in each population ranged from 479.49 mm ( $TL$ ) in the Lower Ohio River to 555.44 mm in the Upper Ohio River. Conversely, the rate at which individuals approached this asymptotic length, or the Brody growth

coefficient ( $k$ ), was lowest (0.18) in the Monongahela River and highest (0.30) in the Lower Ohio River. Growth equations resulting from each model are:

$$L_t = 480.15(1 - e^{-0.22(t-0.51)}) \text{ [Kanawha River]}$$

$$L_t = 542.32(1 - e^{-0.15(t-0.75)}) \text{ [Monongahela River]}$$

$$L_t = 555.44(1 - e^{-0.21(t-0.55)}) \text{ [Upper Ohio River]}$$

$$L_t = 479.49(1 - e^{-0.30(t-0.53)}) \text{ [Lower Ohio River]}$$

By rearranging the standard parameterization to solve for age at which an individual reached a specified length, age at quality-size ( $A_Q$ ) was calculated for each population and ranged from 2.43 years in the Lower Ohio River to 3.93 years in the Kanawha River. Lastly, von Bertalanffy growth models estimated from West Virginia study populations were compared to range-wide growth estimates from Beamesderfer and North (1995) (Figure 3). This comparison shows that relative to rangewide growth estimates, Smallmouth Bass in these rivers appear to show above-average growth in early years that persists with age, leading to older fish (Age-5+) growing similarly to the rangewide average.

Length-at-age estimates generated from otolith back-calculation were also compared to a standard growth model developed by Starks and Rodger (2020) which represents the average growth of lotic Smallmouth Bass throughout their range (Table 4). Length-at-age estimates for the Upper Ohio and Lower Ohio rivers displayed above-average growth from age-2 to age-6 ( $\overline{RGI} = 106.0 - 121.1$ ), with fish in the Upper Ohio River growing above average to age-8 ( $\overline{RGI} = 115.4$ ). Estimates for Smallmouth Bass in the Kanawha remained high from age-2 to age-6 ( $\overline{RGI} > 96.4$ ), while Smallmouth Bass growth in the Monongahela River remained consistently high from age-2 to age-8 ( $\overline{RGI} > 92.0$ ).

## Spotted Bass

In total, 491 Spotted Bass were sampled in this study, with 367 retained for aging. The number of fish sampled and number retained for aging (in parentheses) from each study reach are as follows: 93 (86) from the Kanawha River, 196 (87) from the Monongahela River, 35 (35) from the Upper Ohio River, and 167 (159) from the Lower Ohio River. Relative abundance was highest in the Monongahela River at 18.9 fish/hour and lowest in the Upper Ohio River at 2.0 fish/hour. CPUE for Spotted Bass quality-sized and above was highest in the Kanawha River (0.9 fish/hour) and lowest in the Upper Ohio River (0.3 fish/hour). Sex information was collected from retained individuals (Table 5) and showed that sex ratios ranged from 51.5% (Kanawha River) to 60.3% (Monongahela River). To see if the sex ratio of any reach differed significantly from 1:1 (50%), a one-proportion z-test was performed using the aforementioned sex ratios. The results of the test showed that none of the Spotted Bass sex ratios differed significantly from 50%.

Length frequency and size structure varied by study reach (Figure SSPB-1). Mean total length was lowest in the Lower Ohio River ( $159.9 \pm 5.8\text{mm}$ ) and highest in the Kanawha River ( $180.8 \pm 7.0\text{mm}$ ). Mean TL was similar in the Upper Ohio River and Monongahela River ( $177.2 \pm 11.3$  and  $169.0 \pm 3.9\text{mm}$ , respectively). A one-way ANOVA showed no significant difference in mean total length between the populations ( $F_{3, 487} = 2.23, P = 0.08$ ). PSD in each study reach ranged from 7.8 in the Monongahela River to 33.3 in the Upper Ohio River. The number of fish observed in Gabelhouse (1984) five-cell length-categories (including substock-sized fish) from each study reach can be found in Table SSPB-1.

Condition was estimated for each population using the relative weight ( $W_r$ ) index. Only fish sampled during fall surveys were included in condition analyses. Average  $W_r$  ranged from

101.6 in the Monongahela River to 107.3 in the Lower Ohio River. There was a statistically significant difference in condition between reaches as demonstrated by one-way ANOVA ( $F_{3, 358} = 4.502, P = 0.00407$ ). Results from a Tukey's HSD *post hoc* test showed that there were significant differences in  $W_r$ , with condition in the Lower Ohio River significantly higher than condition in the Monongahela River. There was no significant difference between the Kanawha and Upper Ohio River relative to all other reaches. When relative weight was averaged for individuals within Gabelhouse (1984) size categories, certain populations showed declines in condition as size-class increased (Table SSPB-2). Condition was also regressed on total length at capture (mm) for each population. Results of the linear models showed that TL had a significant, negative effect on condition in Spotted Bass populations in the Monongahela River ( $t_{115} = -3.144, P = 0.00212$ ) and the Upper Ohio River ( $t_{28} = -2.762, P = 0.01$ ).

A total of 367 Spotted Bass were successfully aged using sagittal otoliths in this study, with the remaining 124 individuals assigned age estimates using an age-length key constructed from 25-mm length bins. Age-at-capture estimates ranged from 0 to 8 years. Age structure varied by population, with mean age-at-capture ranging from 0.6 years (Lower Ohio River) to 1.7 years on the Monongahela River (Table 5). A one-way ANOVA showed a significant difference in mean age at capture between the populations ( $F_{3, 487} = 20.82, P < 0.001$ ), with Tukey's HSD suggesting that Spotted Bass sampled from the Monongahela River were older than all other populations and fish sampled from the Kanawha River were older on average than fish sampled from the Lower Ohio River.

Log-transformed catch-at-age data were used to construct weighted catch curves to estimate instantaneous ( $Z$ ) and total annual ( $A$ ) mortality (Figure SSPB-3). Coefficient of determination ( $R^2$ ) values ranged from 0.76 to 0.90, suggesting that log-transformed catch data

has a strong correlation with age-class. Estimates of  $A$  (with  $Z$  in parentheses) for each study reach is as follows: 41.4% (0.534) on the Kanawha River; 49.4% (0.682) on the Monongahela River; 44.5% (0.589) on the Upper Ohio River; and 56.8% (0.838) on the Lower Ohio River.

Studentized residuals from the weighted catch-curve regression were used to approximate Spotted Bass year-class strength (Figure SSPB-4). Residuals above the 80<sup>th</sup> percentile for all age classes represented strong year-classes and those below the 20<sup>th</sup> percentile represented weak year-classes. For Spotted Bass, the following years, with their corresponding reaches in parentheses, displayed relatively strong year-class: 2016 (KAN); 2015 (MON); 2015 and 2020 (UOR); and 2012, 2016, and 2020 (LOR). Weak-year classes were as follows: 2015 (KAN); 2016 (MON); 2018 (UOR); and 2018 (LOR). Recruitment variability index ( $RVI$ ) scores show that recruitment is relatively stable in the Kanawha, Monongahela, and Upper Ohio rivers ( $RVI = 0.76$  to  $0.81$ ), while recruitment on the Lower Ohio River may be less stable ( $RVI = 0.37$ ).

Back-calculated estimates calculated using the Dahl-Lea direct proportion method were used to fit von Bertalanffy growth curves to length-at-age data. Estimates for the average theoretical maximum length obtained by individuals ( $L_{\infty}$ ) in each population ranged from 274.59 mm ( $TL$ ) in the Upper Ohio River to 372.68 mm in the Lower Ohio River. The rate at which individuals approached this asymptotic length, or the Brody growth coefficient ( $k$ ), was lowest (0.36) in the Lower Ohio River and highest (0.91) in the Upper Ohio River. Growth equations resulting from each model are:

$$L_t = 276.13(1 - e^{-0.59(t-0.07)}) \text{ [Kanawha River]}$$

$$L_t = 287.62(1 - e^{-0.40(t-0.38)}) \text{ [Monongahela River]}$$

$$L_t = 274.59(1 - e^{-0.91(t+0.08)}) \text{ [Upper Ohio River]}$$

$$L_t = 372.68(1 - e^{-0.36(t-0.35)}) \text{ [Lower Ohio River]}$$

By rearranging the standard parameterization to solve for age at which an individual reached a specified length, age at quality-size ( $A_Q$ ) was calculated for each population and ranged from 3.53 years in the Lower Ohio River to 8.67 years in the Upper Ohio River. Since  $L_\infty$  was less than quality-size for Spotted Bass,  $A_Q$  could not be calculated for the Kanawha and Monongahela rivers. Additionally, no standard growth equation has been developed for Spotted Bass, so comparisons to range-wide growth could not be made.

## **DISCUSSION**

In terms of black bass species, Largemouth, Smallmouth, and Spotted Bass are ubiquitously distributed (Taylor et al. 2019) relative to their congeners and are arguably three of the most recreationally important species within *Micropterus* (Quinn and Paukert 2009). The overall goal of this study was to describe the population characteristics and dynamic rate functions of these recreationally important species in West Virginia's navigable river systems. This study was not only an opportunity to fill regional gaps in knowledge regarding the life history of these three species, but also a chance to study them in sympatry. Results suggest that variation exists not only between populations of black bass in the Ohio River and two of its major tributaries, the Kanawha and Monongahela rivers, but also along the continuum of the Ohio River itself. Data from this study could be used to support adaptive management strategies and could enhance meta-analyses aiming to develop relative growth standards for riverine black bass populations.

Compared to relative abundance estimates from other studies in similarly impounded river systems, electrofishing CPUE of black bass species in the upper Ohio River drainage is low. Eggleton et al. (2010; 2012) compiled relative abundance estimates for Largemouth (2010) and Spotted Bass (2012) from large, impounded river systems from the southeast and found that



electrofishing CPUE averaged 54.5 fish/hour and 10.8 fish/hour, respectively. Although CPUE in the Monongahela River is high for Spotted Bass, relative abundances found throughout this study were lower than findings from Eggleton et al. (2012) and other impounded systems have CPUE estimates for Largemouth Bass more than two times higher than in the upper Ohio River drainage. Similarly, relative abundances of Smallmouth Bass are low when compared to CPUE data from the Upper Mississippi River, where CPUE ranges from 9.5 to 91.6 fish/hour (Dieterman et al. 2019). Despite low CPUE in this study, relative abundances for all three species were similar to earlier estimates obtained from the Ohio River by Xenakis (2005). The proportional distribution of the three species in the Ohio River also reflect observations made by Xenakis (2005) that upper reaches of the Ohio River are more conducive for Smallmouth, whereas higher numbers of Largemouth and Spotted Bass can be found in pools further downstream. This may be due to the higher gradient of the river at this point, which requires a higher density of locks and dams to allow for navigation, suggesting a serial discontinuity in the fish community, particularly among black basses, along the Ohio River continuum (Miranda and Dembkowski 2016). Furthermore, this might explain the increased relative abundance of Smallmouth Bass in the Kanawha and Monongahela River, which have much shorter pool lengths than the mainstem Ohio River allowing for more tailwater habitat.

Black bass growth in West Virginia's navigable river systems appears to be variable, but with some similarities; namely, rapid growth in early years that diminishes with age, particularly for Largemouth (Fig. 2) and Spotted Bass. Theoretical maximum lengths ( $L_{\infty}$ ) are low relative to similar systems, particularly for Largemouth (Eggleton et al. 2010) and Spotted Bass (Eggleton et al. 2012; Abell et al. 2018), although estimates for Smallmouth Bass appear average in comparison to rangewide estimates (Fig. 3; Beamesderfer and North 1995) and to other lotic

populations (Starks and Rodger 2020). Beamesderfer and North (1995) used age at quality length ( $A_Q$ ; see Table 2 for size categories) as a metric for measuring growth in a population and found that on average, it took Largemouth Bass 3.7 years and Smallmouth Bass 4.1 years to reach this size. Largemouth Bass in the Upper Ohio River drainage took between 3.1 and 3.7 years to reach this age, while Smallmouth Bass reached quality size between 2.4 and 4.1 years, indicating above-average growth to this size-class. Growth to preferred-size for these two species takes 6.0 years (range = 4.91 to 6.6 years) for Largemouth Bass, which is longer than the average predicted by Beamesderfer and North (1995) of 5.3 years. Conversely, Smallmouth Bass have lower predicted ages at both preferred- and memorable-sizes when compared to estimates from Beamesderfer and North (1995), showing that growth trajectories in these systems sustain average to above-average growth well into the observed lifespan of Smallmouth Bass. Coupled with the low relative abundances of all three species in these study systems, growth does not appear to be density dependent and may vary due to a suite of environmental (e.g., water temperature, stream flow, precipitation regimes) and anthropogenic (e.g., artificial angling selection, vessel traffic) factors.

Despite seemingly slower growth rates,  $W_r$  indices indicate that black bass in these systems are in average to above-average condition. Average  $W_r$  estimates for Largemouth Bass and Spotted Bass on all four study reaches met or exceeded 100, the index value that represents the 75th percentile of condition from rangewide data on the species. These data appear similar to past estimates of condition from the Ohio River (Xenakis 2005). There is evidence, however, showing a negative relationship between total length and relative weight of individuals of all three species. Black bass anglers tend to utilize gear and bait types that select for individuals with sufficient gape-sizes (e.g., larger, older fish), so increased total length may come with

additional angling risk. Although catch-and-release fishing attempts to avoid inducing direct mortality through harvest, the sublethal effects of the practice, such as air exposure, hypoxia resulting from crowded livewell conditions, and nest displacement during spawning, have been well-documented (Siepker et al. 2007). Declines in condition with size may result as a tertiary response to these size-related stressors (Barton 2002; Barton et al. 1987) induced by catch-and-release fishing. Diminishing condition with age may also suggest that black bass in these systems invest heavily in gonadal growth at an early age, leaving less energy for growth (Pope and Willis 1996). Lastly, a negative relationship between length and relative weight may also inflate condition estimates calculated from samples consisting of many smaller individuals and fewer representatives from larger size- and age-classes, such as in this study.

Navigable river systems in this study have been highly modified to allow for commerce and are far removed from their natural states, which may be a driving factor responsible for the low relative abundances and poor rates of growth experienced by black bass species that inhabit them. Rivers that have been developed for navigation undergo habitat homogenization from dredging and impoundment via locks and dams (Niles and Hartman 2009), which can adversely affect larval fish survival (Letcher et al. 1997) as well as the natural partitioning of forage and habitat utilized by sympatric species (Miranda et al. 2021). Water level fluctuations due to seasonal changes in hydrology have been linked to spawning success, growth, and overall productivity in riverine fisheries (Lorenz et al. 1997) and these effects may be diminished or exacerbated by intense modification in regulated systems (Eggleton and Peacock 2020). Lastly, dams have been shown to increase sediment deposition in the rivers they impound (Bhowmik and Adams 1986), resulting in a gradual reduction in the amount of tributary backwater and embayment habitat (Grubaugh and Anderson 1989). Loss of embayment habitat may negatively

affect Largemouth Bass populations, as adults have been shown to utilize embayment habitat in the Ohio River considerably in the winter and spring (Freund and Hartman 2005); these areas also serve as vital nursery habitat for young-of-the-year Largemouth Bass in large river systems (Wallace and Hartman 2006).

In addition to increased rates of sediment deposition, navigable river systems can also experience high concentrations of total suspended solids (TSS) due to impoundment as well as from vessel-induced erosion of the riverbed and banks (Göransson et al. 2014). Wood and Armitage (1997) identified several ways in which increased fine sediment in lotic environments can adversely affect fish at both the individual (e.g., clogged gill rakers) and population levels (e.g., spawning habitat quality, altered migratory patterns), but one of the most significant may be reducing capture success of visual predators. Sweka and Hartman (2001) found that Brook Trout *Salvelinus fontinalis* specific growth rate diminished with increased turbidity, although it had no effect on consumption, suggesting that fish may have to expend more energy when foraging. For Smallmouth Bass, turbidity seems to influence their reactive distances, reducing the ability of the fish to detect and capture prey, as Sweka and Hartman (2003) found that reactive distances decreased from 65 to 10 cm when turbidity increased from 0 to 40 NTU, with the largest decrease in reactive distance occurring between 0 and 25 NTU. Turbidity may also affect prey selection, as laboratory experiments have shown shifts in consumption rates of Largemouth Bass from higher proportions of Gizzard Shad *Dorosoma cepedianum* at 0 and 5 NTU to selecting more Bluegill *Lepomis macrochirus* at 40 NTU. Regarding foraging efficiency, Gizzard Shad provide a higher caloric density when compared to other prey fishes, so a shift to less efficient prey could decrease growth potential for individual fish (Pope et al. 2001).

Unpublished data from the Ohio River Valley Water Sanitation Commission (ORSANCO) shows that turbidity in the Ohio River routinely exceeds 40 NTU, with some observations exceeding 100 NTU, lending credence to the idea that field conditions may affect the growth potential of black bass. In addition to land use and flow regimes that vary the water clarity within the Ohio River, other anthropogenic factors unique to large, impounded rivers may be affecting turbidity as well. Bank erosion and sediment upwelling has been well-documented from primary and secondary waves produced by large vessel traffic in the Göta Älv River, a major Swedish commercial waterway (Göransson et al. 2014). Bilkovic et al. (2019) found evidence that recreational boating was contributing to shoreline erosion and increases in turbidity in estuaries of the Chesapeake Bay. In addition to shoreline habitat degradation, wakes produced from commercial and recreational traffic also has the potential to strand larval fish on the shore (Adams et al. 1999). As major routes of commerce into Central Appalachia, recreational and commercial boat traffic may affect the habitat quality of large river systems, negatively impacting foraging success and larval survival for species such as black bass.

## **MANAGEMENT IMPLICATIONS & CONCLUSIONS**

Data collected in this study suggests that the Largemouth and Spotted Bass fisheries supported by the Ohio, Kanawha, and Monongahela rivers in West Virginia exhibit average to low productivity, according to dynamic rate estimates. Smallmouth Bass in these systems, however, seem to grow average relative to range wide estimates, though relative abundance is still comparatively low. Black bass fisheries are both economically and ecologically important, making informed, adaptive management a regional priority. Hundreds of thousands of anglers fish within West Virginia each year, adding millions of dollars in revenue to the state and local economies. In addition to individual recreational experiences, black bass are also the most

popular tournament target in the region, as over 90% of fishing tournaments are geared towards black bass in West Virginia (Wellman and Smith 2021). Moving forward, steps should be taken to elucidate the sources responsible for variation in life history and dynamic rates for black bass populations described in this study.

In other systems, management actions have been taken to increase angler catch rates, alter the size structure of black bass populations, and attempt to control angler exploitation. Stocking has long been a tool which managers have used to establish new black bass fisheries or supplement natural reproduction in existing fisheries (Long et al. 2015). In systems where bass productivity is already low, however, stocking efforts may act to exacerbate poor vital rates with additional density-dependent effects. Sammons (2012) found that natural habitat and diet partitioning of native black basses were disrupted by stocked individuals in the Flint River, Georgia. Survival rates of stocked individuals have also been reportedly low in some instances (Diana and Wahl 2009), particularly in the Ohio River, where stocked Largemouth Bass failed to enhance the fishery (Hartman and Janney 2006). Managers could also aim to control exploitation of these species by altering length-limit regulations, as the Ohio River is the only system currently with a minimum length-limit (MLL). However, Beamesderfer and North (1995) suggested that MLLs are most effective in highly productive fisheries, which the populations in this study do not appear to be. Miranda et al. (2017) also remarked upon how the shift in angling culture from catch-and-release fishing may diminish the effects length regulations would have on a particular fishery. Lastly, results from yield-per-recruit simulations suggest that current length limits do not appear to put these systems in danger of growth overfishing (see Chapter 3). Agencies have also worked to protect spawning bass in attempt to increase nest success by implementing seasonal closures or establishing protected zones (i.e., sanctuaries) that are closed

to angling. Suski et al. (2002) found that Largemouth and Smallmouth Bass reproductive success in Ontario Lakes increased in sanctuaries protected for spawning; however, without proper enforcement, advertising these areas drew unwanted, unethical angler effort, negating the intended positive effects. Seasonal closures in Ontario have also met with mixed-results, as variation in water-warming during the spring led to the seasonal closures and spawning seasons of Largemouth and Smallmouth Bass to only intermittently align, leading to these protections having greater effects in certain waterbodies and no effects in others (Kubacki et al. 2002). In most instances, problems arising with regulations appear to mostly be social in nature (Quinn 2002), as they require some level of stakeholder compliance that may not always be ubiquitous.

