HABITAT USE AND DISTRIBUTION OF LITHOPHILIC SPAWNING AND RIFFLE FISHES IN THE EAST FORK BLACK RIVER

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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HABITAT USE AND DISTRIBUTION OF LITHOPHILIC SPAWNING

AND

RIFFLE FISHES IN THE EAST FORK BLACK RIVER

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ABSTRACT

Freshwater streams are dynamic ecosystems that house diversity of taxa adapted to and dependent on habitat characteristics these flowing systems. Conservation of these ecosystems, requires an understanding of the abiotic and biotic factors and relationships that influence the presence, survival, and persistence of stream organisms. Stream fishes face natural challenges inherent to stream life and anthropogenic threats such as fragmentation and impoundment of streams. In addition to inhibiting movement of fish, dams influence habitat characteristics such as substrate distribution and size. Dams alter downstream substrate characteristics, which in turn influences availability of habitat characteristics necessary for native lithophilic spawning fishes. The goal of our project was to determine if substrate size and distribution are limiting habitat characteristics for lithophilic spawning fishes of the East Fork Black River downstream of Taum Sauk Reservoir in the Missouri Ozarks. Our questions were: 1) What habitat characteristics do Hornyhead Chubs, *Nocomis biguttatus*, select for spawning in the East Fork Black River? and 2) What habitat characteristics are associated with fish communities within riffles and runs in the East Fork Black River?

Spawning mounds were identified in riffle-run habitats, and habitat characteristics measured at the microhabitat scale included water depth, canopy cover, distance to the nearest bank, presence of velocity shelters, and stream wetted width. Habitat characteristics at the mesohabitat scale included water surface area within the defined riffle-run habitat, distance from dam, mean depth, mean wetted width, mean canopy cover, water-surface gradient, and substrate size distribution. Discrete-choice models within a Bayesian framework were utilized at the microhabitat scale, and selected habitat characteristics for spawning mounds included depths of 0.20 m to 0.35 m, velocities of 0.10 m/s to 0.30 m/s, wetted widths of 7 m to 10 m, and the presence of velocity shelters for Hornyhead Chub spawning mounds. At the mesohabitat scale, shallower mean depths and increased amounts of small substrate were the most important habitat characteristics for the presence of spawning mounds. To answer the second objective, we sampled fish from riffle-run habitats on the East Fork Black River downstream of Taum Sauk Reservoir using backpack electrofishing and prepositioned grid electrofishing. Hill number diversity indices were used with Generalized Linear Models (GLMs) to predict the relationship between habitat characteristics (area, distance from dam, mean depth, mean wetted width, mean canopy cover, water surface gradient, and substrate size distribution) and fish diversity. Two Hills number indices were used for three groups of fishes including the overall fish community, fishes sampled with prepositioned electrofishing grids, and Hornyhead Chubs spawning associates. Increased reach area and smaller substrate size were the most important habitat characteristics for increased diversity in the overall fish community and Hornyhead Chub spawning associates. For fishes sampled with prepositioned electrofishing grids, lesser mean depths lead to increased diversity. Substrate size distribution was an important habitat characteristic for both objectives, based on our research, and we believe that riffle-run habitats in the East Fork Black River have diminished substrate sizes in the range 8 mm to 32 mm. The lack of this small substrate may be influencing the fish communities within riffle-run habitat downstream of Taum Sauk reservoir.

GENERAL INTRODUCTION

Freshwater streams are dynamic ecosystems that are often influenced by anthropogenic activities in attempt to control flow for various purposes (Pohl 2002), and these actions frequently lead to degraded lotic habitat causing a threat to freshwater organisms (Ward and Stanford 1983; Bunn and Arthington 2002; Dudgeon et al. 2006; Jelks et al. 2008). Anthropogenic threats to freshwater streams include but are not limited to increased nutrients, increased fine substrate, chemical pollution, dewatering, and fragmentation through the construction of dams and dewatering (Malmqvist and Rundle 2002; Van Looy et al. 2014). In mid-size streams, fragmentation can be influential not only for disconnecting populations and habitats (Perkin and Gido 2011), but also influencing hydrology and downstream habitat (Ward and Stanford 1983; Kondolf 1997).