In West Virginia, navigable river systems support popular fisheries for a variety of fishes, but black bass are arguably the most economically important group of species. Recent anecdotal evidence suggests that black bass fisheries in these systems are diminished relative to their historic stocks. This study sought to take the first steps in identifying the factors responsible for this decline by establishing baseline population characteristics and dynamic rate information. Reliable estimates of relative abundance, growth, condition, and mortality of black bass species in each of these study systems fills in regional gaps in knowledge and provides a unique opportunity to study these species in sympatry. Though the results of this study do not explain variation in angler capture success or overall fishery quality, an in-depth description of the populations lays a baseline of information to better inform adaptive management strategies. As a valuable resource to both state and local economies, it is vital that these systems are managed in order to maximize their potential as recreational fisheries. Though future research should aim to identify the factors responsible for the variation in population characteristics, dynamic rate

estimates will help guide management decisions in order to conserve these vital species and allow the fishery to maximize its potential.



## LITERATURE CITED

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## TABLES & FIGURES

**Table 1.** Primary sampling dates and total sampling effort for each pool in each river, with responsible sampling agency in italics: Ohio Department of Natural Resources (ODNR) and West Virginia Division of Natural Resources (WVDNR).

<b>River</b>	<b>Pool</b>	<b>Pool Length (km)</b>	<b>Sample Dates</b>	<b>Total Effort (hrs.)</b>
Kanawha (KAN)	Marmet	24.62	10/8/19 ( <i>WVDNR</i> ) 10/14/20 ( <i>WVDNR</i> ) 10/16/20 ( <i>WVDNR</i> )	3.75
	Winfield	60.83	10/15/19 ( <i>WVDNR</i> ) 10/16/19 ( <i>WVDNR</i> ) 10/6/20 ( <i>WVDNR</i> ) 10/8/20 ( <i>WVDNR</i> ) 11/17/20 ( <i>WVDNR</i> )	7.88
Monongahela (MON)	Opekiska	21.40	10/2/19 ( <i>WVDNR</i> ) 5/19/20 ( <i>WVDNR</i> ) 10/5/20 ( <i>WVDNR</i> )	3.75
	Morgantown	9.66	5/20/20 ( <i>WVDNR</i> ) 5/28/20 ( <i>WVDNR</i> ) 10/7/20 ( <i>WVDNR</i> )	2.50
	Pt. Marion	18.02	9/25/19 ( <i>WVDNR</i> ) 5/27/20 ( <i>WVDNR</i> ) 9/30/20 ( <i>WVDNR</i> )	3.75
Upper Ohio (UOR)	New Cumberland	36.53	10/15/19 ( <i>ODNR</i> )	2.50
	Pike Island	47.96	10/21/19 ( <i>ODNR</i> ) 10/20/20 ( <i>WVDNR</i> )	4.00
	Hannibal	67.91	10/1/19 ( <i>WVDNR</i> ) 10/2/19 ( <i>WVDNR</i> ) 5/12/20 ( <i>WVDNR</i> ) 10/5/20 ( <i>WVDNR</i> ) 10/8/20 ( <i>WVDNR</i> )	5.67
	Willow Island	56.81	10/15/20 ( <i>WVDNR</i> ) 10/18/20 ( <i>WVDNR</i> )	5.08
Lower Ohio (LOR)	Belleville	67.91	10/21/19 ( <i>ODNR</i> ) 5/13/20 ( <i>WVDNR</i> ) 10/26/20 ( <i>ODNR</i> )	6.99
	Racine	54.07	5/13/20 ( <i>WVDNR</i> ) 10/19/20 ( <i>ODNR</i> ) 10/20/20 ( <i>ODNR</i> )	6.92
	R.C. Byrd	67.11	10/28/19 ( <i>ODNR</i> ) 10/30/19 ( <i>ODNR</i> ) 5/14/20 ( <i>WVDNR</i> ) 10/12/20 ( <i>WVDNR</i> ) 10/13/20 ( <i>WVDNR</i> )	5.19
	Greenup	99.46	10/24/19 ( <i>ODNR</i> ) 10/28/19 ( <i>ODNR</i> ) 10/22/20 ( <i>ODNR</i> ) 10/26/20 ( <i>ODNR</i> )	5.5



**Table 2.** Proposed PSD length categories in millimeters for black bass species evaluated in this study. Values in the table were gathered from Neumann et al. (2012).

<b>Species</b>	<i>PSD Length Categories (mm)</i>				
	<b>Stock</b>	<b>Quality</b>	<b>Preferred</b>	<b>Memorable</b>	<b>Trophy</b>
Largemouth Bass	200	300	380	510	630
Smallmouth Bass	180	280	350	430	510
Spotted Bass	180	280	350	430	510

**Table 3.** Catch summary data and life history estimates for Largemouth Bass sampled from West Virginia’s navigable river systems in 2019 and 2020. Catch and effort are summarized by catch-per-unit-effort (CPUE; fish/hour) and *CPUE* for quality-sized (300 mm) and above individuals. Size structure estimates, including proportional size distribution (PSD), are derived from measurements of total length (*TL*) and condition was analyzed using the relative weight ( $W_r$ ) index. Estimates for both instantaneous (*Z*) and total annual mortality (*A*) are provided. Length infinity ( $L_\infty$ ) and the Brody growth coefficient (*k*) are parameters of the von Bertalanffy growth curve, which was used to solve for age at quality length ( $A_Q$ ). Standard length equation used for relative growth index (*RGI*) comparisons from Jackson et al. (2008).

Metric	Parameter	River			
		Kanawha	Monongahela	Upper Ohio	Lower Ohio
Catch/Effort	n	123	188	121	574
	CPUE	10.6	18.8	7.0	23.3
	CPUE-Q	2.7	4.1	1.2	4.2
Size Structure	Min TL (mm)	80	82	104	85
	Max TL (mm)	451	518	418	509
	Mean TL	258.9	237.2	203.7	224.4
	PSD	31.0	32.8	46.5	31.7
Age Structure	Max Age	7	11	9	12
	Mean Age	1.4	2.0	1.0	0.9
Sex Ratio	% Female	50.9	66.7	61.0	47.7
Condition	$\overline{Wr}$	102.3	103.9	115.4	109.6
Mortality	<i>Z</i>	0.996	0.577	0.673	0.729
	<i>A</i> (%)	63.1	43.9	49.0	51.8
Growth	$L_\infty$	409.22	496.00	361.44	575.96
	<i>K</i>	0.38	0.20	0.54	0.19
	$A_Q$	3.11	3.72	3.14	3.11
Relative Growth Index ( <i>RGI</i> )	Age-1	132.2	123.5	134.2	127.5
	Age-2	113.6	108.9	114.2	109.3
	Age-3	101.9	94.1	101.8	
	Age-4	93.6	88.7	94.8	95.8
	Age-6	88.4	83.5	78.6	102.4
	Age-8	-	91.4	-	-
Recruitment Variability	<i>RVI</i>	0.83	0.83	0.72	0.29

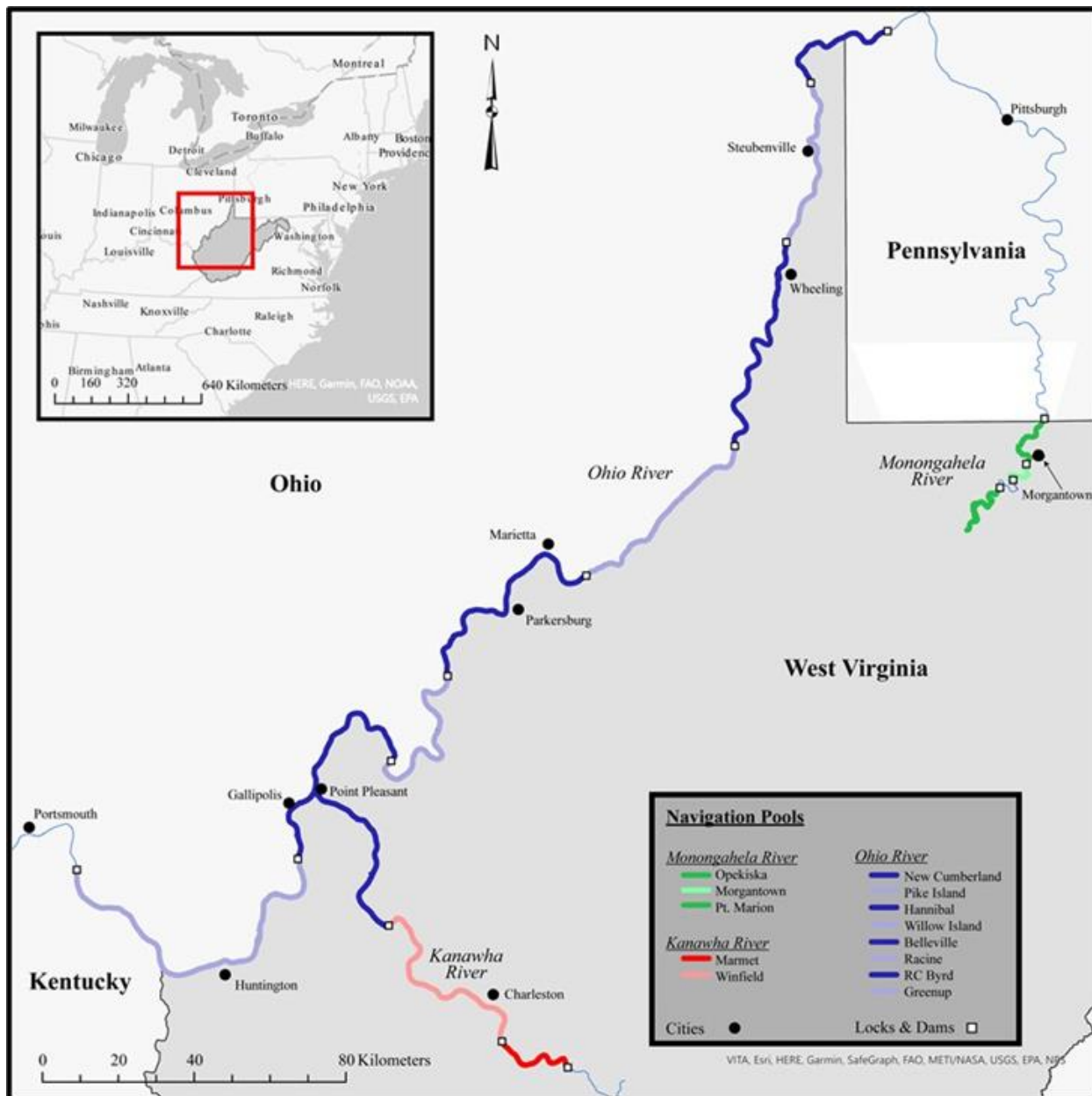
**Table 4.** Catch summary data and life history estimates for Smallmouth Bass sampled from West Virginia’s navigable river systems in 2019 and 2020. Catch and effort are summarized by catch-per-unit-effort (CPUE; fish/hour) and CPUE for quality-sized (280 mm) and above individuals. Size structure estimates, including proportional size distribution (PSD), are derived from measurements of total length (TL) and condition was analyzed using the relative weight ( $W_r$ ) index. Estimates for both instantaneous ( $Z$ ) and total annual mortality ( $A$ ) are provided. Length infinity ( $L_\infty$ ) and the Brody growth coefficient ( $k$ ) are parameters of the von Bertalanffy growth curve, which was used to solve for age at quality length ( $A_Q$ ). Standard length equation used for relative growth index (RGI) comparisons from Starks and Rodger (2020).

Metric	Parameter	River			
		Kanawha	Monongahela	Upper Ohio	Lower Ohio
Catch/Effort	n	295	217	173	198
	CPUE	25.4	21.3	10.0	8.0
	CPUE-Q	1.7	2.4	3.3	2.0
Size Structure	Min TL (mm)	77	83	77	93
	Max TL (mm)	517	546	509	505
	Mean TL	173.9	199.9	241.3	216.8
	PSD	19.6	18.6	42.9	54.4
Age Structure	Max Age	8	11	11	8
	Mean Age	0.9	1.9	1.8	1.0
Sex Ratio	% Female	50.7	57.5	63.7	48.4
Condition	$\overline{W_r}$	87.8	92.5	97.5	106.9
Mortality	$Z$	0.851	0.710	0.607	0.627
	$A$ (%)	57.3	50.8	45.5	46.6
Growth	$L_\infty$	480.15	542.32	555.44	479.49
	$K$	0.22	0.15	0.21	0.30
	$A_Q$	3.47	4.09	2.79	2.39
RGI	Age-1	83.2	76.7	95.1	106.0
	Age-2	96.4	92.0	110.2	121.1
	Age-3	98.7	93.4	115.5	119.6
	Age-4	102.3	93.7	116.4	120.4
	Age-6	108.0	95.7	119.7	116.2
	Age-8	78.9	96.9	115.4	-
Recruitment Variability Index	$RVI$	0.91	0.70	0.85	0.89

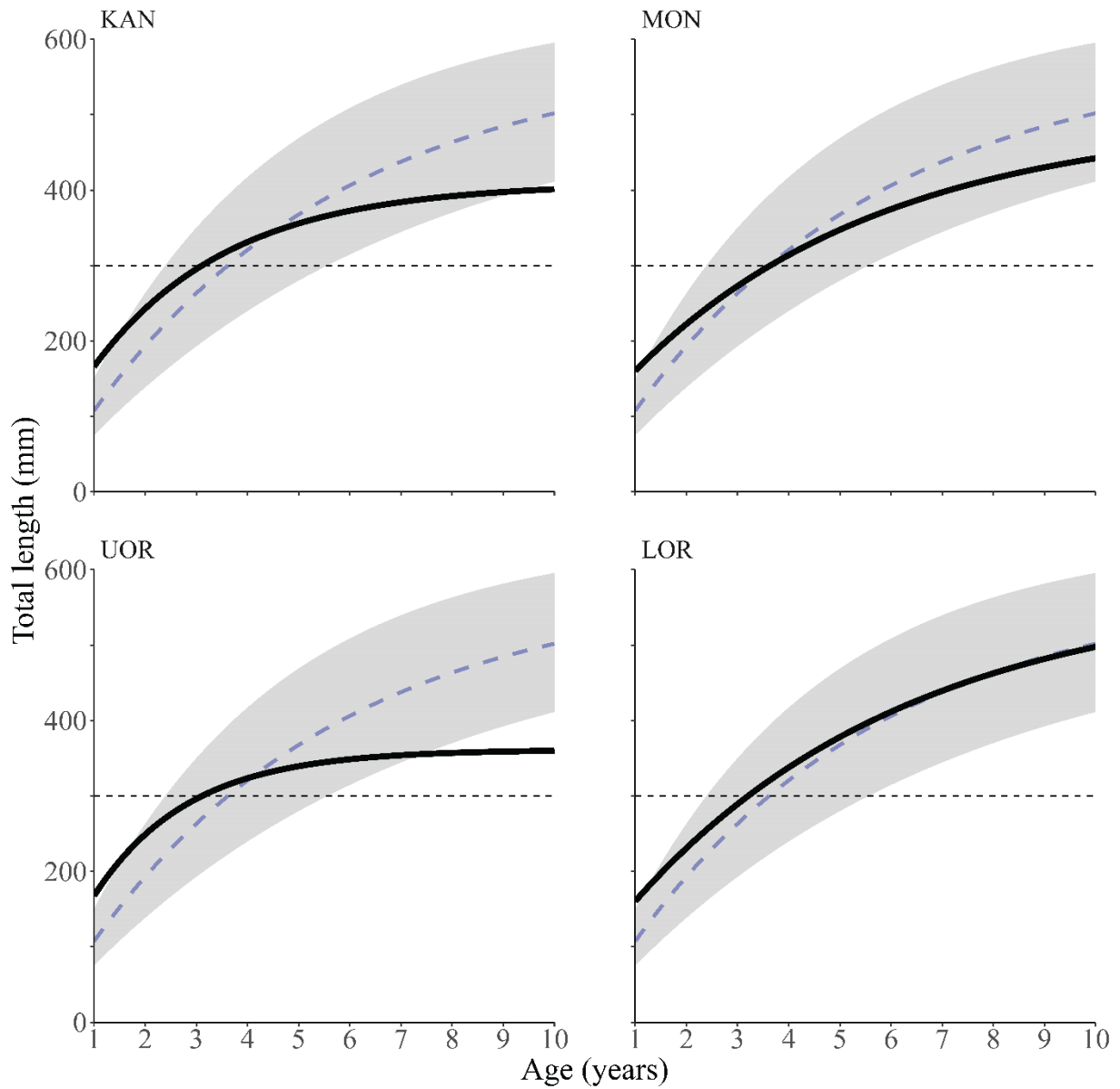
**Table 5.** Catch summary data and life history estimates for Spotted Bass sampled from West Virginia’s navigable river systems in 2019 and 2020. Catch and effort are summarized by catch-per-unit-effort (CPUE; fish/hour) and CPUE for quality-sized (280 mm) and above individuals. Size structure estimates, including proportional size distribution (PSD), are derived from measurements of total length (TL) and condition was analyzed using the relative weight ( $W_r$ ) index. Estimates for both instantaneous ( $Z$ ) and total annual mortality ( $A$ ) are provided. Length infinity ( $L_\infty$ ) and the Brody growth coefficient ( $k$ ) are parameters of the von Bertalanffy growth curve, which was used to solve for age at quality length ( $A_\varrho$ ).

Metric	Parameter	River			
		Kanawha	Monongahela	Upper Ohio	Lower Ohio
Catch/Effort	n	93	196	35	167
	CPUE	8.0	18.9	2.0	6.8
	CPUE-Q	0.9	0.7	0.3	0.6
Size Structure	Min TL (mm)	81	84	75	61
	Max TL (mm)	335	291	311	396
	Mean TL	180.8	169.0	177.2	159.9
	PSD	23.3	7.8	33.3	30.0
Age Structure	Max Age	5	6	3	8
	Mean Age	1.2	1.7	0.8	0.6
Sex Ratio	% Female	51.5	60.3	56.5	54.2
Condition	$\overline{W_r}$	104.8	101.6	106.3	107.3
Mortality	$Z$	0.534	0.682	0.589	0.838
	$A$ (%)	41.4	49.4	44.5	56.8
Growth	$L_\infty$	276.13	287.62	274.59	372.68
	$K$	0.59	0.40	0.91	0.36
	$A_\varrho$	NA*	8.70	NA*	3.52
Recruitment Variability Index	$RVI$	0.79	0.76	0.81	0.37

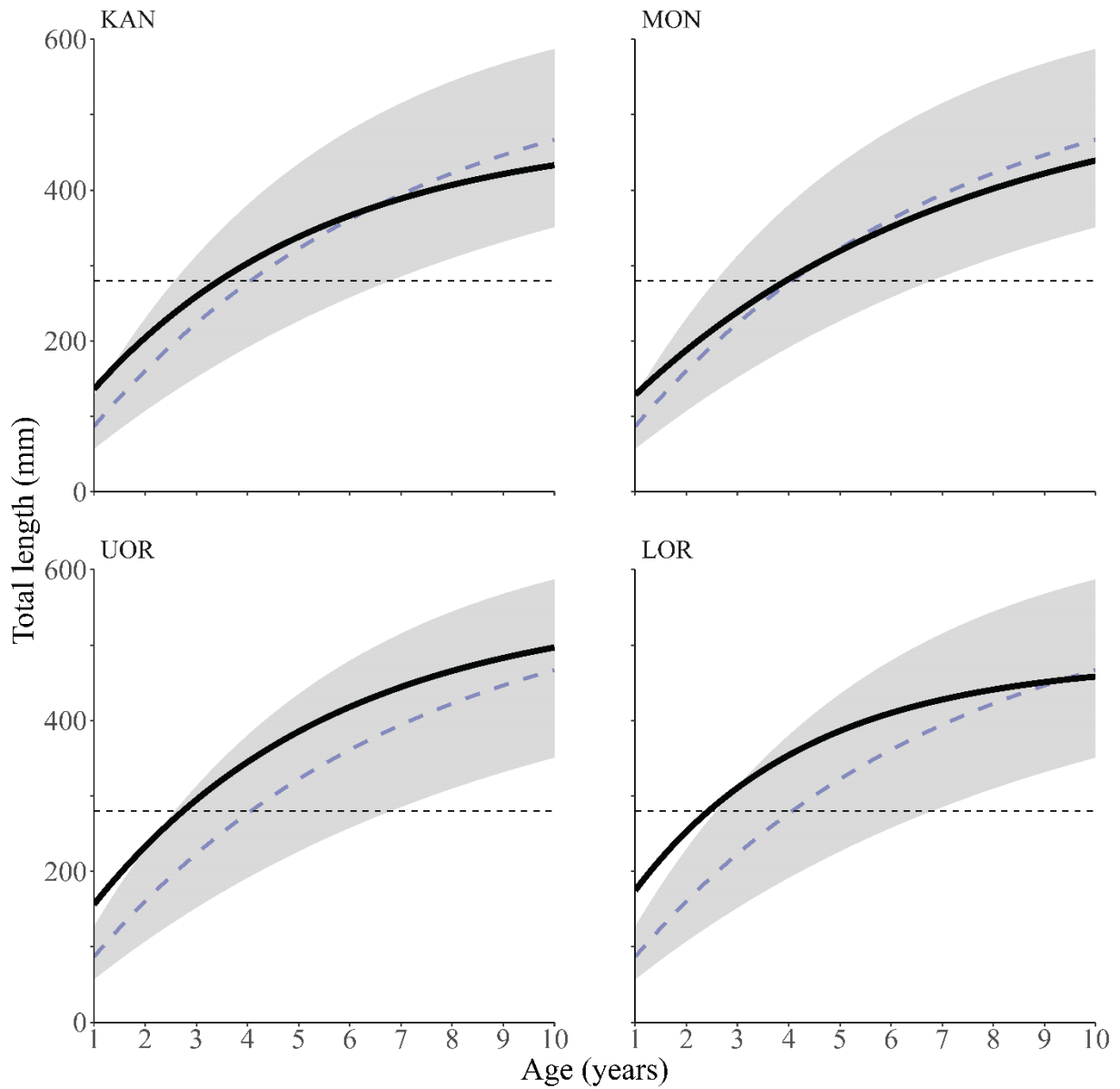
\*Unable to calculate due to quality length (280mm) exceeding length infinity.



**Figure 1.** Map of the Ohio, Kanawha, and Monongahela rivers, with focus on the extent of each river sampled for black bass. Navigation pools sampled in this study are highlighted and listed in the legend from upstream to downstream, with select cities shown for spatial reference.



**Figure 2.** von Bertalanffy growth models from Largemouth Bass study populations in this study compared to range wide growth estimates from Beamesderfer and North (1995). Solid, black lines represent growth models from WV navigable river populations and shaded, grey region corresponds to 25<sup>th</sup> to 75<sup>th</sup> percentile range wide growth estimates. Dashed, blue lines display 50<sup>th</sup> percentile growth and horizontal, dashed line demarcates quality size (300-mm) as a visual marker for comparison.



**Figure 3.** von Bertalanffy growth models from Smallmouth Bass study populations in this study compared to range wide growth estimates from Beamesderfer and North (1995). Solid, black lines represent growth models from WV navigable river populations and shaded, grey region corresponds to 25<sup>th</sup> to 75<sup>th</sup> percentile range wide growth estimates. Dashed, blue lines display 50<sup>th</sup> percentile growth and horizontal, dashed line demarcates quality size (280-mm) as a visual marker for comparison.

### **Chapter 3: Simulated Effects of Variable Minimum Length-limits on Smallmouth and Largemouth Bass Yield and Size Structure in the Upper Ohio River Drainage**

#### **ABSTRACT**

The Ohio, Kanawha, and Monongahela rivers are impounded river systems that serve as economically important commerce routes while also supporting robust fisheries. Black bass are popularly targeted species in these systems, yet anglers report that the fishery has declined relative to historic stocks. Currently, the only length-based regulation for these black bass fisheries exists on the Ohio River (12" minimum length-limit); however, a contemporary evaluation of this regulation regarding its effectiveness has yet to be conducted. In order to evaluate current length limit regulations, length, weight, and age information were collected from Smallmouth *Micropterus dolomieu* and Largemouth Bass *Micropterus salmoides* in 2019 and 2020 from these rivers. These data were integrated into yield-per-recruit models to assess the impacts of growth overfishing under varying rates of conditional fishing mortality and across several common length-limits: no MLL, 10", 12" and 14". Data suggests that neither Largemouth or Smallmouth Bass fisheries in these systems are at risk of growth overfishing, even when no minimum length-limit is present. Yield is generally maximized under a 305-mm (12") minimum length-limit under moderate rates (0.1-0.4) of exploitation. Results from this study should be taken into consideration when enacting future length-limit regulations in these systems, although more precise estimates of fishing mortality for Largemouth and Smallmouth Bass should be collected first.



## INTRODUCTION

Inland recreational fisheries provide a unique opportunity for anglers to interact with natural resources while they also contribute to state and local economies, making them a vital component of the outdoor recreation industry. As such, it is important for fisheries scientists to manage aquatic systems within the bounds of ecological sustainability while also maximizing their potential as fisheries. Certain valued fishery attributes, such as expected catch and average size (Dabrowska et al. 2017), are determined by population characteristics such as recruitment (Novinger 1987) which is in turn driven by a suite of biotic and abiotic factors that result in high year-to-year variation (Parkos et al. 2013). While fisheries may be scrutinized by the perceived quality of the fish populations that are found in them, fish population management is only one facet of fisheries management. Along with management of aquatic organisms, it is also important to consider the habitat that these organisms inhabit, as well as manage how stakeholders can utilize these resources (Nielsen 1999). One common practice in "people management", with regard to fisheries resources, is through the implementation of various fishing regulations.

Regulations have been historically implemented to influence fish populations, control overfishing, and to manage sociological objectives (Cooke et al. 2013), such as providing anglers with reasonable expectations for adequate fishing opportunities (Noble and Jones 1999). Although fishing regulations come in many forms and have evolved over the course of time, their purpose in management can generally be categorized into one of two strategies: input control and output control (Arlinghaus et al. 2013). Input regulations attempt to control the manner in which the resource is utilized, such as closed seasons and the formation of no-take sanctuaries (Bartholemew and Bohnsack 2005), whereas output controls regulate the amount of harvest and outcome of the overall catch (Arlinghaus et al. 2013). In freshwater recreational

fisheries, managing fishing mortality is typically a high priority for biologists, making output controls like creel limits and length-based regulations commonplace in most North American freshwater fisheries (Radomski et al. 2001).

Although properly implemented regulations can succeed in improving catch rates and restructuring the size distribution of a population, improper regulations can negatively affect fisheries by increasing fishing mortality, decreasing the size structure, and promoting overfishing (Dotson 2013). Long-term evaluation is required in order to detect fishery response to regulations, especially for fish species that can reach ten years of age or more in the wild (Pierce 2010), yet evaluations for species such as Largemouth Bass *Micropterus salmoides* are typically based on no more than two years of data before and after the implementation of limits (Wilde 1997; Allen and Pine 2000). When resources and priorities dictate that lengthy regulation evaluations are too costly, simulation modeling provides an alternative to achieve an estimate of fishery response to different regulations using empirical data. One common method for evaluating the potential for aquatic systems to experience overfishing, as well as evaluate the effectiveness of proposed length-limits, is Beverton and Holt's (1957) yield-per-recruit (YPR) model, which estimates the theoretical yield, in weight, of a year-class as it experiences both natural and fishing mortality (Waters and Huntsman 1986). For certain popular sportfishes, such as the black basses, YPR models have been extensively used to simulate the effects of various length limits, in addition to varying degrees of fishing mortality, on specific populations (Beamesderfer and North 1995; Peacock et al. 2011; Sterling et al. 2019; Spaulding and Rogers 2020).

Smallmouth *M. dolomieu* and Largemouth Bass are among the most abundant and widely distributed of the black basses and headline a group of centrarchids that are considered some of

the most sought-after and economically important freshwater fish species (Warren 2009). In West Virginia, navigable river systems such as the Ohio River are popular destinations for anglers to target these species (Duda et al. 2005). Recent anecdotal information suggests that anglers consider these black bass fisheries diminished relative to their historic stocks (Dave Wellman, personal communication), but biological information has yet to confirm these claims. The objective of this study is to model the response of the Largemouth and Smallmouth Bass fisheries in the upper Ohio River drainage under varying degrees of fishing mortality across several length-limit simulations. We will also model the impact of length-based regulations on changes to the size structure of these fisheries. Data collected from this study will be useful information for fisheries managers regarding future management decisions applied to conserve these vital fisheries.

## **METHODS**

### **Study Area**

The three rivers of interest in this study are: the Kanawha River from Winfield Lock and Dam upstream to London Lock and Dam; the Monongahela River from Point Marion Lock and Dam upstream to the confluence of the West Fork and Tygart rivers; and Ohio River from Greenup Lock and Dam upstream to Montgomery Lock and Dam (Fig. 1). All three rivers have been heavily modified to allow for large vessel traffic, making them important routes of commerce from Central Appalachia to the Mississippi River. To add to their economic importance, the Ohio River and its tributaries support popular fisheries for a variety of targeted species, including black bass. Currently, the Ohio River is the only navigable river system in West Virginia managed with a length-based regulation (12" minimum length-limit).

## **Fish Collection & Processing**

Altogether, black bass were sampled in 2019 and 2020 from eight navigation pools on the Ohio River, three on the Monongahela River, and two on the Kanawha River (Table 1).

Sampling for black bass was conducted in conjunction with West Virginia Division of Natural Resources (WVDNR) and Ohio Department of Natural Resources (ODNR) fish community sampling. Fish were sampled using night-time, pulsed DC-mounted boat electrofishing, with crews consisting of two netters and the vessel operator. At each of the thirteen navigational pools, four to six sites were chosen that were representative of each river reach (e.g., tributary mouths, embayments, and dam tailwaters). At each site, sampling consisted of ten to fifteen-minute transects, with transect duration altered depending on the amount of sampleable habitat at each site. Sampling goals, dates, and subsequent fish processing were outlined in Chapter 2, in addition to the estimation of dynamic rate functions used as modeling parameters in this chapter.

For analysis, the Ohio River was split into an Upper (UOR) and Lower (LOR) reach based upon the results of a non-metric multidimensional scaling (NMDS) analysis of black bass relative abundance data from electrofishing surveys conducted by Ohio River Valley Water Sanitation Commission (ORSANCO) from 1958-2018. Results showed that electrofishing catches from the upper reaches of the Ohio River in West Virginia's jurisdiction had higher proportions of Smallmouth Bass relative to the lower reaches, which saw higher relative catch rates for Spotted and Largemouth Bass. This suggests that habitat in the upper reaches may be more suitable for Smallmouth Bass, while pools further down the river may be more suitable for Largemouth and Spotted Bass; these findings reflect observations noted by Xenakis et al. (2005).

## Mortality Estimation

Estimates of total instantaneous ( $Z$ ) and annual ( $A$ ) mortality were obtained in Chapter 2 using a catch-curve approach. The natural logarithm of catch (y-axis) was regressed on age (x-axis) for each species in each river system. The slope of these individual regression models represented  $Z$ , from which  $A$  was obtained using the equation:

$$A = 1 - e^{-Z}$$

Miranda and Bettoli (2007) suggested that data collected from subsequent years be pooled for catch-curve analysis to dampen the effect of erratic recruitment, so data collected from 2019 and 2020 were aggregated for each species in each study reach.

Instantaneous natural mortality ( $M$ ) and conditional natural mortality ( $n$ ) were estimated for each species in each reach using the following equation developed by Hoenig (1983)

$$\ln(M) = 1.46 - 1.01 * \ln(t_{max})$$

where  $t_{max}$  is the maximum age observed from a sample within a population. This equation assumes that total annual mortality approximates  $M$  due to negligible fishing or harvest mortality. Fishing mortality consists of three components: mortality related to harvest, delayed mortality due to recreational catch-and-release, and delayed mortality from tournament fishing (Kerns et al. 2016). For the purposes of this study, we will define fishing mortality as the aggregate of these three components and not seek to discriminate between sources. No empirical estimates of fishing mortality exist for black bass fisheries in these systems, so estimates were obtained using the relationships between various mortality parameters. Since  $Z = M + F$  (instantaneous fishing mortality), an estimate of  $F$  was obtained using  $Z$  and  $M$ , and an estimate of exploitation ( $u$ ) was obtained using the equation  $A = u + v$ . Instantaneous fishing mortality ( $F$ ) was further used to derive an estimate of conditional fishing mortality ( $cf$ ) using the equation:

$$cf = 1 - e^{-F}$$

Conditional fishing mortality is the exploitation rate when no natural mortality occurs and is used as an input parameter in FAMS (Slipke and Maceina 2014). Therefore,  $cf$  will be referred to as exploitation hereafter. Parameters describing mortality and their relationships among one another can be found in Table 1 (Miranda and Bettoli 2007).

### **Length-limit Simulations**

Using the Fisheries Analysis and Modeling Simulator (FAMS v1.64; Slipke and Maceina 2014) software, demographic data were entered into the yield-per-recruit modeling option to evaluate possible courses of action for black bass management. FAMS uses the Jones (1957) modification of the Beverton-Holt equilibrium, which is used to determine harvest potential in terms of yield (i.e., kilograms of biomass harvested per recruit) under various length-limit scenarios. This model assumes fixed recruitment in addition to constant growth and mortality across age classes (Beverton and Holt 1957). Yield-per-recruit modeling has commonly been used to simulate the response of minimum length limits on black bass populations in a variety of systems (e.g., Beamesderfer and North 1995; Tyszko and Pritt 2017; Sterling et al. 2019; Vale and Gelwick 2019). The equation used in the Jones (1957) modification in FAMS (Slipke and Maceina 2014) is as follows:

$$Yield = \frac{F * N_t * e^{Z*r} * W_{\infty}}{K} [\beta(X, P, Q)] - [\beta(X_1, P, Q)]$$

where:

F = instantaneous rate of fishing mortality

N<sub>t</sub> = the number of recruits entering the fishery at some minimum length at time ( $t$ )

Z = instantaneous rate of total mortality

$r$  = time in years to recruit to the fishery ( $t_r - t_o$ )

$W_\infty$  = maximum theoretical weight

$K$  = Brody growth coefficient

$B$  = incomplete Beta coefficient

$X = e^{-Kr}$

$X_1 = e^{-K(t_{max} - t_o)}$  ( $t_{max}$  is the maximum age observed in the population)

$P = Z/K$

$Q$  = slope of the weight-length relationship + 1

Von Bertalanffy growth parameters ( $L_\infty$ ,  $K$ , and  $t_o$ ) calculated in Chapter 2 were used alongside coefficients ( $b$ ,  $a$ ) of the weight (g):length regression (mm) for each species within each study reach to solve for  $W_\infty$ , measured in grams. This estimate of  $cm$  was fixed for each length limit simulation, while conditional fishing mortality ( $cf$ ) was allowed to vary from 0.05 to 0.95 in increments of 0.05 in order to model the effects of varying rates of conditional fishing mortality.

Output from these simulations included the yield of the fishery (in kilograms) and the number of individuals remaining in the population above a specified length (in millimeters) under certain length-limit scenarios. The potential for growth-overfishing can be found in yield plots on the descending right limb of the curve. Length-limits were set at 254 mm (~ 10 inches), 305 mm (~12 inches, current Ohio River MLL), and 356 mm (~14 inches), reflecting commonly-used MLL regulations for bass (Long et al. 2015). Fishery response was also simulated under a no minimum length-limit scenario, where fish were modelled to enter the fishery and experience fishing mortality at stock length: 180 mm for Smallmouth Bass and 200 mm for Largemouth Bass (Gabelhouse 1984). Pritt (2019) found that Ohio River anglers harvested black bass starting at 210 mm, while Austen and Orth (1986) found that anglers on the

New River harvested Smallmouth Bass as small as 160 mm. Therefore, there is a reasonable expectation that stock length-sized individuals for both species could realistically experience fishing mortality in the absence of a minimum length-limit. Specified lengths could not exceed the value of  $L_{\infty}$  estimated for the population and were set at stock, quality, and preferred-sized (Gabelhouse 1984) for each species. This showed how many individuals above a certain size class (i.e., quality-sized, preferred-size, etc.) survived in different length-limit scenarios under varying rates of conditional fishing mortality.

## **RESULTS**

### **Sampling Effort**

During the Fall 2019, Spring 2020, and Fall 2020 sampling seasons, Ohio Department of Natural Resources (ODNR) and West Virginia Division of Natural Resources (WVDNR) combined to sample black bass in four navigation pools on the Upper Ohio River and four on the Lower Ohio River. West Virginia DNR also sampled two navigation pools on the Kanawha River and three on the Monongahela River. Electrofishing surveys combined for 63.5 hours of effort across the four study reaches: 11.6 hours in the Kanawha River, 10.0 in the Monongahela River, 17.25 hours on the Upper Ohio River, and 24.6 hours on the Lower Ohio River.

Altogether, 1,008 Largemouth and 883 Smallmouth Bass were sampled during black bass electrofishing events, with an additional four Smallmouth Bass collected from ancillary surveys. Of those, 731 Largemouth and 641 Smallmouth Bass were retained for aging; the remaining 519 were released and age-length keys were used to estimate their ages. Results regarding aging, population characteristic estimation, and growth modeling can be found in Chapter 2.



## **Mortality Estimates**

Estimates of total annual ( $A$ ) and instantaneous total mortality ( $Z$ ; in parentheses) obtained from catch-curve analysis ranged from 43.9 to 63.1% (0.577 to 0.996) for Largemouth Bass, while estimates for Smallmouth Bass in these systems ranged from 45.5 to 57.3% (0.607 to 0.851; Table 2). Instantaneous natural mortality ( $M$ ; in parentheses) and conditional natural mortality ( $cm$ ) estimates calculated using Hoenig's (1983) method ranged from 0.3 to 0.45 (0.350 to 0.603) for Largemouth Bass and 0.32 to 0.41 (0.382 to 0.527) for Smallmouth Bass. Using these data, annual fishing mortality ( $u$ ) and conditional fishing mortality ( $cf$ ; in parentheses) for both species in each system was estimated and ranged from 14.8 to 26.9% (0.177 to 0.325) for Largemouth Bass and 7.4 to 23.5% (0.095 to 0.279) for Smallmouth Bass.

## **Length Limit Simulations**

In all systems, yield increased in the presence of any length-limit regulation, except in the cases of 356-mm (14") MLLs on the Kanawha and Upper Ohio rivers when experiencing conditional fishing mortality rates between roughly 5-60% (Fig. 2). Size structure (PSD) declined precipitously for all rivers under no-MLL and 254-mm (10") MLL scenarios, while remaining consistent under larger MLLs (Fig. 3). The number of preferred-sized fish per 1,000 recruits changed little in the Kanawha River regardless of MLL, but the number of preferred-sized fish in the Monongahela and Lower Ohio rivers grew with each increase in MLL (Fig. 4). There is no evidence to suggest that growth overfishing is occurring for any of the modelled Largemouth Bass populations under current estimated rates of fishing mortality.

Trends for Smallmouth Bass were similar to those observed in Largemouth Bass. Expected growth overfishing was predicted to occur in these systems between 20-30% conditional fishing mortality, with no minimum length-limit (Fig. 5). Under current estimated

rates of conditional fishing mortality, none of the modelled populations were at risk of growth overfishing. Yield increased in all length-limit scenarios, with 305-mm (12”) MLLs producing the highest yields at moderate rates of conditional fishing mortality (10-40%). Size structure declined under no-MLL and 256-mm MLL scenarios and remained consistent under 305- and 356-mm MLLs (Fig. 6). The number of preferred-sized fish (350-mm) per 1,000 recruits remained constant in all populations under a 14-inch MLL, then declined with each decrease in MLL (Fig. 7).

## **DISCUSSION**

Largemouth and Smallmouth Bass are economically important species in West Virginia, yet anecdotal evidence suggests that anglers consider these fisheries diminished relative to their historic stocks. Currently, the Ohio River is West Virginia’s only navigable river system managed with length-based regulations for black bass. This study sought to evaluate the impacts of current length-based regulations and simulate the effects of different length-limit regulations under varying levels of conditional fishing mortality. Results suggest that Largemouth Bass in the Kanawha River and Smallmouth Bass in the Kanawha and Monongahela rivers may be at risk of growth overfishing at current estimated rates of conditional fishing mortality. In simulations, all systems benefitted from the different length-limit scenarios; however, the 12” minimum length-limit appeared to create the best balance between yield and size structure.

By modeling fishery yield as a response of conditional fishing mortality (*cf*), the potential for growth overfishing can be calculated (Chestnut-Faull et al. 2021). With no length-limit regulations, Largemouth Bass fisheries in all rivers may experience growth overfishing at conditional fishing mortality rates as low as 36%, whereas Smallmouth Bass could experience growth overfishing at 37%. The data suggests that the likelihood of these populations

experiencing growth overfishing diminishes with each increase in minimum length limit. Under a 12” minimum length-limit, the current regulation on the Ohio River, growth overfishing occurs for Largemouth Bass between *cf* rates of 75% and 95%. Smallmouth Bass experience negative effects from recreational angling when rates of *cf* are between 87% and 95%. Yield-per-recruit models have also shown the benefits of implementing length-limit regulations for other species in this region and in similar systems when the goal is to minimize the likelihood of growth overfishing. Chestnut-Faull et al. (2021) found that Channel Catfish *Ictalurus punctatus* populations in the Monongahela River, which are currently managed with no length-limit regulations, may be experiencing growth overfishing and recommended the implementation of either a 375- or 450-mm minimum length-limit. On the Upper Mississippi River, simulation modeling was used to identify overexploitation thresholds for Channel Catfish, recommending an increase in the minimum length-limit; after the length-limit increase, evaluations showed that the fishery was no longer threatened by overexploitation (Slipke et al. 2002).