Dams are frequently constructed on freshwater streams for flood control, water consumption, recreation, hydropower, and navigation (Pohl 2002), and in the last few decades, dams have been removed to increase stream connectivity, especially for diadromous species dependent on long-distance migration (Liermann et al. 2012). Dams affect aquatic habitat by altering temperature and flow temperature and flow regimes (Ward and Stanford 1983; Nilsson et al. 2005), and this can affect fish spawning triggers (Schlosser and Angermeier 1995; Bunn and Arthington 2002) and aquatic communities (Ligon et al. 1995). Physical habitat is also affected by dams by changing substrate characteristics (Kondolf 1997), diminishing woody debris (Foster et al. 2003), and altering stream channel shapes (Kondolf 1997). Streams are dynamic, constantly changing, ecosystems, but when a dam is constructed, homogenous habitat is frequently created directly downstream of the dam. Streams may not return to their natural state until further downstream depending on characteristics of the habitat and landscape (Kondolf 1997; Cooper et al. 2016).

Substrate-altered streams occur when bed movement continues downstream of dams, but substrate is not replaced in a continuous cycle because of interruption of bedload supply. Substrate-altered streams present multiple threats to aquatic organisms including increased bank erosion, decreased riparian shading, and homogenization of substrate (Kondolf 1997; Bunn and Arthington 2002). Substrate heterogeneity may be associated with provision of critical spawning habitat, and interstitial spaces for benthic and lithophilic fishes in fast-flowing water. Substrate-altered streams have been studied to understand their influence on Salmonid fishes of the western United States (Kondolf 1997), but few studies have been done to understand the influence of substrate alteration on small-bodied fishes native to the Mississippi River drainage.

The East Fork Black River (EFBR) is located in southeast Missouri (Figure 1-1), and like many Ozark streams, has a high fish diversity of more than 60 species. Starting in the St. Francis Mountains, the EFBR has very few springs and is highly dependent on surface runoff; it has a high gradient with an average of 3.2% (Cieslewicz 2004). Once leaving the St. Francis Mountains and flowing onto the Ozark Plateau, the EFBR joins the main stem of the Black River, a 7^{th} order stream, and continues into the lowland faunal region of Missouri.

The East Fork Black River downstream from Taum Sauk Reservoir was selected for this study because previous habitat studies by the Missouri Department of Conservation (MDC) have shown that it is a substrate-altered system. Understanding the importance of substrate size distribution may help with future gravel augmentation practices. Taum Sauk Reservoir stores water for a pump-storage facility used to generate electricity (Figure 1-2). Because the pump-storage operation is independent of outflows from the reservoir, the outflow of the reservoir closely matches the inflow from the two streams that feed the reservoir. This prevents some potential complications frequently created by hydropower releases create high variation in stream discharge (Ellis and Jones 2013). In addition, Taum Sauk Reservoir utilizes a meso-limnetic release, leading to minimal influence on the Lower East Fork Black River (LEFBR) water temperature and dissolved oxygen.

The goal of our research was to determine the influence of a substrate-altered stream on small-bodied lithophilic spawning fishes. The first portion of our research focused on Hornyhead Chub, *Nocomis biguttatus*, spawning habitat characteristics. Hornyhead Chubs were chosen because it was of concern that the presence of their spawning mounds was decreasing. Hornyhead Chubs are known to have spawning habitat preferences related to depth and velocity (Vives 1990; Wisenden et al. 2009), and their constructed spawning mounds are easily located making it feasible to measure habitat characteristics at spawning locations. In addition, five other species of fish previously sampled on the EFBR are known to be spawning associates with the Hornyhead Chub. In some studied streams, *Nocomis* fish spawning mounds create required spawning habitat for multiple species that is not readily available (Vives 1990; Peoples and Frimpong 2013; Peoples et al. 2014). The second portion of our research focused on fish communities in the riffle-run habitats of the LEFBR and the habitat characteristics that drive species richness and diversity of this system. In order to answer questions in these areas of focus, we defined two objectives

Objectives

1) Determine habitat characteristics that Hornyhead Chubs select for spawning in the East Fork Black River
2) Determine habitat characteristics that influence fish communities within riffle and run habitat of the East Fork Black River

With the results from our study, we hope to provide recommendations of substrate size and locations for future gravel augmentations on the East Fork Black River downstream of Taum Sauk Reservoir.