In regard to Largemouth and Smallmouth Bass, Beamesderfer and North (1995) found that restrictive length-limits improved the quality of the fishery only when productivity (i.e., growth and recruitment) was high. Wilde (1997) compiled a review on Largemouth Bass fishery responses to length-limit regulations across the species range and found that minimum length-limits increased abundance but failed to increase the size structure of individuals caught by anglers. Hansen et al. (2015) found that increases in Largemouth Bass abundance and angler catch rates following restrictive harvest regulations (i.e., greater minimum length-limits, reduced bag limits) led to negative effects on growth, which were primarily attributed to be density-dependent. Miranda et al. (2017) analyzed data from a 28-year time period that saw fluctuations in the length-limit regime regarding Largemouth Bass on Ross Barnett Reservoir, Mississippi,

and found that voluntary catch-and-release may also explain the fact that these regulations have thus far failed to restructure the population. While certain black bass fisheries currently experienced diminished exploitation rates relative to historic levels, certain species and populations, such as Shoal Bass *Micropterus cataractae* in the Flint River, Georgia, experience exploitation rates of roughly 22% and over 53% of all Shoal Bass captured by anglers were harvested (Sammons 2016). This suggests that although catch-and-release has become a ubiquitous practice in black bass angling culture, exploitation may still play a part in shaping these fisheries, and in some situations, as outlined by Sullivan et al. (2020), may help to alleviate the spread of nuisance black bass populations as a result of climate change.

Other management options exist that should be explored to re-shape the current state of Largemouth and Smallmouth Bass fisheries in the upper Ohio River drainage. Certain populations have been supplemented with stockings (Long et al. 2015), although studies suggest that these stocked individuals disrupted natural diet and habitat partitioning (Sammons 2012) and in some cases only provided no enhancement to fisheries (Hartman and Janney 2006). Findings by Hansen et al. (2015) show that increasing abundance may lead to negative, density-dependent effects on growth for Largemouth Bass, suggesting that initial improvements to relative abundance and angler catch rates may come at the cost of the fisheries' potential to grow large, trophy-sized individuals. Habitat enhancement and restoration is another method for improving black bass fisheries, with emphasis placed on returning impaired systems to their natural states (Long et al. 2015), especially for threatened, endemic species such as Guadalupe *M. treculii* and Redeye Bass *M. coosae*. The river systems in this study were altered to allow for commerce, however, so any attempt to return them to their natural state will certainly diminish the surrounding economies. Similar efforts to return channelized waterways to their natural states

have proven to be extremely costly and labor intensive: the Kissimmee River Restoration project, which was initiated in 1999 to recreate physical and hydrologic attributes of the natural system, is projected to exceed \$1 billion and take more than twenty years to complete (Koebel and Bousquin 2014)

As an alternative to minimum length-limits, harvest slot limits are also a popular method for managing fisheries (Noble and Jones 1999). Ahrens et al. (2019) suggested that harvest slot limits provided the best compromises when considering multiple management objectives (e.g., size structure, angler catch rates), and Gwinn et al. (2013) found that slot limits repeatedly resulted in higher catch rates and more trophy fish caught, relative to conditions under a minimum length-limit. While other options exist to reshape black bass fisheries in the upper Ohio River drainage, one major factor that influences the effectiveness of any regulation is stakeholder buy-in and adherence (Noble and Jones 1999). When considering this, the most parsimonious management option may be to standardize the length-based regulations between the three river systems. The effects of slot-based regulations should also be reviewed in addition to minimum- or maximum-length limits. Prior to this, however, more precise estimates of fishing mortality need to be gathered to make accurate inferences of modeled populations.

## **MANAGEMENT IMPLICATIONS & CONCLUSIONS**

Results from this study suggest that populations of Largemouth and Smallmouth Bass in the Kanawha and Monongahela rivers may benefit from the implementation of length-based regulations, and that fisheries in the Upper and Lower Ohio River are best suited with current regulations. While minimum length-limits may act to increase overall abundance of black bass (Wilde 1997), they may fail to significantly alter size structure (Miranda et al. 2017). Exploitation of black bass fisheries has been shown to vary significantly over time (Allen et al.

2008), mostly due to the shift in angling culture to catch-and-release (Miranda et al. 2017), and from population to population (Allen et al. 2008). However, conditional fishing mortality estimates produced from this study do not exceed those observed in the literature (Spaulding and Rogers 2020; Love et al. 2017; Sammons 2016; Allen et al. 2008). Future studies should focus on estimating more precise rates of exploitation for these fisheries to better understand how recreational fishing is affecting these populations and evaluate whether further change to current regulations is necessary. Tagging studies, in conjunction with creel surveys, have been shown to be a valid method for estimating rates of exploitation while incorporating angler catch (Fontaine et al. 2009). Estimates obtained from efforts like these in the Upper Ohio River and its tributaries may serve to better elucidate the effects length-limit regulations have on these economically important black bass fisheries.

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## TABLES & FIGURES

### Tables

**Table 1.** Mortality parameter notations with corresponding formulas linking their relations, from Miranda and Bettoli (2007).

Mortality Rate	Total	Fishing	Natural
Interval	$A = \mu + v$	$\mu = \frac{FA}{Z}$	$v = \frac{MA}{Z}$
Instantaneous	$Z = F + M$	$F = \frac{\mu Z}{A}$	$M = \frac{vZ}{A}$
Conditional Interval	$cA = cf + cm - cfcm$	$cf = 1 - e^{-F}$	$cm = 1 - e^{-M}$

**Table 2.** Annual, instantaneous, and conditional estimates of mortality for Largemouth Bass in West Virginia’s navigable river systems. Estimates for  $Z$  and  $A$  were obtained from weighted catch-curve regression. Estimates for  $M$  and  $cm$  were calculated using Hoenig’s (1983) t-max equation. From there, relationships obtained from Miranda and Bettoli (2007; Table 2) were used to derive the remaining estimates. Abbreviations for each parameter are italicized.

River	Interval (Annual)			Instantaneous			Conditional		
	Fishing $\mu$	Natural $\nu$	Total $A$	Fishing $F$	Natural $M$	Total $Z$	Fishing $cf$	Natural $cm$	Total $cA$
KAN	0.382	0.249	0.631	0.393	0.603	0.996	0.325	0.45	0.629
MON	0.291	0.148	0.439	0.195	0.382	0.577	0.177	0.32	0.440
UOR	0.341	0.149	0.490	0.205	0.468	0.673	0.185	0.37	0.487
LOR	0.249	0.269	0.518	0.379	0.350	0.729	0.315	0.30	0.521

**Table 3.** Annual, instantaneous, and conditional estimates of mortality for Smallmouth Bass in West Virginia’s navigable river systems. Estimates for  $Z$  and  $A$  were obtained from weighted catch-curve regression. Estimates for  $M$  and  $cm$  were calculated using Hoenig’s (1983) t-max equation. From there, relationships obtained from Miranda and Bettoli (2007; Table 2) were used to derive the remaining estimates. Abbreviations for each parameter are italicized.

River	Interval (Annual)			Instantaneous			Conditional		
	Fishing <i>v</i>	Natural <i>u</i>	Total <i>A</i>	Fishing <i>F</i>	Natural <i>M</i>	Total <i>Z</i>	Fishing <i>cf</i>	Natural <i>cm</i>	Total <i>cA</i>
KAN	0.218	0.355	0.573	0.324	0.527	0.851	0.277	0.41	0.573
MON	0.235	0.273	0.508	0.328	0.382	0.710	0.279	0.32	0.510
UOR	0.169	0.286	0.455	0.225	0.382	0.607	0.201	0.32	0.457
LOR	0.074	0.392	0.466	0.100	0.527	0.627	0.095	0.41	0.466

**Table 4.** Parameter estimates used in yield-per-recruit (YPR) length limit simulations for Largemouth Bass, starting with 1000 total recruits. Length infinity ( $L_{\infty}$ ), Brody growth coefficient ( $K$ ), and  $t_0$  were estimated using von Bertalanffy growth curves fit to back-calculated length-at-age information. Total annual mortality ( $A$ ) was estimated using weighted catch-curve regression and conditional natural mortality ( $cm$ ) was calculated using Hoenig's (1983) method. Coefficients of the weight:length ( $W:L$ ) were incorporated, along with the maximum observed age in each system.

<b>Parameter</b>	<b>Kanawha</b>	<b>Monongahela</b>	<b>Upper Ohio</b>	<b>Lower Ohio</b>
$L_{\infty}$	409.22	496.00	361.44	575.96
$K$	0.38	0.20	0.54	0.19
$t_0$	-0.37	-0.92	-0.14	-0.76
Maximum Age	7.00	11.00	9.00	12.00
$cm$	0.45	0.32	0.37	0.30
$cf$	0.05 to 0.95			
$W:L$ intercept	-5.16	-5.17	-5.20	-5.27
$W:L$ slope	3.13	3.13	3.16	3.18
$W_{\infty}$	1012.95	1886.43	753.84	3197.18
$A$	63.10	43.90	49.00	51.80

**Table 5.** Parameter estimates used in yield-per-recruit (YPR) length limit simulations for Smallmouth Bass, starting with 1000 total recruits. Length infinity ( $L_{\infty}$ ), Brody growth coefficient ( $K$ ), and  $t_0$  were estimated using von Bertalanffy growth curves fit to back-calculated length-at-age information. Total annual mortality ( $A$ ) was estimated using weighted catch-curve regression and conditional natural mortality ( $cm$ ) was calculated using Hoenig's (1983) method. Coefficients of the weight:length ( $W:L$ ) were incorporated, along with the maximum observed age in each system.

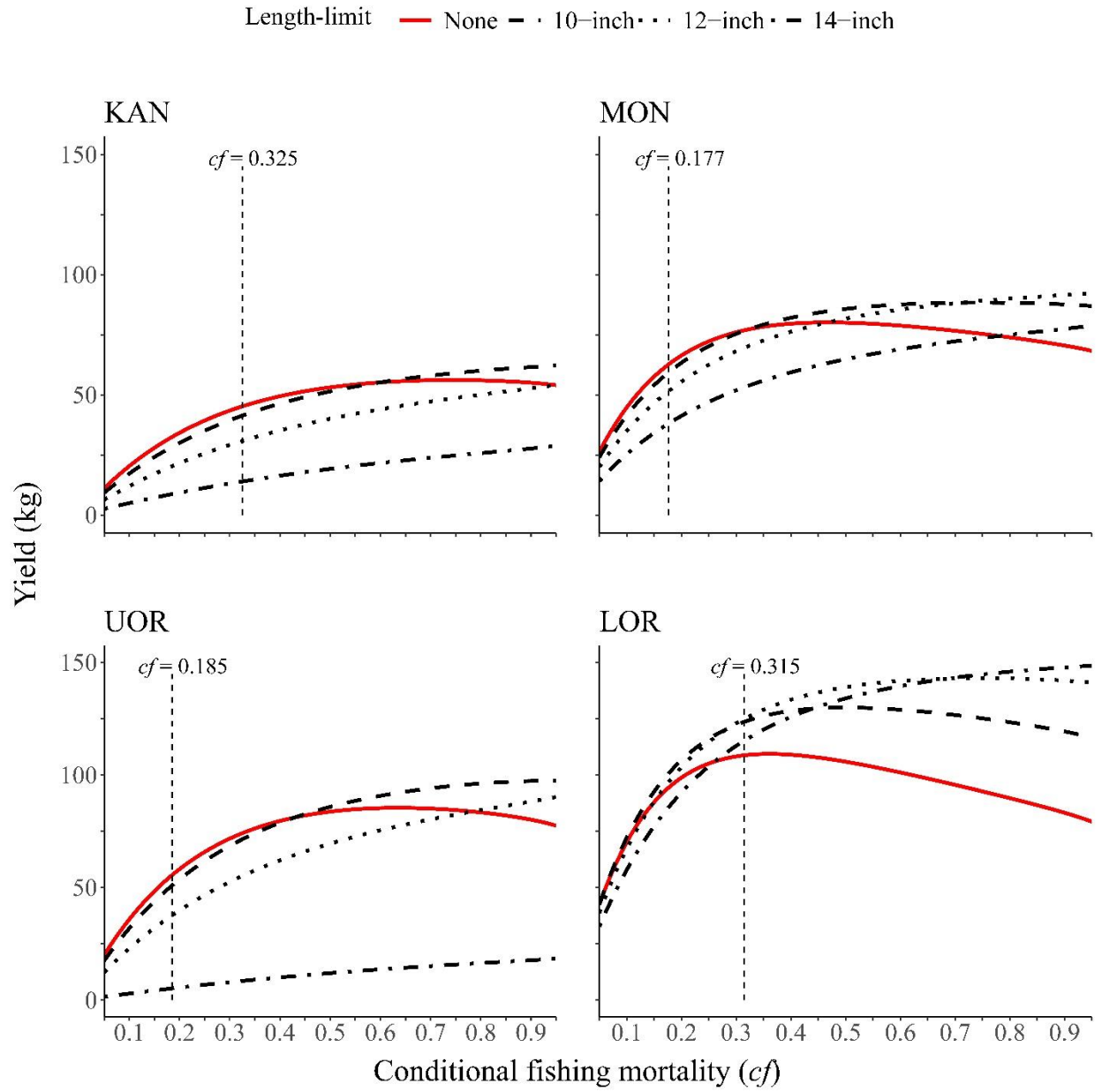
<b>Parameter</b>	<b>Kanawha</b>	<b>Monongahela</b>	<b>Upper Ohio</b>	<b>Lower Ohio</b>
$L_{\infty}$	480.15	542.32	555.44	479.49
$K$	0.22	0.15	0.21	0.30
$t_0$	-0.51	-0.75	-0.55	-0.53
Maximum Age	8.00	11.00	11.00	8.00
$cm$	0.41	0.32	0.32	0.41
$cf$	0.05 to 0.95			
WL: int	-4.97	-5.06	-5.03	-5.42
WL: slope	3.02	3.07	3.07	3.25
$W_{\infty}$	1366.10	2139.61	2506.32	1914.83
$A$	57.30	50.80	45.50	46.60

Figures

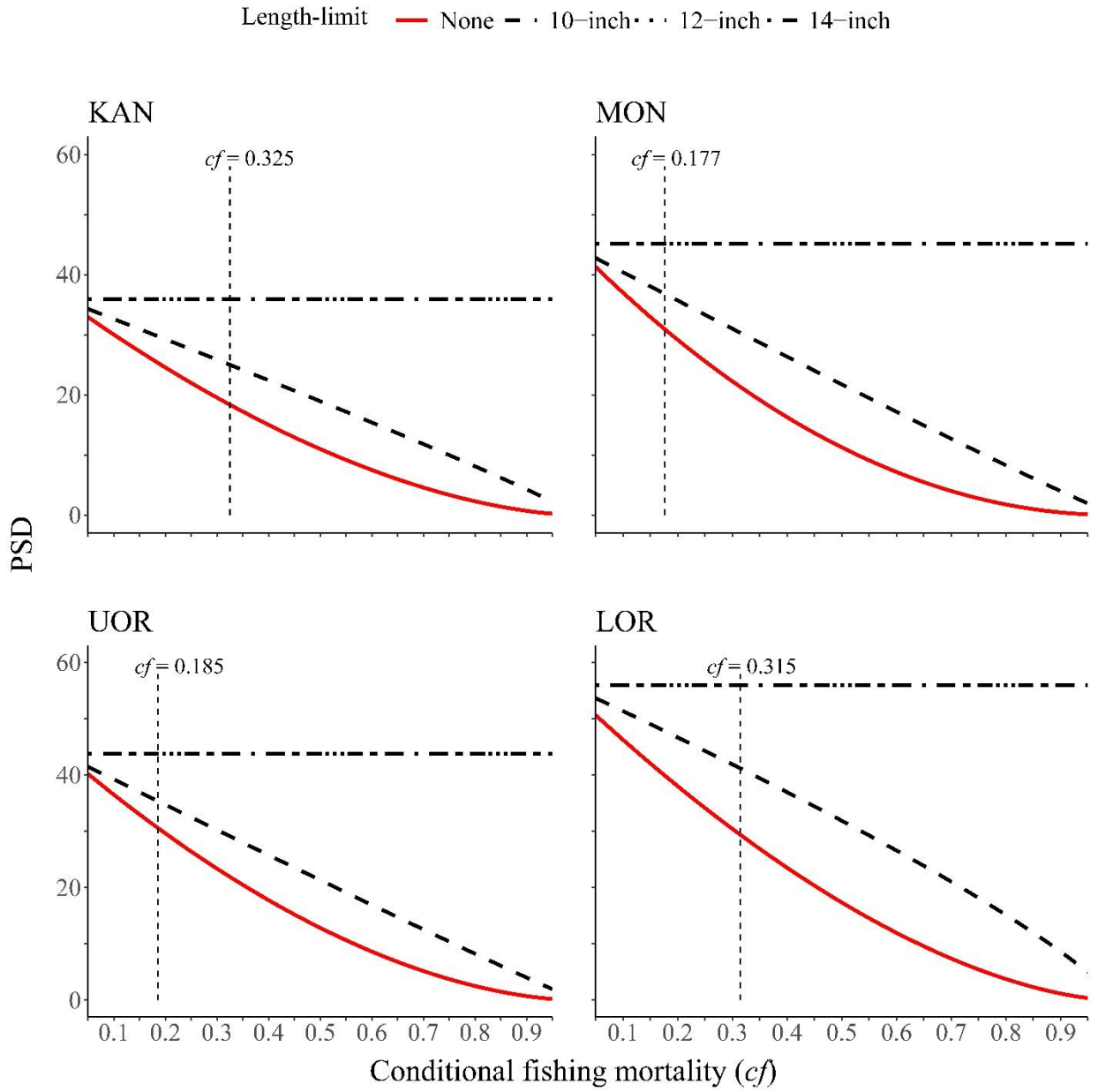


**Figure 1.** Map of the Ohio, Kanawha, and Monongahela rivers, with focus on the extent of each river sampled for black bass. Navigation pools sampled in this study are highlighted and listed in the legend from upstream to downstream, with select cities shown for spatial reference.

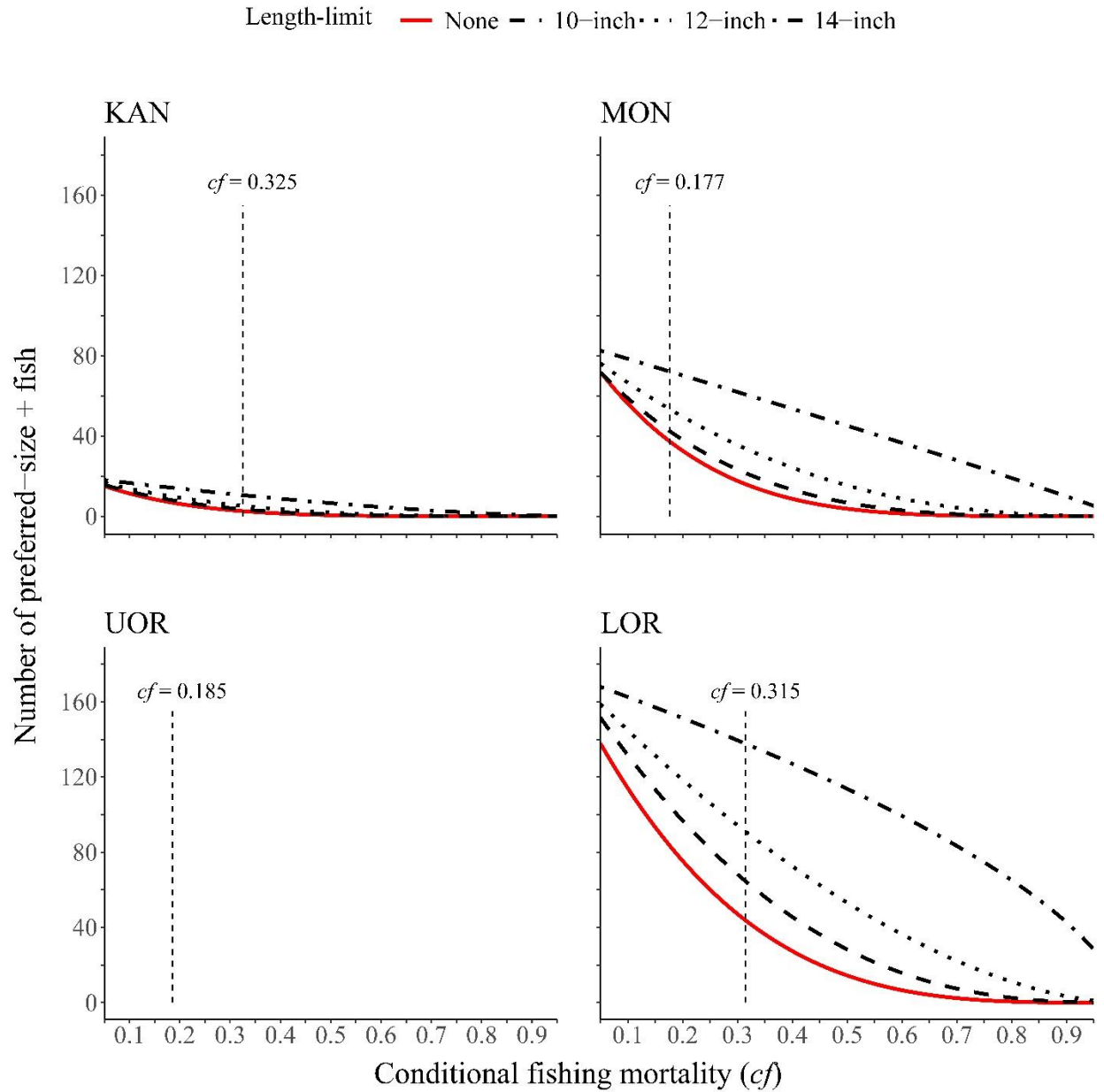




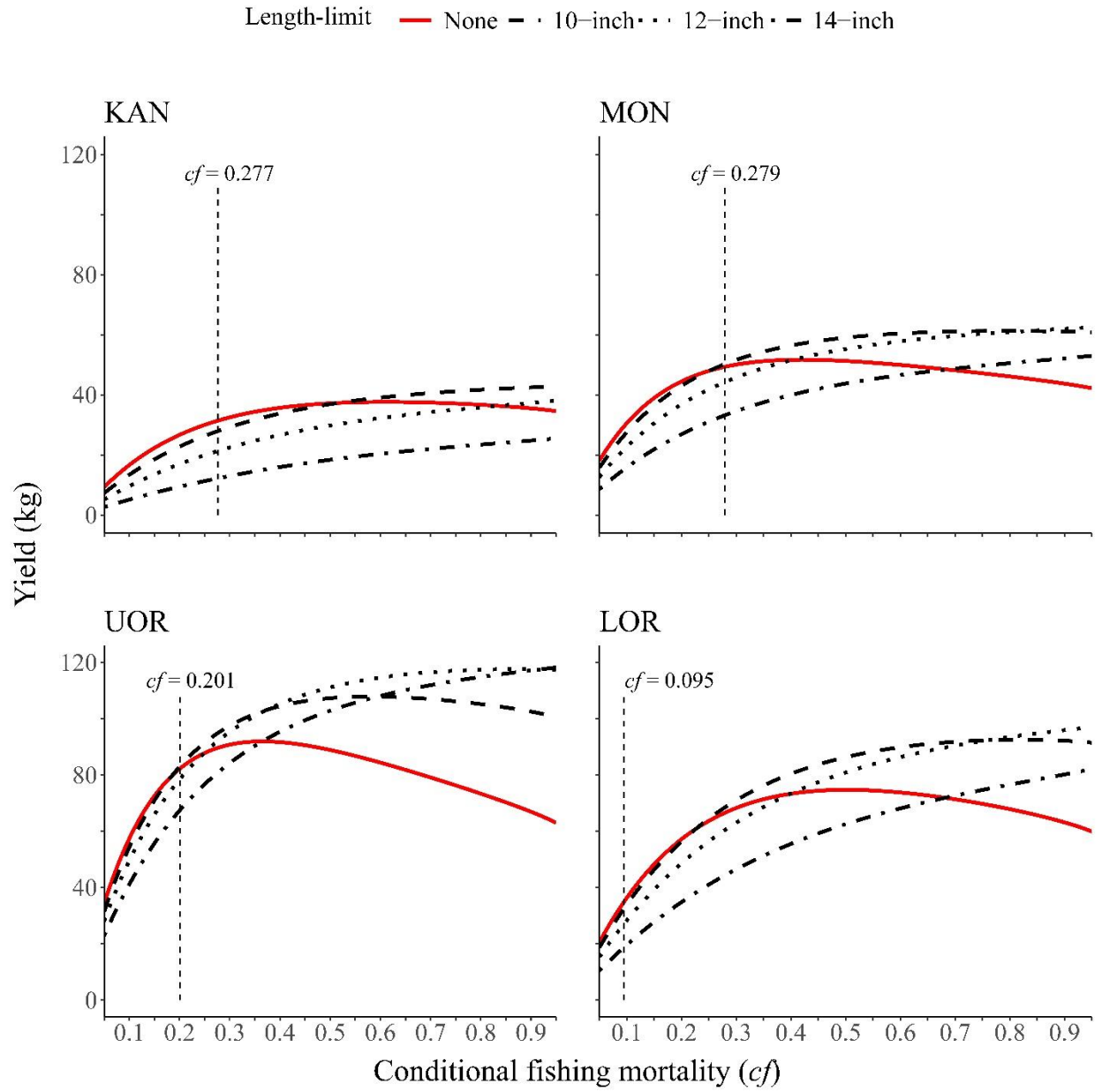
**Figure 2.** Yield-per-recruit models for Largemouth Bass study populations under different length-limit scenarios. Models were built using theoretical cohorts of 1,000 fish.



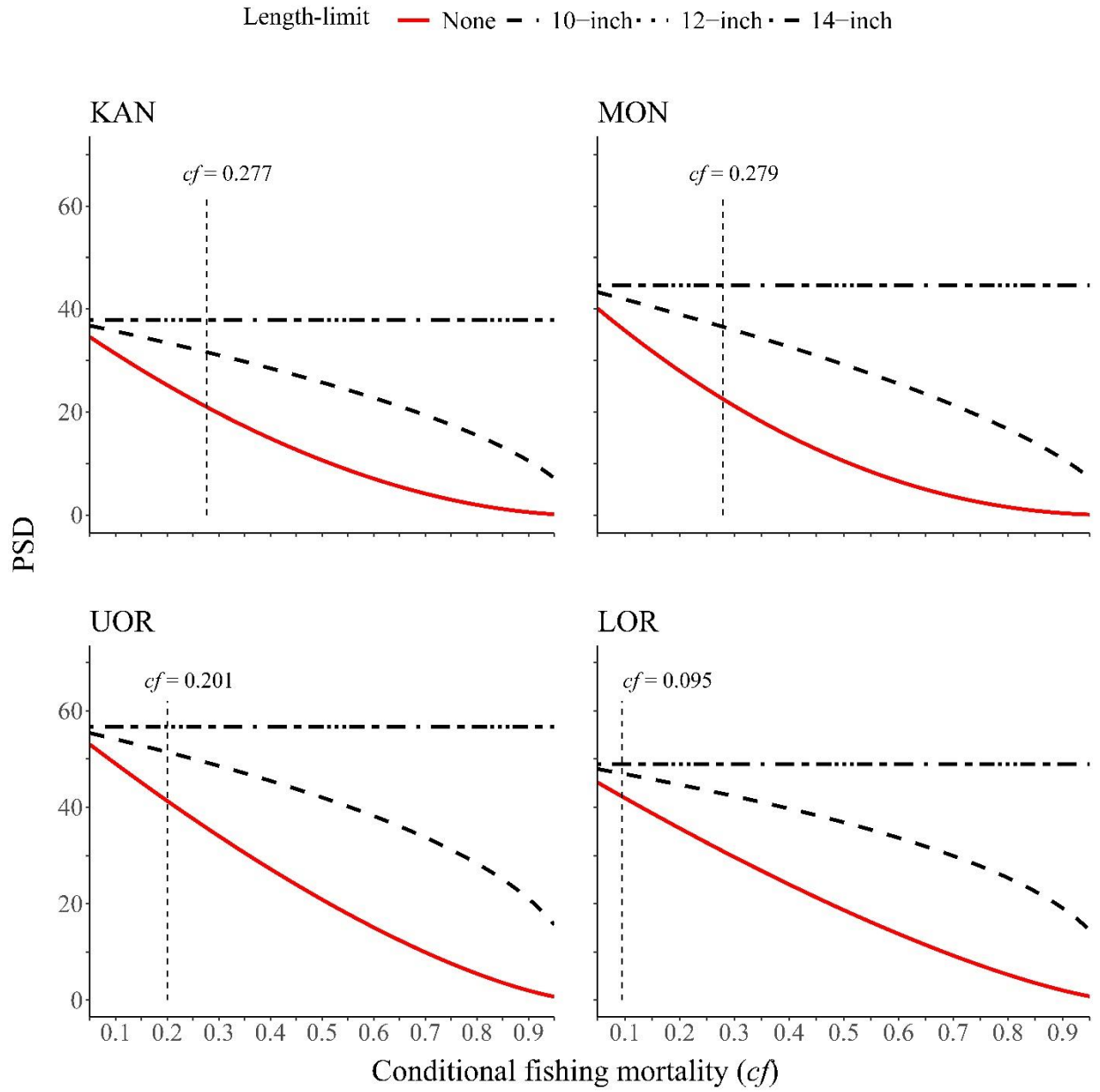
**Figure 3.** Proportional size distribution (PSD) output from yield-per recruit simulations under varying length limit scenarios for Largemouth Bass. Models were built using theoretical cohorts of 1,000 fish.



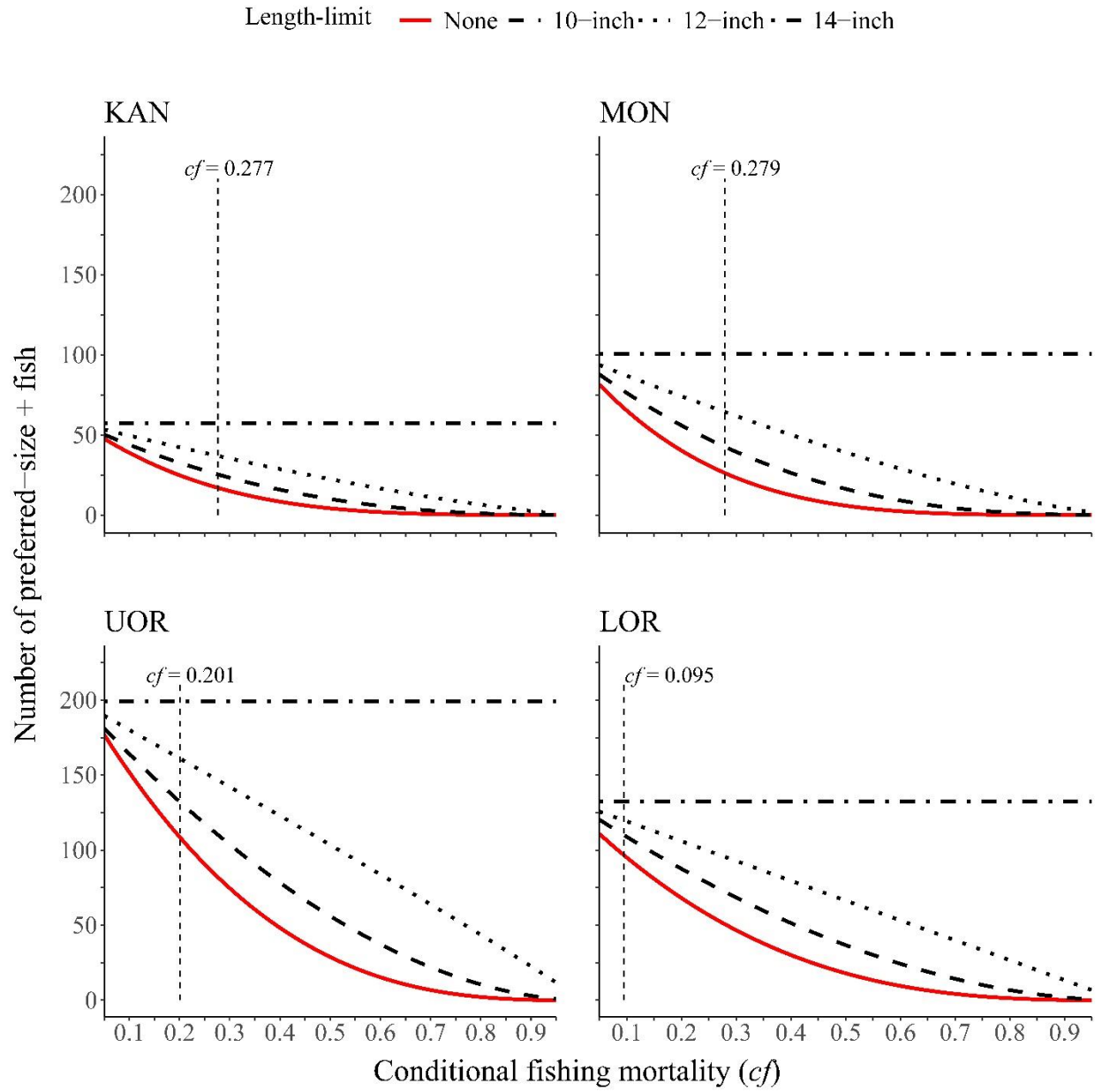
**Figure 4.** Number of surviving Largemouth Bass preferred-size (380mm) and above under varying length-limit scenarios. Models were built using theoretical cohorts of 1,000 fish. No figure for the Upper Ohio was generated due to preferred-size exceeding  $L_{\infty}$  for the population.



**Figure 5.** Yield-per-recruit models for Smallmouth Bass study populations under different length-limit scenarios. Models were built using theoretical cohorts of 1,000 fish.



**Figure 6.** Proportional size distribution (PSD) output from yield-per recruit simulations under varying length limit scenarios for Smallmouth Bass. Models were built using theoretical cohorts of 1,000 fish.



**Figure 7.** Number of surviving Smallmouth Bass preferred-size (350mm) and above under varying length-limit scenarios. Models were built using theoretical cohorts of 1,000 fish.

**APPENDIX: CHAPTER 2 SUPPLEMENTARY TABLES & FIGURES**

**TABLES**

**Table S-1.** Summary of black bass collected and aged by WVU personnel from 2019-2020. Number of fish (n), percent agreement, average standard deviation (ASD), average absolute deviation (AAD), average coefficient of variation (ACV) and average percent error (APE) was calculated for all fish aged in addition to individual species.

<b>Species</b>	<b>n</b>	<b>Number of Agers</b>	<b>Percent Agree</b>	<b>ASD</b>	<b>AAD</b>	<b>ACV</b>	<b>APE</b>
All Black Bass	777	2	94.47	0.05	0.03	3.09	2.19
Largemouth Bass	206	2	91.75	0.07	0.05	4.81	3.40
Smallmouth Bass	373	2	95.44	0.04	0.03	1.90	1.34
Spotted Bass	198	2	95.45	0.03	0.02	3.56	2.52

**Table S-2.** Results of chi-square tests for ager bias suggested by Evans and Hoenig (1989).

<b>Test</b>	<b>df</b>	<b><math>\chi^2</math></b>	<b>p</b>
McNemar	1	0.209	0.647
Evans-Hoenig	2	0.587	0.746
Bowker	13	18.733	0.132

**Table SLMB-1.** Number of largemouth bass observed in each of the Gabelhouse (1984) five-cell size-categories from 2019-2020, including substock-sized fish.

<b>River</b>	<b>Substock</b>	<b>Stock</b>	<b>Quality</b>	<b>Preferred</b>	<b>Memorable</b>	<b>Trophy</b>	<b>Total</b>
Kanawha	23	69	26	5	-	-	123
Monongahela	63	84	31	9	1	-	188
Upper Ohio	78	23	17	3	-	-	121
Lower Ohio	251	220	88	15	-	-	574

**Table SLMB-2.** Total number of Largemouth Bass (n) and mean relative weight (Wr) among Gabelhouse (1984) five-cell size categories for each study reach. Only fish collected in fall samplings were included in condition analyses.

River		*Sub-stock (< 200mm)	Stock (200mm)	Quality (300mm)	Preferred (380mm)	Memorable (510mm)	Total
Kanawha	n	11	69	26	5	NA	111
	Wr	109.3	101.1	102.6	102.4	NA	102.3
Monongahela	n	16	55	22	5	1	99
	Wr	109.9	104.8	99.3	97.0	90.2	103.9
Upper Ohio	n	35	14	10	3	NA	62
	Wr	120.3	112.5	103.7	111.0	NA	115.4
Lower Ohio	n	131	154	74	15	NA	374
	Wr	115.1	107.9	106.2	96.9	NA	109.6

\* Wr applicable to largemouth bass exceeding 150 mm (Henson 1991), leading to the exclusion of some individuals (<150 mm) from condition analyses.

**Table SSMB-1.** Number of Smallmouth Bass observed in each of the Gabelhouse (1984) five-cell size-categories from 2019-2020, including substock-sized fish.

River	Substock	Stock	Quality	Preferred	Memorable	Trophy	Total
Kanawha	193	82	13	4	2	1	295
Monongahela	88	105	15	8	-	1	217
Upper Ohio	46	76	35	15	7	-	179
Lower Ohio	102	41	25	17	7	-	192

**Table SSMB-2.** Total number of Smallmouth Bass (n) and mean relative weight (Wr) among Gabelhouse (1984) five-cell size categories for each study reach. Only fish collected in fall samplings were included in condition analyses.

River		*Sub-stock (< 180mm)	Stock (180mm)	Quality (280mm)	Preferred (350mm)	Memorable (430mm)	Trophy (510mm)	Total
Kanawha	n	80	79	13	4	2	1	179
	Wr	87.2	88.0	90.7	84.7	95.2	84.0	87.8
Monongahela	n	33	78	9	7	NA	NA	127
	Wr	99.0	90.8	85.0	90.3	NA	NA	92.5
Upper Ohio	n	7	70	30	14	7	NA	128
	Wr	102.6	98.8	95.9	96.4	87.7	NA	97.5
Lower Ohio	n	41	40	17	14	6	NA	118
	Wr	107.0	108.0	100.6	107.1	116.6	NA	106.9

\* Wr applicable to smallmouth bass exceeding 150 mm (Kolander et al. 1993), leading to the exclusion of some individuals (<150 mm) from condition analyses.



**Table SSPB-1.** Number of Spotted Bass observed in each of the Gabelhouse (1984) five-cell size-categories from 2019-2020, including substock-sized fish.

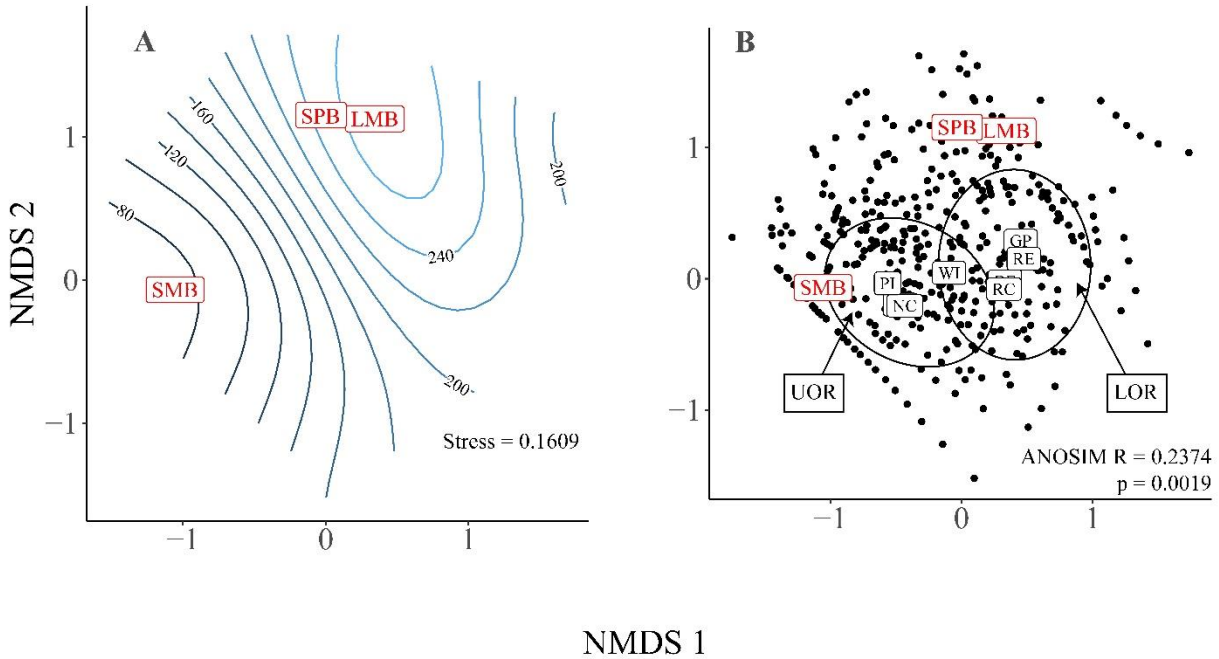
<b>River</b>	<b>Substock</b>	<b>Stock</b>	<b>Quality</b>	<b>Preferred</b>	<b>Memorable</b>	<b>Trophy</b>	<b>Total</b>
Kanawha	50	33	10	-	-	-	93
Monongahela	106	83	7	-	-	-	196
Upper Ohio	22	10	5	-	-	-	37
Lower Ohio	115	35	10	5	-	-	165

**Table SSPB-2.** Total number of Spotted Bass (n) and mean relative weight (Wr) among Gabelhouse (1984) five-cell size categories for each study reach. Only fish collected in fall samplings were included in condition analyses.