Site Selection

The Black River is a seventh order stream that begins in the Ozark Highlands of Southeastern Missouri and flows into the Mississippi Lowlands before continuing into Arkansas and joining the White River. The Lower Taum Sauk Reservoir (80 hectares) was completed in 1963 on the East Fork Black River, and is immediately upstream of our study sites (Figures 1-1 and 1-2). Clearwater Reservoir (670 hectares) was completed in 1951 on the main stem of the Black River 24.8 km downstream of the East Fork Black River and Black River confluence.

Our study sites are within East Fork Black River, a fifth order stream located near Lesterville, Missouri on Highway 72 (Figure 1-1). Starting within the St. Francis

Mountains of the Ozark Highlands, the East Fork Black River has a mean discharge (for 2008 through 2016) below Taum Sauk Reservoir (USGS stream gauge 07061290) of 3.73 cubic meters per second, and an average gradient of 6.6 m/km with a maximum of 37.9 m/km. The watershed of the East Fork Black River covers 246 square kilometers, and the land use is primarily forest and woodlands with small amounts of grasslands in the river bottoms and glade complexes throughout the drainage in the St. Francis Mountains (Cieslewicz 2004). In an assessment of stream habitat conducted by MDC in 1988 (Cieslewicz 2004), the riparian corridor of the East Fork of the Black River was rated 50% fair, 38% good, and 12% poor.

All of the study sites are within 6.3 km downstream of Taum Sauk Reservoir (Figure 1-2) operated by Ameren Missouri, an electric company based out of St. Louis, Missouri. Downstream of the dam, valley bottom land use is made up of row crops, pasture, forest, and few cabins. The outflow from Lower Taum Sauk Reservoir is approximately equal to the inflow of the East Fork of the Black River, but release from the reservoir is not able to achieve the rate of variation in flow events or change in water temperature in the East Fork upstream from the reservoir (Cieslewicz 2004). At the upstream end of the reservoir, there is a small dam that creates a gravel trap (Figure 1-2) to prevent coarse sediment from entering the reservoir and reducing the storage capacity. The trap has an approximate capacity of 23,000 cubic meters and is emptied every eight to ten years (Cieslewicz 2004). The discontinuity in bedload transport has led to a decrease in availability of small bed material to aquatic organisms downstream of the reservoir (Lobb 2016).

The fish community of the East Fork Black River is similar to other south flowing drainages in the Ozark Mountains. Many fishes in this stream require silt free gravel, low turbidity, and higher velocity habitat. Due to these habitat requirements, many species are believed to be sight feeders (Pflieger 1997). In the intensive sampling by MDC for two years following the flood event in 2005, 57 species were sampled in the East Fork Black River downstream of Taum Sauk Reservoir (Combes and Dunnaway 2009). Bleeding Shiners *Luxilus zonatus* and Rainbow Darters *Etheostoma caeruleum* were the most abundant species (Cieslewicz 2004), with other abundant species including Striped Shiners *Luxilus chrysocephalus*, Ozark Minnows *Notropis nubilus*, Largescale Stonerollers *Campostoma oligolepis*, and Longear Sunfish *Lepomis megalotis*.

References

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492–507.

Cieslewicz, P. 2004. Black River watershed inventory and assessment. Missouri Department of Conservation, Jefferson City, MO.

Combes, M. and S. Dunnaway. Assessment of aquatic resources in East Fork Black River after Upper Taum Sauk Reservoir Dam breach. Missouri Department of Conservation, Jefferson City, MO.

Cooper, A. R., D. M. Infante, K. E. Wehrly, L. Wang, and T. O. Brenden. 2016. Identifying indicators and quantifying large-scale effects of dams on fishes. Ecological Indicators 61:646–657. Elsevier Ltd.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A. H. Prieur-Richard, D. Soto, M. L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews of the Cambridge Philosophical Society 81(2):163–182.

Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. J. Schmitter-Soto, E. B. Taylor, and M. L. Warren. 2008. Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. Fisheries 33(8):372–407.

Kondolf, G. M. 1997. Hungry water: Effects of dams and gravel mining on river channels. Environmental Management 21(4):533–551.