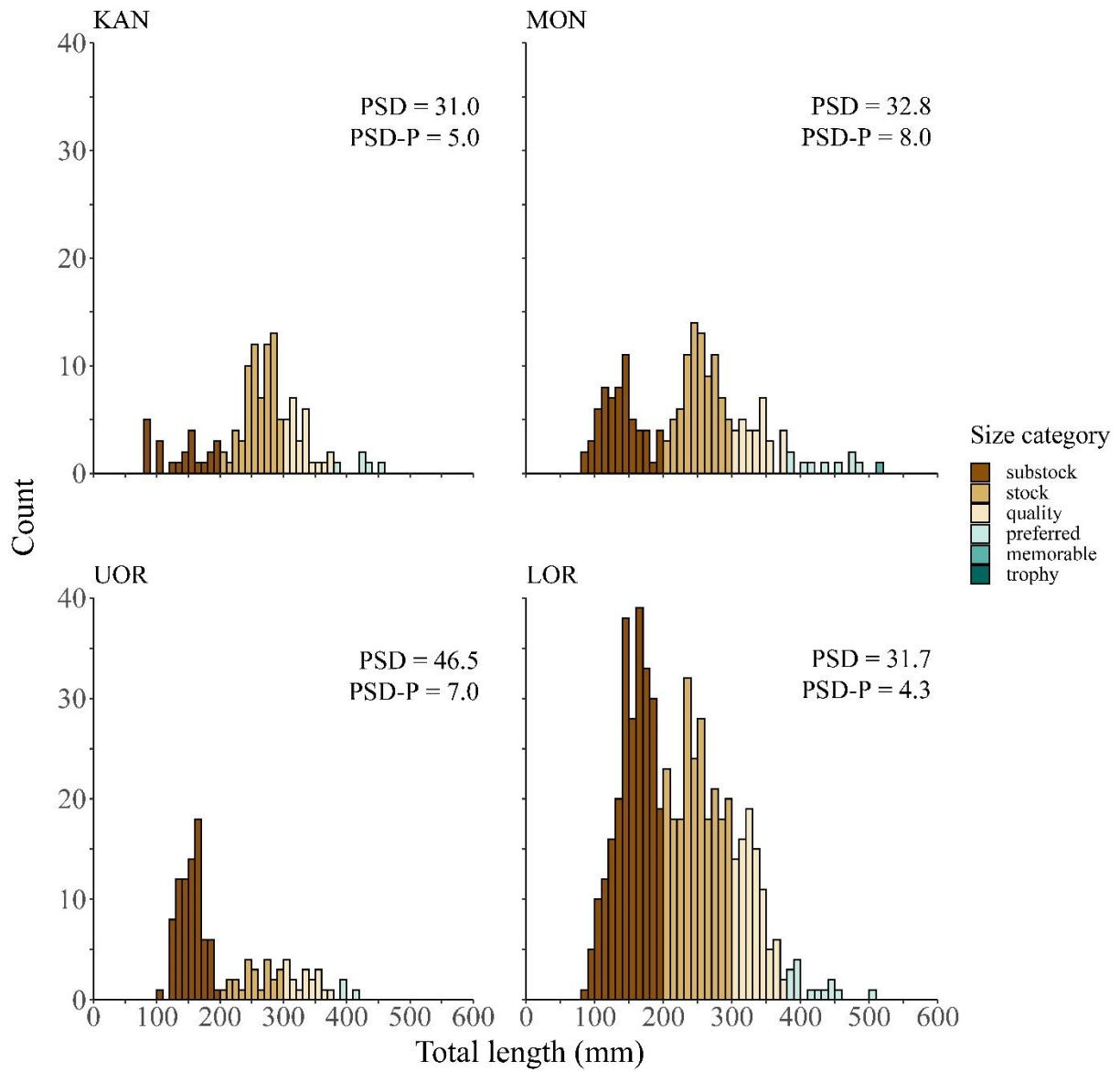
<b>River</b>		<b>*Sub-stock (&lt; 180mm)</b>	<b>Stock (180 mm)</b>	<b>Quality (280mm)</b>	<b>Preferred (350mm)</b>	<b>Total</b>
Kanawha	n	43	33	10	NA	86
	Wr	104.8	103.9	107.5	NA	104.8
Monongahela	n	58	56	3	NA	117
	Wr	103.2	100.7	87.9	NA	101.6
Upper Ohio	n	17	8	5	NA	30
	Wr	110.4	102.5	98.5	NA	106.3
Lower Ohio	n	81	35	8	5	129
	Wr	107.7	107.5	107.0	100.0	107.3

\* Wr applicable to spotted bass exceeding 100 mm (Wiens et al. 1996), leading to the exclusion of some individuals (<100 mm) from condition analyses.

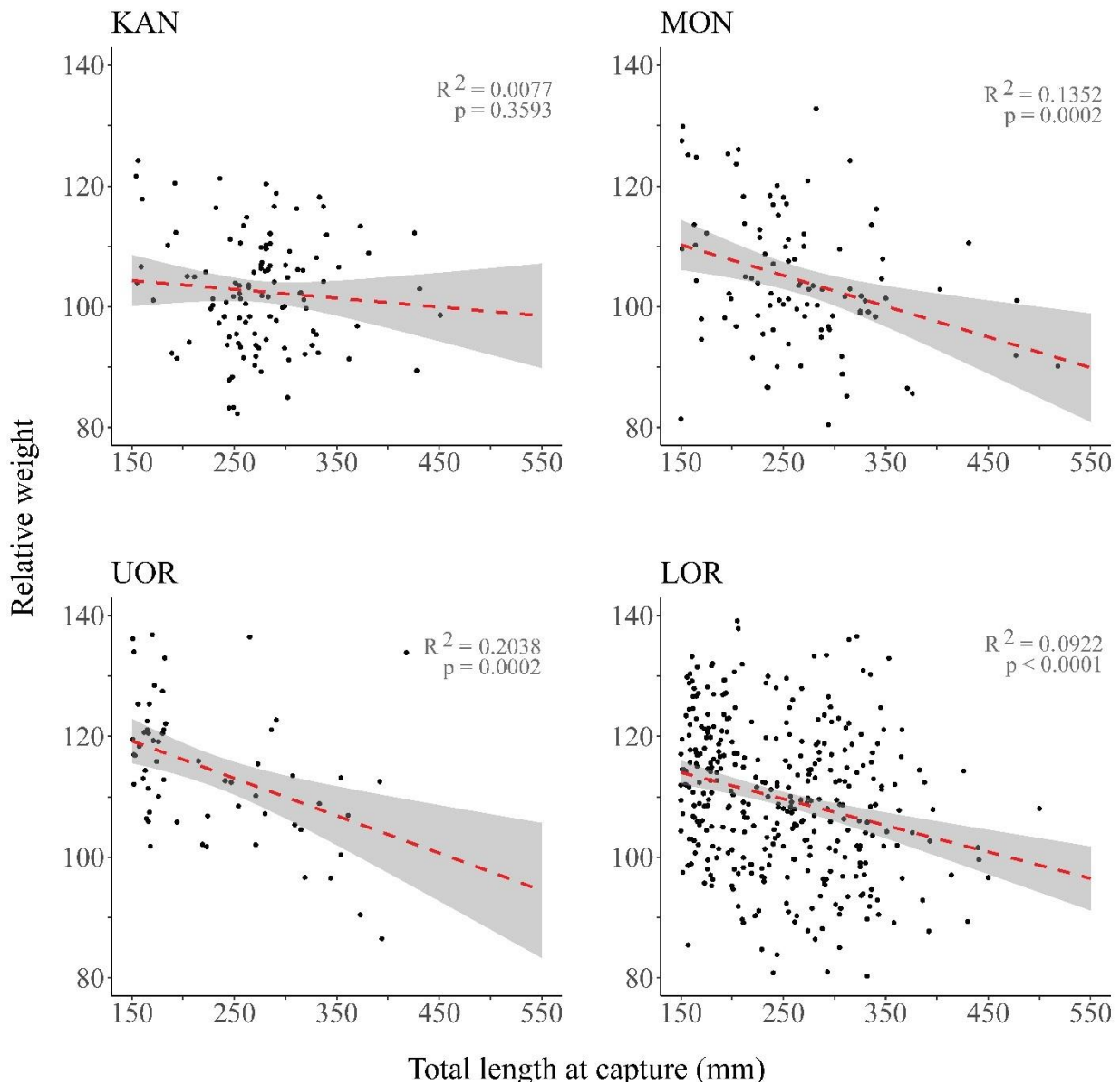
**FIGURES**



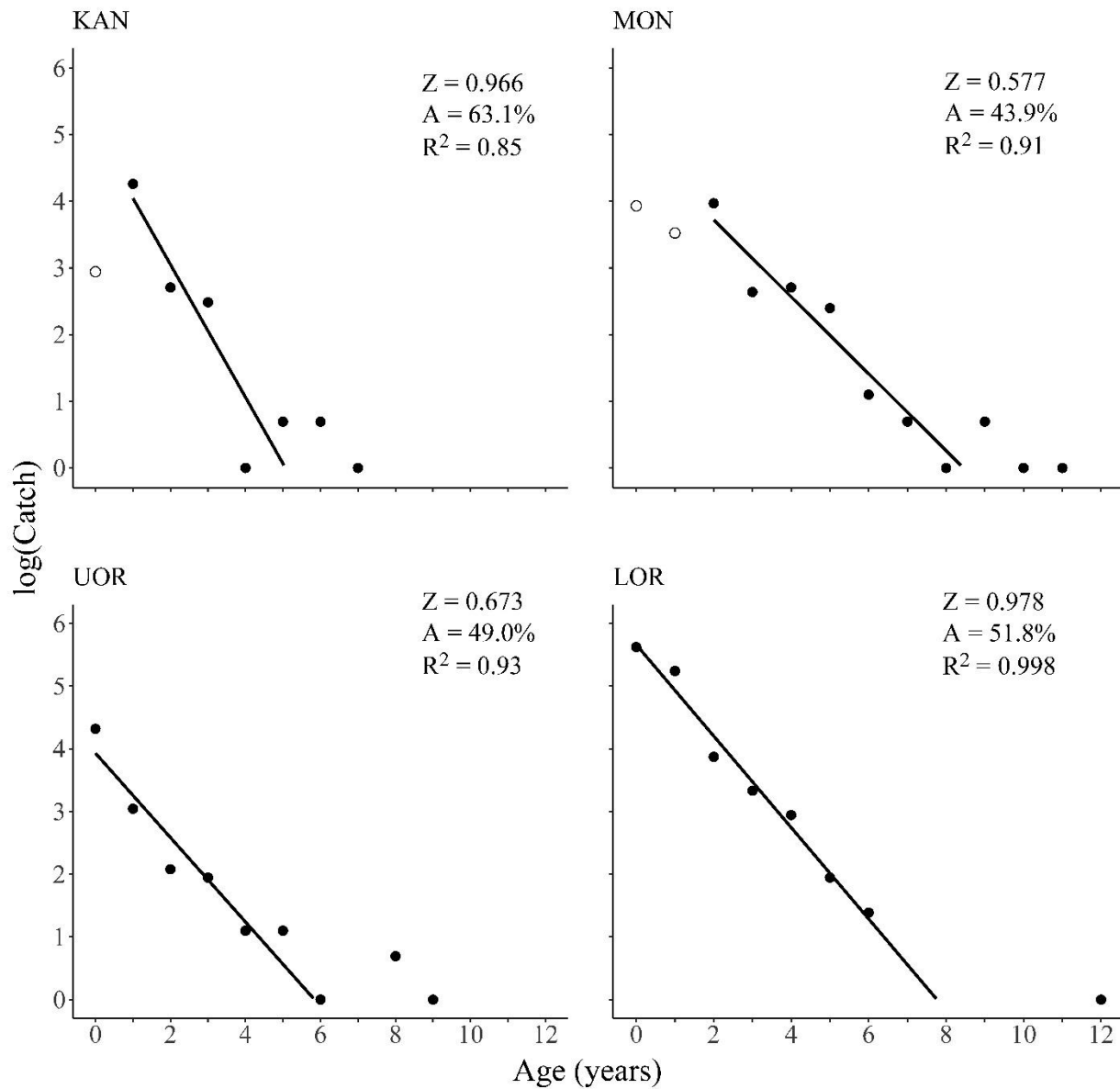
**Figure S-1.** Results from a non-metric multidimensional scaling (NMDS) analysis performed on ORSANCO black bass survey data on the Ohio River from 1958-2018. **A)** Contour plot showing trends in catch data along the river gradient. Contour labels correspond to river mile (0 = Pittsburgh, PA) and abbreviations indicate where catch data trended towards higher proportions of each species. **B)** Individual survey points, with ellipses drawn around two distinct groups: Upper (UOR) and Lower (LOR) Ohio River pools. Analysis of similarity (ANOSIM) shows a significant ( $\alpha = 0.05$ ) difference in the shape and orientation of each ellipse along the ordination.



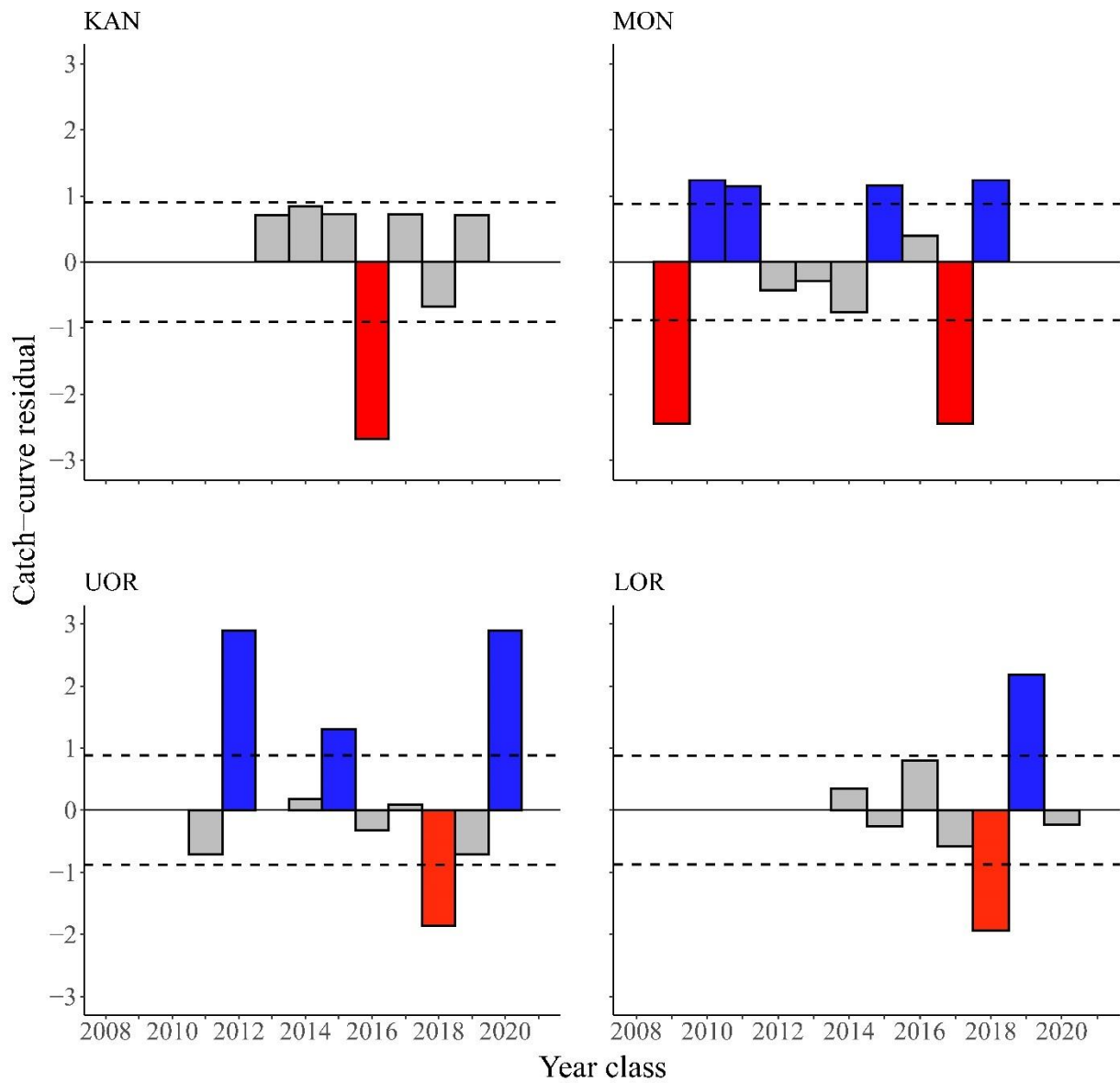
**Figure SLMB-1.** Size distribution of Largemouth Bass sampled in 2019 and 2020, grouped into 10-mm length bins to align with size-category cutoffs. Colors correspond to different Gabelhouse (1984) size categories.



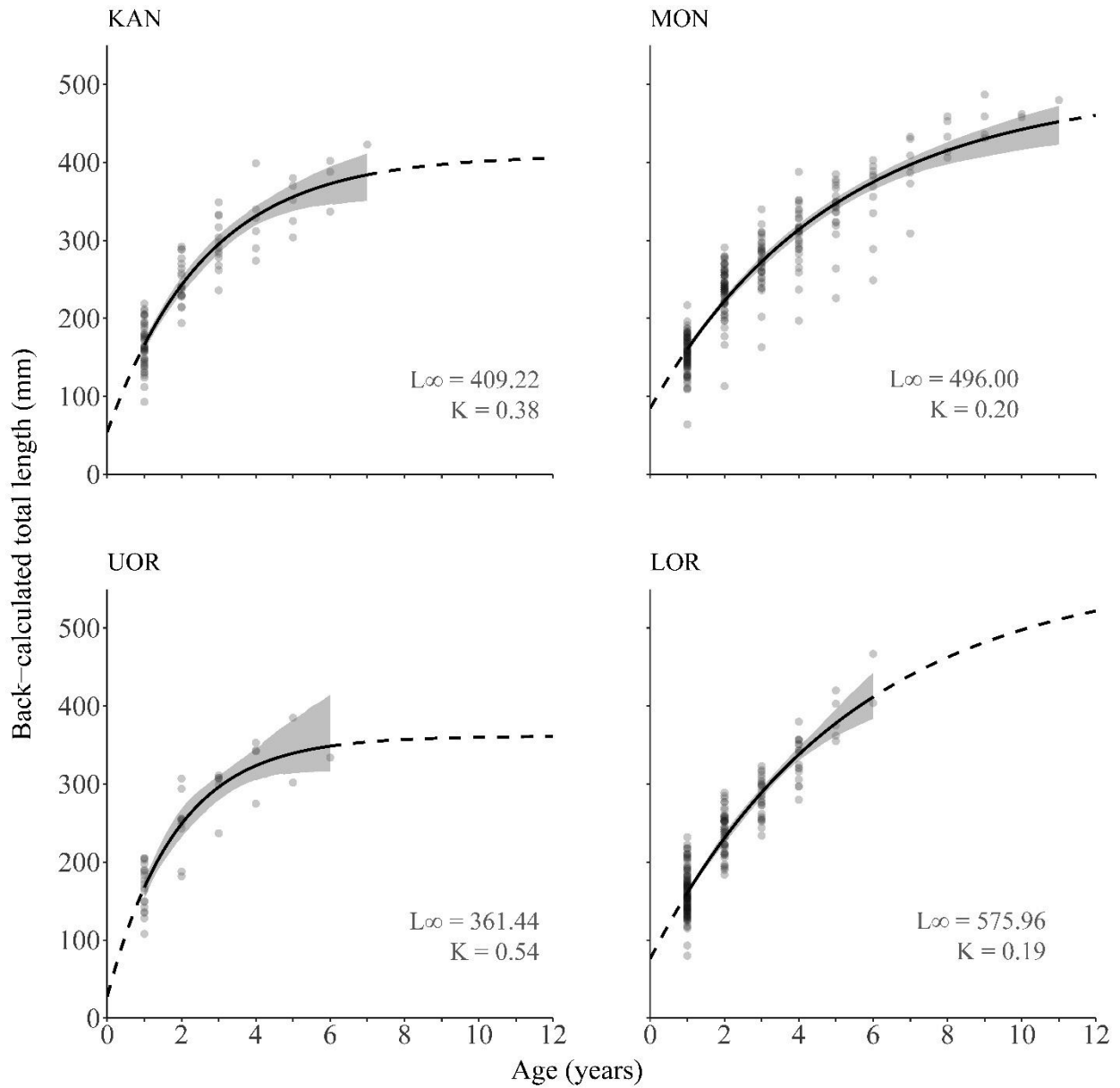
**Figure SLMB-2.** Linear models displaying the relationship between total length and relative weight of Largemouth Bass sampled in this study. The red, dashed line represents the least-squares regression between the two variables, with the gray, shaded region displaying 95% confidence intervals. P-values correspond to the significance of the effect that total length has on relative weight ( $\alpha = 0.05$ ).



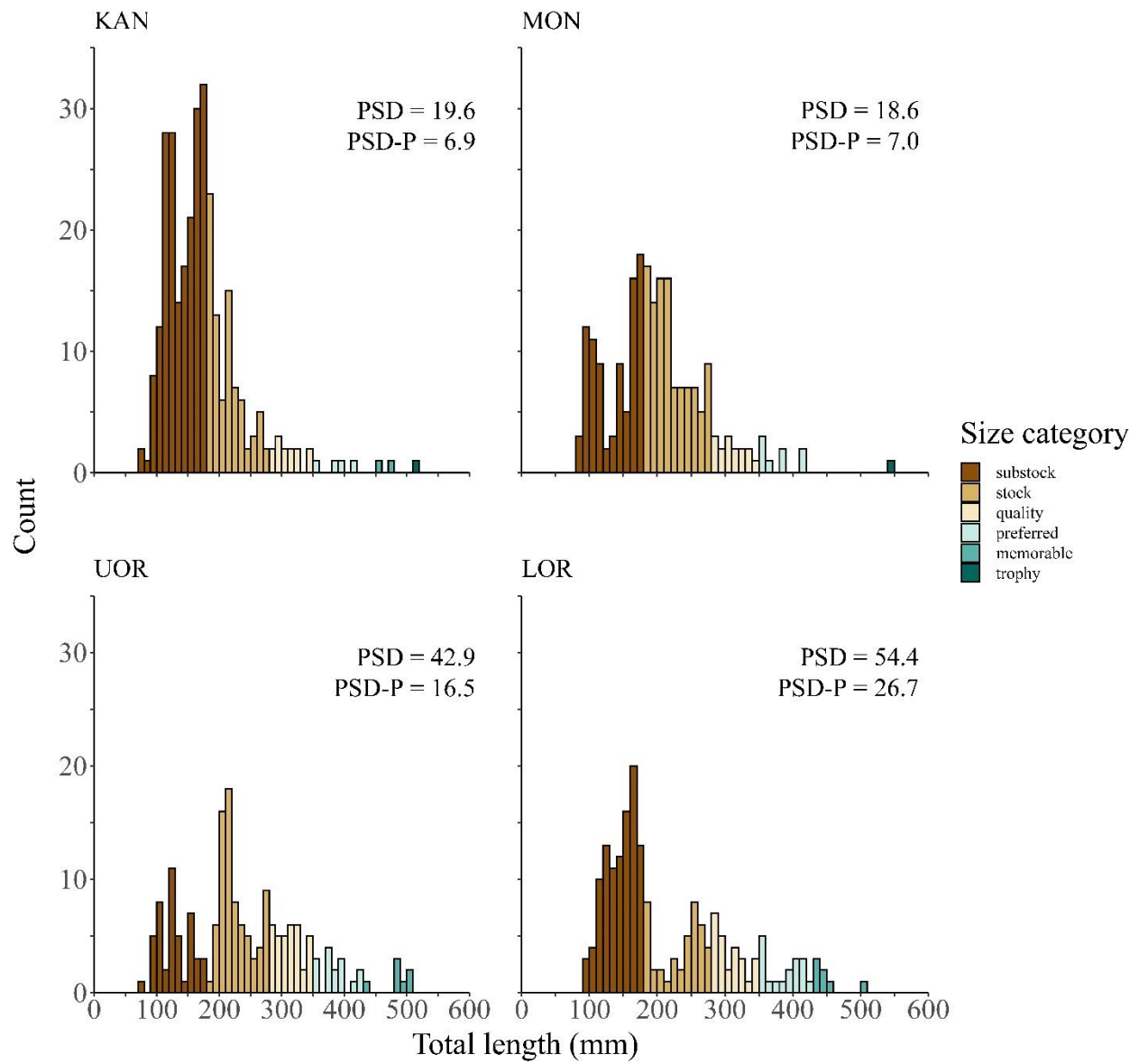
**Figure SLMB-3.** Weighted catch-curve regression used to estimate instantaneous (Z) and total annual (A) mortality for Largemouth Bass sampled in 2019 and 2020. Open points represent year-classes that had not yet fully recruited to the sampling gear and were not included in mortality estimation.



**Figure SLMB-4.** Histograms of studentized residuals from catch-curve regressions of log-transformed catch-at-age information collected from Largemouth Bass in this study. Dashed lines correspond to 20<sup>th</sup> (lower) and 80<sup>th</sup> (upper) percentile residuals. Year-classes above the 80<sup>th</sup> percentile are deemed “strong” (blue bars) and those below the 20<sup>th</sup> are deemed “weak” (red bars).

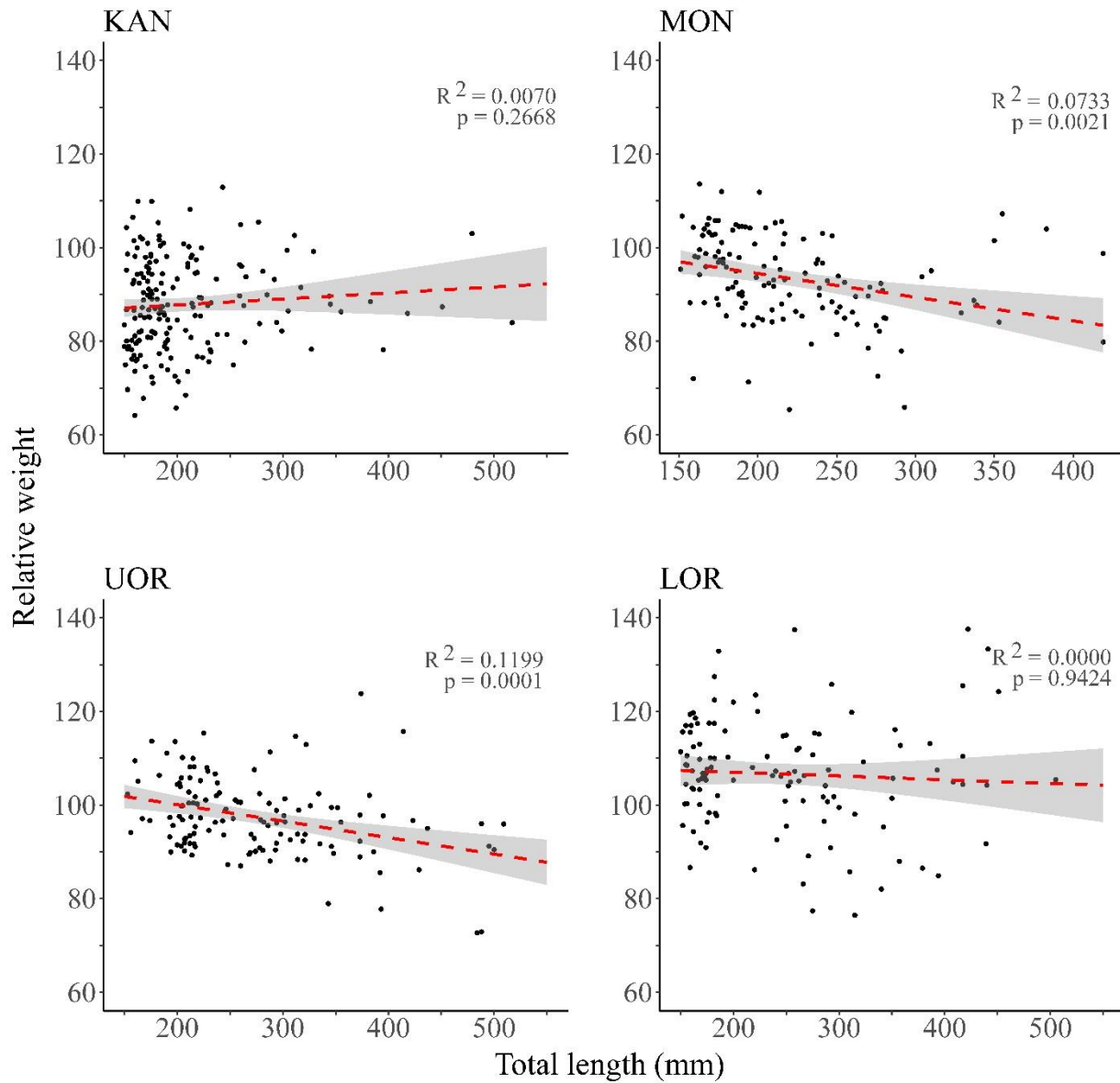


**Figure SLMB-5.** von Bertalanffy growth curve generated from Largemouth Bass back-calculated length-at-age information. The solid line portion represents estimations from observed data, whereas the dashed line represents projections based upon the equation. Shaded regions represent 95% confidence intervals.

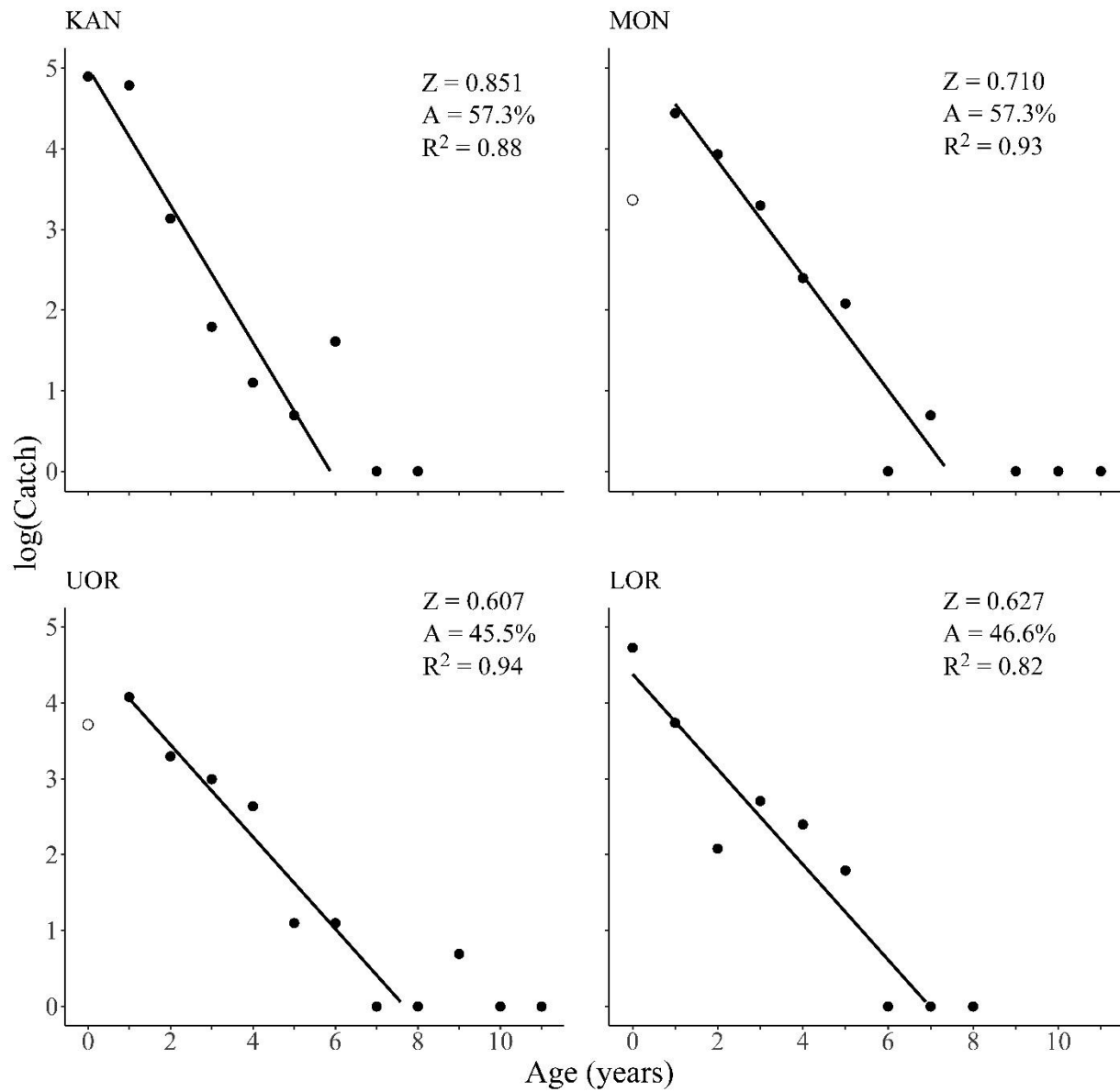


**Figure SSMB-1.** Size distribution of Smallmouth Bass sampled in 2019 and 2020, grouped into 10-mm length bins to align with size-category cutoffs. Colors correspond to different Gabelhouse (1984) size categories.