Van Looy, K., T. Tormos, and Y. Souchon. 2014. Disentangling dam impacts in river networks. Ecological Indicators 37(PART A):10–20. Elsevier Ltd.

Lobb, D. 2016. Habitat use and distribution of lithophilic spawning and riffle fishes in the East Fork Black River study proposal. Missouri Department of Conservation, Jefferson City, MO.

Malmqvist, B., and S. Rundle. 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29(2):134–153.

Peoples, B. K., and E. A. Frimpong. 2013. Evidence of mutual benefits of nest association among freshwater cyprinids and implications for conservation. Aquatic Conservation: Marine and Freshwater Ecosystems 23(6):911–923.

Peoples, B. K., R. A. Mcmanamay, D. J. Orth, and E. A. Frimpong. 2014. Nesting habitat use by river chubs in a hydrologically variable Appalachian tailwater. Ecology of Freshwater Fish 23(2):283–293.

Perkin, J. S., and K. B. Gido. 2011. Stream Fragmentation Thresholds for a Reproductive Guild of Great Plains Fishes. Fisheries 36(8):371–383.

Pflieger, W.L. 1997. The Fishes of Missouri. Missouri Department of Conservation, Jefferson City, MO.

Pohl, M. M. 2002. Bringing down our dams: Trends in American dam removal rationales. Journal of the American Water Resources Association 38(6):1511–1519.

Wisenden, B. D., A. Unruh, A. Morantes, S. Bury, B. Curry, R. Driscoll, M. Hussein, and S. Markegard. 2009. Functional constraints on nest characteristics of pebble mounds of breeding male hornyhead chub Nocomis biguttatus. Journal of Fish Biology 75:1577-1585.

Vives, S. P. 1990. Nesting Ecology and Behavior of Hornyhead Chub Nocomis biguttatus, a Keystone Species in Allequash Creek, Wisconsin. American Midland Naturalist 124(1):46.

Ward, J. V, and J. A. Stanford. 1983. The Serial Discontinuity Concept of Lotic Ecosystems. Pages 29 – 42 *in* T. D. Fontaine, S. M. Bartell, editors. Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, Michigan.

CHAPTER ONE

Hornyhead Chub Spawning Habitat in the East Fork Black River, Missouri

John D. Brant and Craig P. Paukert

Abstract

Dams frequently influence stream habitat and affect aquatic biota. Habitat factors are strongly influenced by the presence of dams, which alter the flow, sediment, temperature, and wood regimes, thereby changing substrate and habitat structure. The presence of dams commonly leads to homogenization of habitat and therefore diminished species diversity. Substrate size and distribution are influenced because dams typically trap bedload. Lithophilic-spawning fishes are sensitive to changes in flow and physical habitat including substrate size and quantity for reproduction success. The Hornyhead Chub *Nocomis biguttatus* is a widely distributed lithophilic-spawning minnow that occurs at low densities in suitable streams and that constructs large spawning mounds in locations that provide habitat for multiple other lithophilic-spawning fishes in locations that meet specific habitat requirements. Our objectives were to determine spawning-habitat characteristics, particularly substrate distribution, for Hornyhead Chub spawning mounds at the microhabitat and mesohabitat spatial scales. Microhabitat has been described for Hornyhead Chub spawning habitat, but little is known why mounds are frequently found in congregations and not in other mesohabitat locations. At the microhabitat scale Hornyhead Chubs constructed their spawning mounds at depths from 0.25 m to 0.45 m, water velocities of 0.10 m/s to 0.35 m/s, and behind the presence of velocity shelters. These conditions were selected in all systems observed. In the Lower East Fork Black

River, spawning mounds were constructed at stream wetted widths of 7 m to 11 m, but in other streams, the distanced to the nearest bank was selected for rather than the stream wetted width. At the mesohabitat scale, it was found that shallower mean depths than our mean value (0.24 m), and smaller substrate sizes were related to the presence of spawning mounds. Based on our findings, we recommend that future gravel augmentations primarily include substrate of sizes 8 mm to 32 mm in addition to a heterogenous mixture. We recommend that gravel augmentations take place within 1.26 km downstream of the dam.

Introduction

Dams are one of the most prominent disturbances to stream ecosystems. Dams are typically constructed for flood control, hydroelectric power, water storage, navigation, and recreation (Pohl 2002). They alter aquatic ecosystems by creating discontinuites, which in turn can decrease faunal diversity, and affect ecosystem processes, stream-bed movement, and ecological functions (Ward and Stanford 1983; Kondolf 1997; Poff et al. 1997; Bunn and Arthington 2002; Paukert and Galat 2010). Dams alter hydrology and water quality downstream (Ward and Stanford 1983; Ellis and Jones 2014), which may affect fish spawning and fish community composition. Dams often create reservoirs that act as buffers for extreme flow events, alter stream temperature, decrease dissolved oxygen downstream of the dam, and affect nutrient dynamics depending on seasonal changes and characteristics of the impoundment (Ellis and Jones 2014; McManamay et al. 2015). However, these disturbances vary intime and space, and among dams (Ward and Stanford 1983; Kondolf 1997). As distance downstream from the dam increases, the effects on the stream typically decrease creating a longitudinal gradient (Ward and

Stanford 1983; Bunn and Arthington 2002; Ellis and Jones 2014).The effects are often mediated by stream size and the amount of hydrologic alteration caused by the dam (Ward and Stanford 1983; Kondolf 1997; Bunn and Arthingtonm 2002; Paukert and Galat 2010).

All dams trap substrate to some degree and interrupt continuity of sediment transport (Kondolf 1997). Streams below reservoirs are often referred to as "hungry water" because the sediment load is reduced, and excess energy moves substrate from the stream bed below the reservoir until equilibrium is met where the bed can no longer be moved or the banks eroded (Kondolf 1997). The stream below the impoundment has diminished supply of smaller substrate, and the remaining habitat becomes more homogeneous (Kondolf 1997). Reduction in the abundance of substrate may also lead to channel-morphology and habitat changes (Kondolf 1997). Therefore, fishes with specific substrate requirements may be affected by dams and segmented streams (Ellis and Jones 2014; McManamay et al. 2015).

Over timeframes of years to decades, slope can be considered an independent control on sediment transport capacity. A direct relationship exists between stream slope and substrate particle size (Richards 1982: 170, 229). When bedload flux or sediment size is altered, it can lead to alterations in fish spawning habitat (Kondolf 2000; Peoples 2014). Salmonids have been heavily studied in substrate-altered western streams to understand the influence of impoundments on spawning habitat (Kondolf 2000; Merz and Setka 2004; Zimmerman and Lapointe 2005; Zeug et al. 2014). However, spawning habitat requirements of common small bodied fishes are often overlooked, but likely play an important role for community diversity (Peoples 2014).

Fish community diversity is strongly driven by habitat complexity because many species fill niches within specific habitat types (Gorman and Karr 1978). Aquatic organisms depend on variation in habitat including substrate spatial distribution, ranges of velocities and depths, temperature regime, size of habitat areas, and cover that may enable protection, foraging, and spawning (Gorman and Karr 1978; Johnston and Page 1992; Peterson and Rabeni 2001; Merz and Ochikubo Chan 2005; Zeug et al 2014). In particular, substrate is a critical component for lotic fishes, which depend on substrate for spawning and foraging. If these substrate requirements are not met, populations may decrease or become extirpated (Berkman and Rabeni 1987).

Stream habitat can be evaluated at multiple spatial scales (Fausch et al. 2002). Analyzing stream habitat at multiple spatial scales can reveal patterns in habitat traits and fish distributions. Patterns can be connected to variables that are continuous throughout the stream such as temperature or distance downstream (Vadas and Orth 2000; Fausch et al. 2002). Relying on only one spatial scale to assess fish habitat selection may lead to biased results because characteristics may be overlooked or habitat scale may be misjudged compared to the actual size of habitat used (Heggenes et al. 1999). Studying suitable spawning habitat for fish at two spatial scales is essential in understanding the differences in required mesohabitat and microhabitat characteristics (Hamann et al. 2014) because fish may have further habitat requirements beyond the immediate (microhabitat) surroundings.