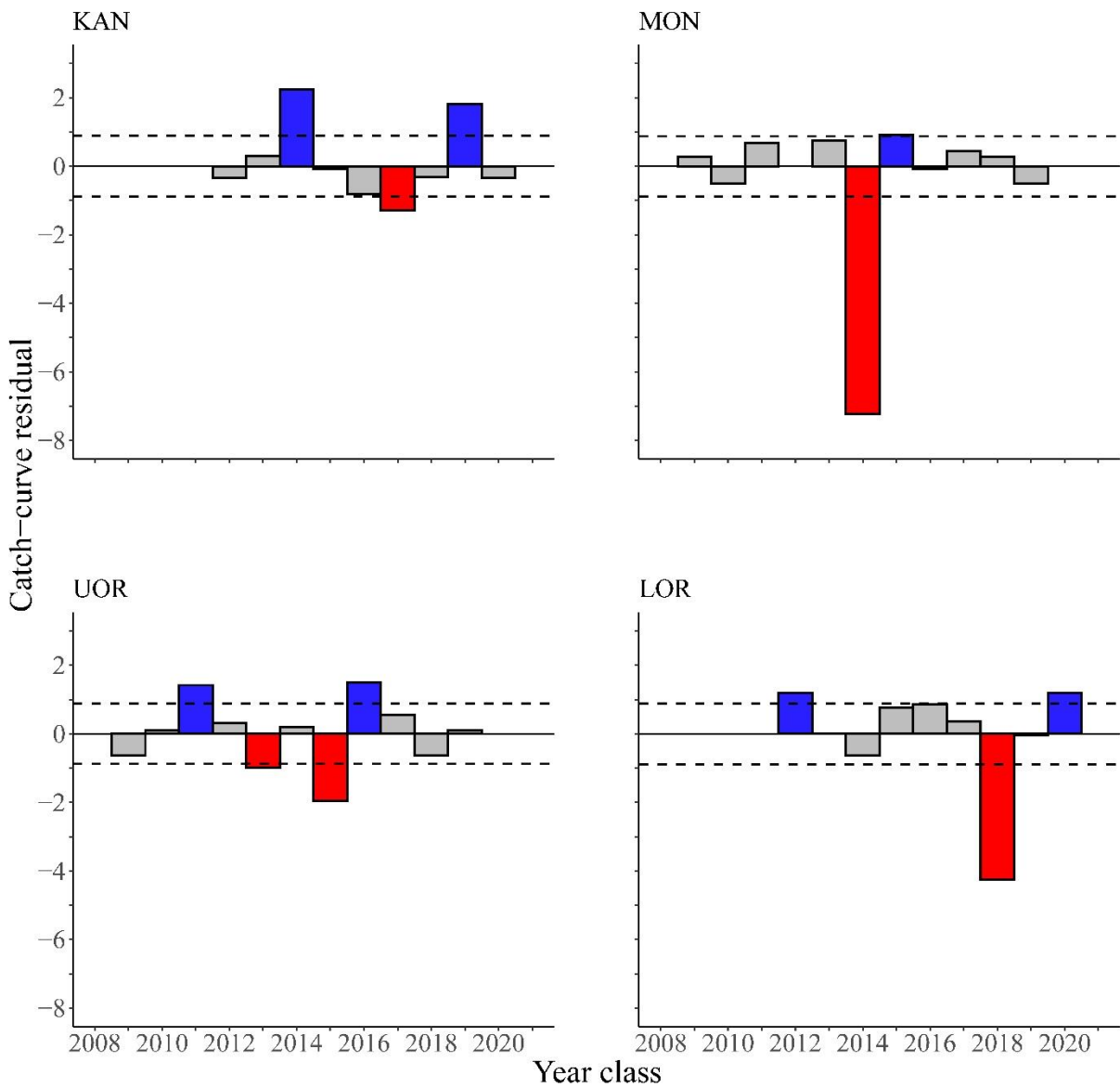




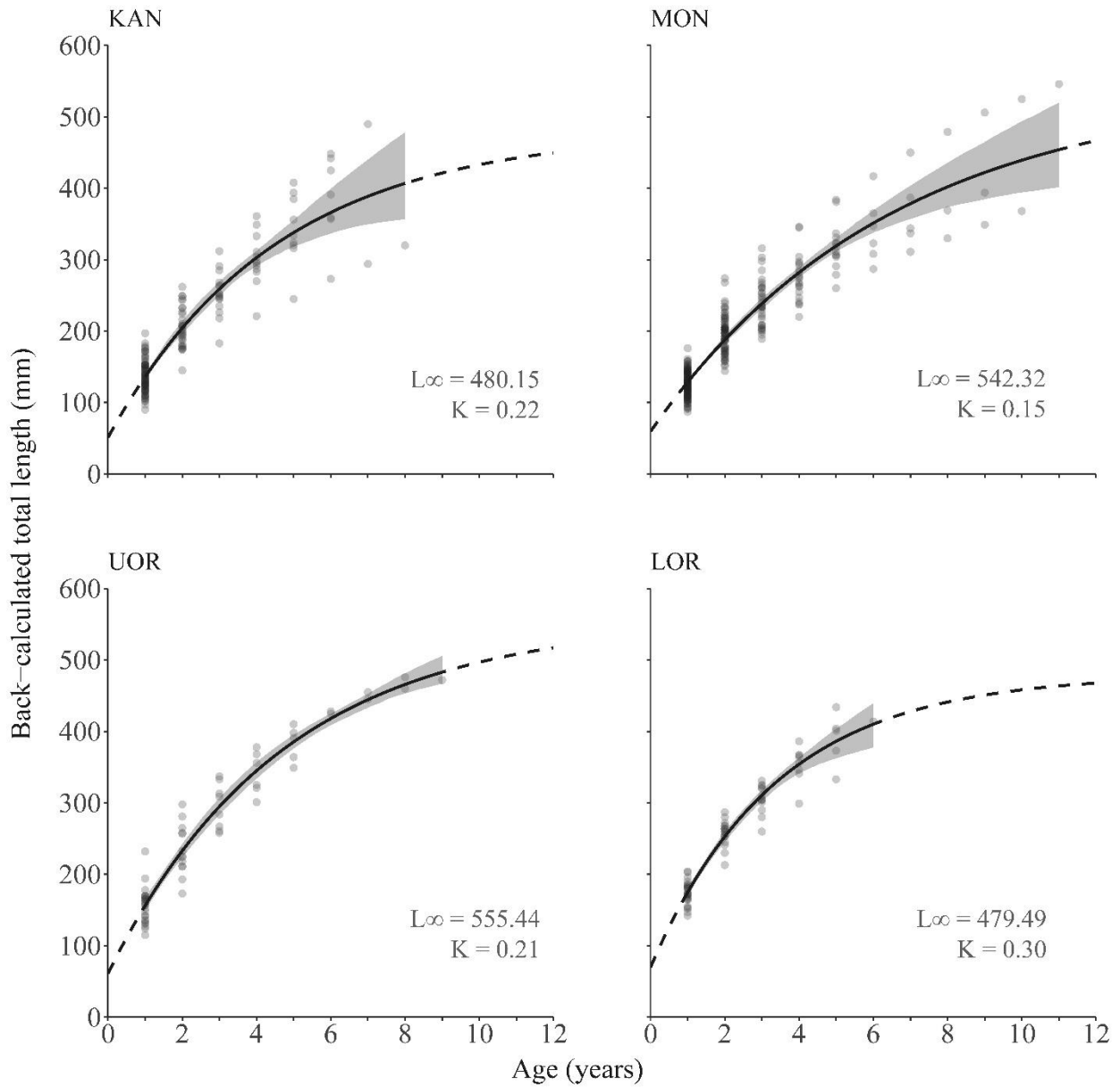
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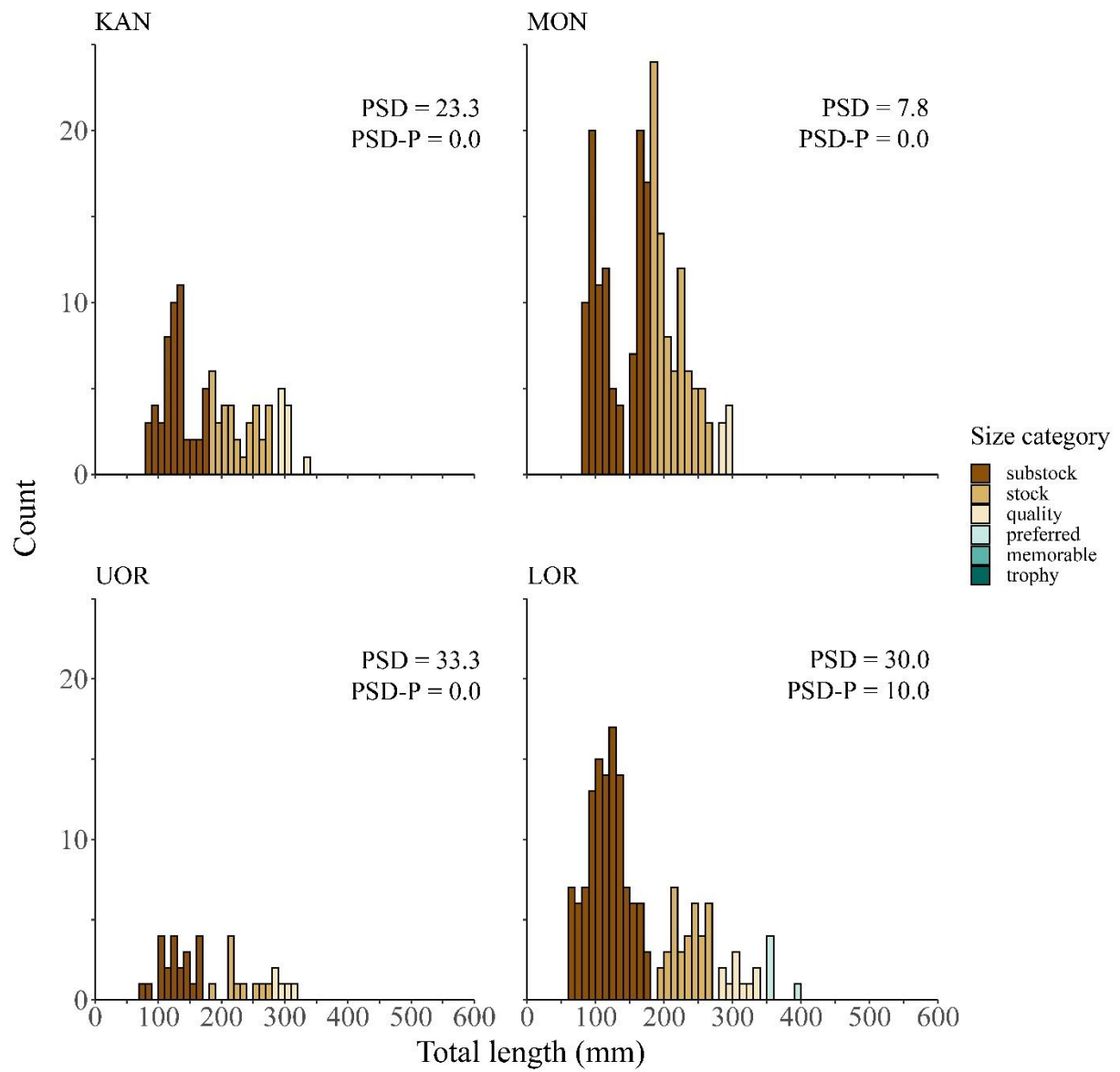
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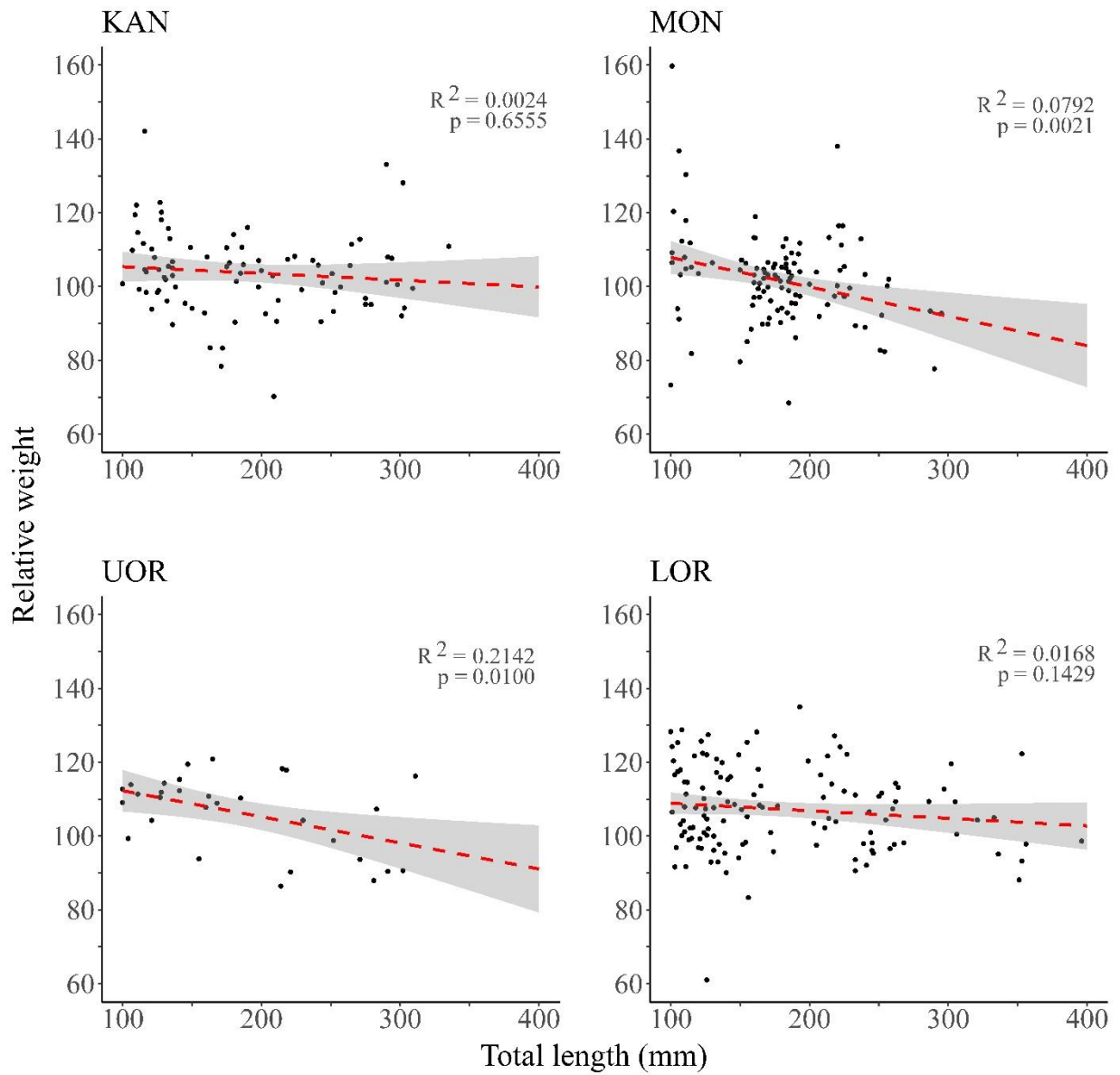
**Figure SSMB-4.** Histograms of studentized residuals from catch-curve regressions of log-transformed catch-at-age information collected from Smallmouth Bass in this study. Dashed lines correspond to 20<sup>th</sup> (lower) and 80<sup>th</sup> (upper) percentile residuals. Year-classes above the 80<sup>th</sup> percentile are deemed “strong” (blue bars) and those below the 20<sup>th</sup> are deemed “weak” (red bars).



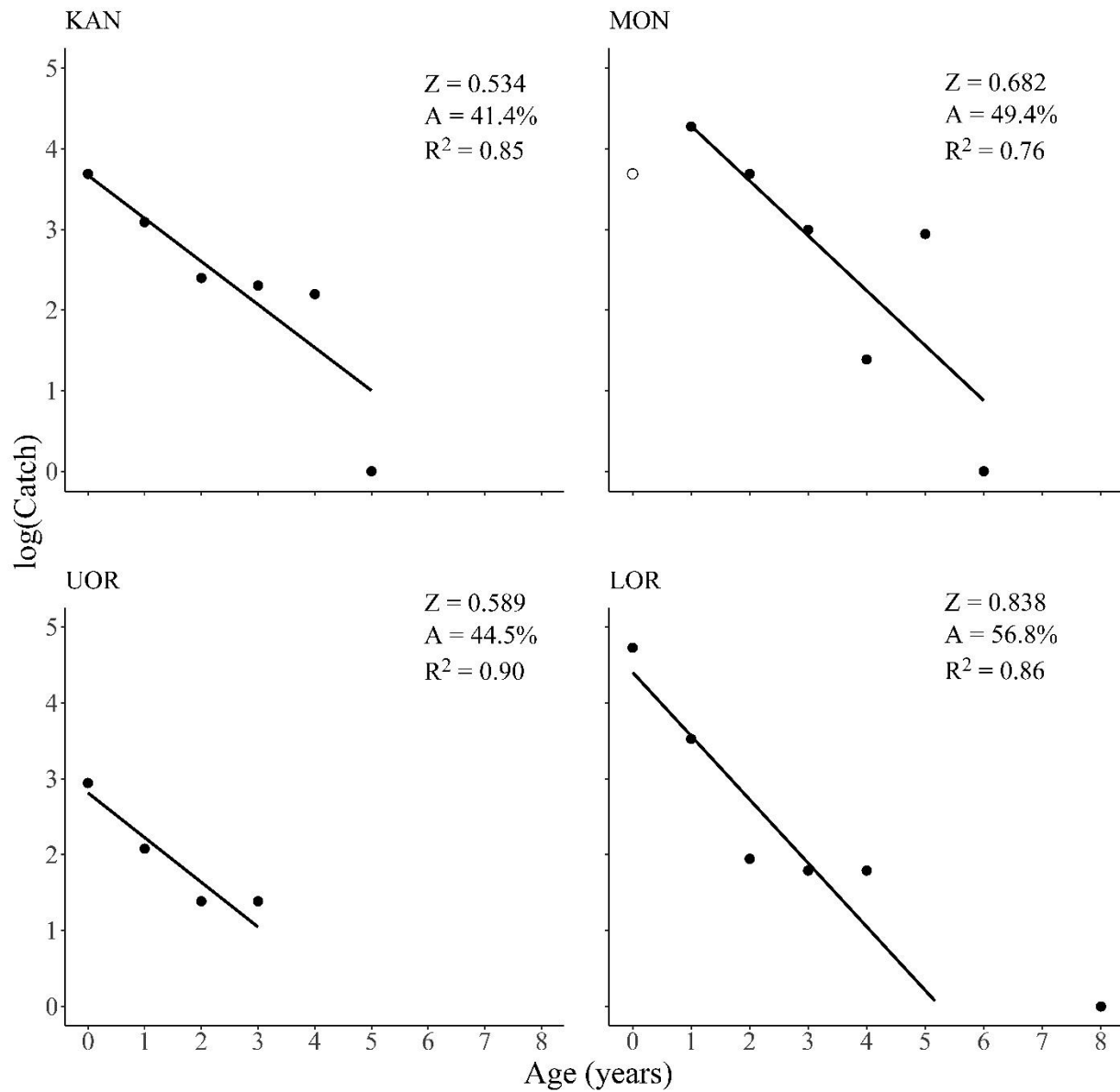
**Figure SSMB-5.** von Bertalanffy growth curve generated from Smallmouth Bass back-calculated length-at-age information. The solid line portion represents estimations from observed data, whereas the dashed line represents projections based upon the equation. Shaded regions represent 95% confidence intervals.



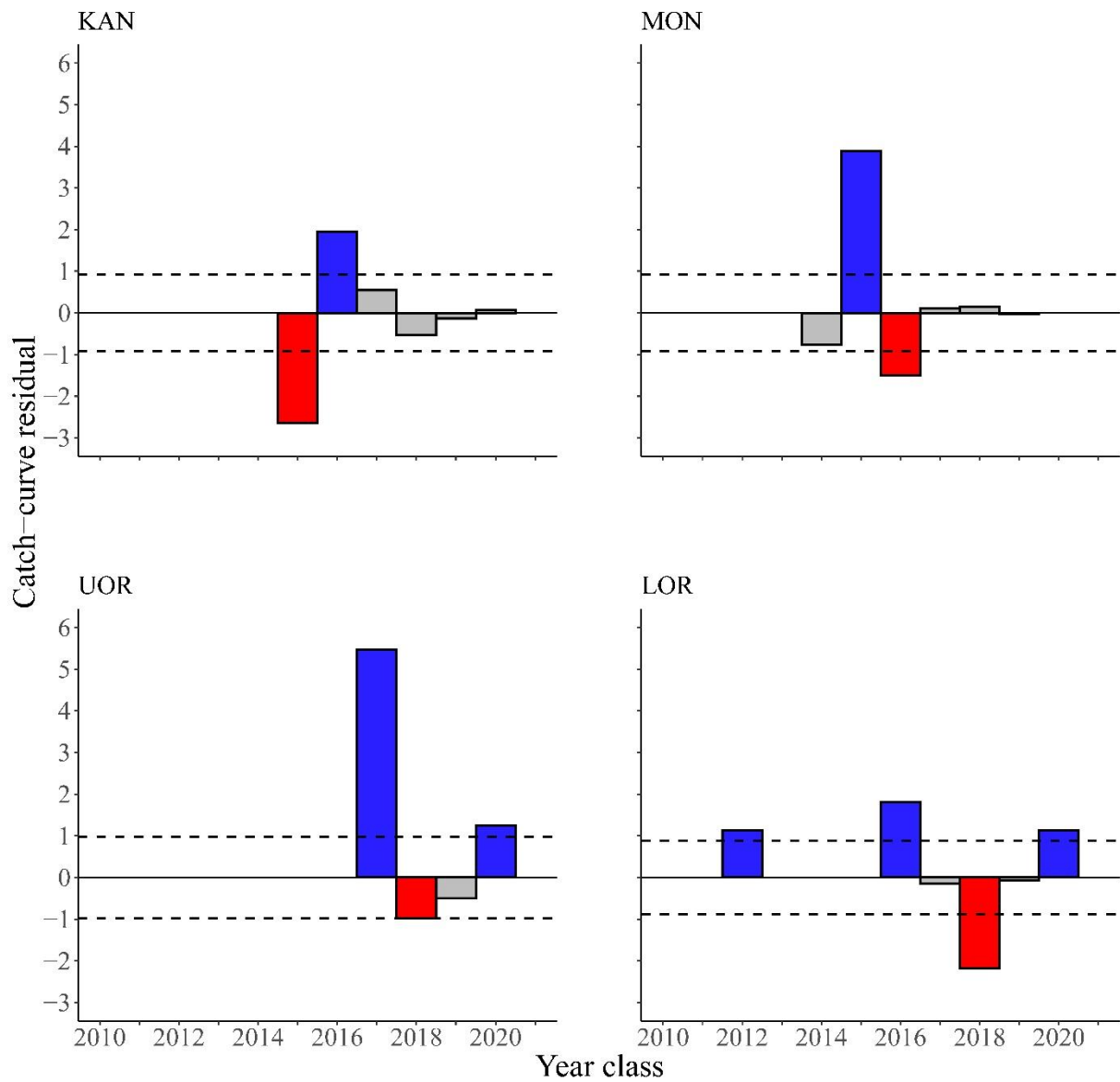
**Figure SSPB-1.** Size distribution of Spotted Bass sampled in 2019 and 2020, grouped into 10-mm length bins to align with size-category cutoffs. Colors correspond to different Gabelhouse (1984) size categories.



**Figure SSPB-2.** Linear models displaying the relationship between total length and relative weight of Spotted Bass sampled in this study. The red, dashed line represents the least-squares regression between the two variables, with the gray, shaded region displaying 95% confidence intervals. P-values correspond to the significance of the effect that total length has on relative weight ( $\alpha = 0.05$ ).

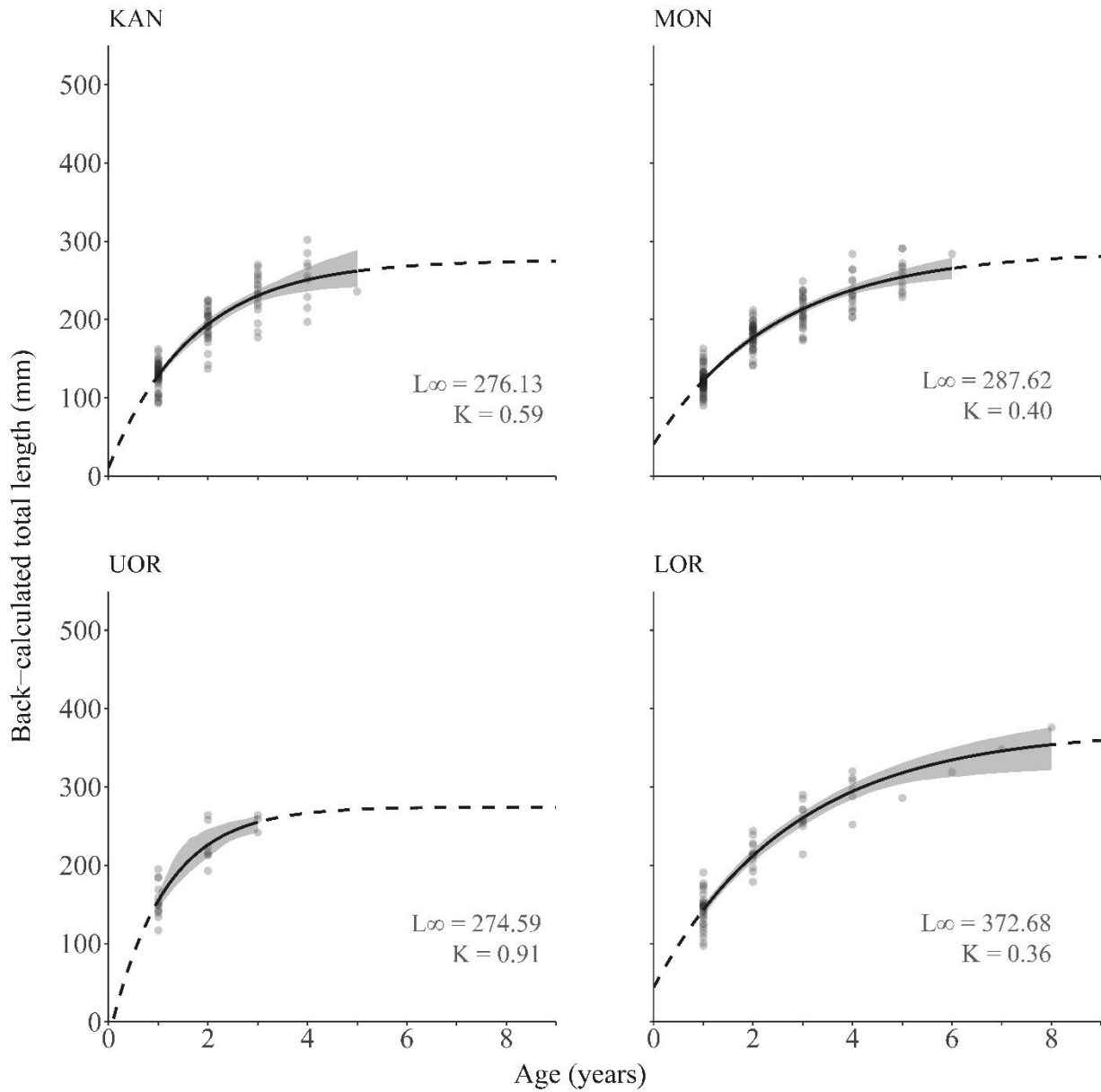


**Figure SSPB-3.** Weighted catch-curve regression used to estimate instantaneous ( $Z$ ) and total annual ( $A$ ) mortality for Spotted Bass sampled in 2019 and 2020. Open points represent year-classes that had not yet fully recruited to the sampling gear and were not included in mortality estimation.



**Figure SSPB-4.** Histograms of studentized residuals from catch-curve regressions of log-transformed catch-at-age information collected from Spotted Bass in this study. Dashed lines correspond to 20<sup>th</sup> (lower) and 80<sup>th</sup> (upper) percentile residuals. Year-classes above the 80<sup>th</sup> percentile are deemed “strong” (blue bars) and those below the 20<sup>th</sup> are deemed “weak” (red bars).





**Figure SSPB-5.** von Bertalanffy growth curve generated from Spotted Bass back-calculated length-at-age information. The solid line portion represents estimations from observed data, whereas the dashed line represents projections based upon the equation. Shaded regions represent 95% confidence intervals.