Dams and habitat alterations associated with stream fragmentation affect lithophilic-spawning fishes, species that require particular sizes of substrate to be available for successful spawning (Johnston and Page 1992), but habitat characteristics that are drivers for the presence or absence and spawning success of these species are not fully understood. Lithophilic-spawning fishes are often sensitive to changes in substrate size, embeddedness, and composition because their spawning habitats require movable and silt-free substrate (Smith and Kraft 2005; Wisenden et al. 2009, Manny et al. 2015; Whitney et al. 2020). In particular, the Hornyhead Chub *Nocomois biguttatus* (hereafter "HHC") is a large minnow (commonly 13 to 18 cm in total length) that reaches sexual maturity at ages of 2-3 and rarely live longer than four years (Pflieger 1997. These fish are considered mound builders because in preparation for spawning, males construct a gravel mound by moving gravel with their mouth (Lachner 1952) and excavate a shallow pit, followed by constructing several layers of gravel on which fishes spawn. To complete the mound, the *Nocomis* male will place a final layer of gravel on the outside to protect the mound from erosion and predation (Lachner 1952). Spawning mounds for *Nocomis* species provide spawning habitat for over 30 species of North American minnows; thus, *Nocomis* have been considered a keystone species (Lachner 1952).

Research has described microhabitat characteristics immediately surrounding Hornyhead Chub spawning mounds (Vives 1990; Wisenden 2009), but habitat characteristics at a larger stream scale (habitat not adjacent to spawning mounds) have not been studied to understand why spawning mounds are densely present in some areas but not others. Hornyhead Chubs are thought to depend on having the right size of distribution of gravel available to construct spawning mounds (Wisenden et al 2009) for protection and aeration of eggs (Maurakis et al. 1991); velocity and depth are thought to relative to spawning habitat (Vives 1990; Wisenden 2009). Therefore, understanding the mesohabitat and microhabitat requirements for these fishes and how stream alterations may affect substrate (and thus spawning) is needed to help resource management agencies guide efforts to restore or enhance habitats for lithophilic spawning stream fishes. At the mesohabitat scale, our hypothesis is mesohabitats with Hornyhead Chub spawning mounds will have a surface gradient leading to average spring season velocities between 0.1 m s^{-1} and 0.5 m s^{-1} (Vives 1990; Wisenden et al., 2009; Peoples et al., 2014), an average depth between 0.2 m and 0.6 m (Vives 1990; Wisenden et al., 2009; Peoples et al., 2014), a presence of structures including macrophytes and boulders, substrate distribution including sizes of 22.6 mm and smaller, and no direct response to distance from the dam. In addition, we hypothesize that spawning mounds will be located in microhabitats at a depth between 0.2 m and 0.5 m, a mean velocity between 0.1 m s^{-1} and 0.4 m s^{-1}, and within two meters of a velocity shelter (e.g. woody debris, boulders) (Vives 1990; Wisenden et al. 2009).

Methods

Study Site

The East Fork Black River (EFBR) is a fifth order stream that flows for 32 km out of the St. Francis Mountains within the Southeastern Missouri Ozark Highlands (Figure 1-1), which typically have pristine streams with low turbidity, small amounts of silt, high gradients, and high biodiversity. The EFBR watershed covers 246 km^2 with a primary land use of forest and woodlands and, a small amount of grasslands in river bottoms and glade complexes throughout the drainage in the St. Francis Mountains (Cieslewicz 2004). The EFBR joins the Black River, an Ozark stream of seventh order, and continues to flow through the Ozark Highlands and the Mississippi Lowlands before entering Arkansas and joining the White River.

Two reservoirs are present in the Missouri portion of the Black River drainage including Lower Taum Sauk Reservoir on the EFBR and Clearwater Reservoir on the Black River 25 km downstream of the EFBR and Black River confluence. Lower Taum Sauk Reservoir, which is immediately upstream of our study sites, has been operated as a pump-storage hydroelectric facility since 1963 by Ameren Missouri Electric Company. Water is stored in an upper reservoir, 230 m higher in elevation, which allows water to flow through turbines during times of energy high demand. Because the pump-storage operation is largely independent from the inflows, outflow from Lower Taum Sauk Reservoir is approximately equal to in the inflow of the East Fork Black River and Taum Sauk Creek on a daily basis. The exception is that release from the reservoir is not able to achieve the rate of variation in flow or water temperature of inflowing water (Cieslewicz 2004). At the upstream end of the reservoir, there is a small dam that creates a gravel trap (Figure 1-2) to prevent coarse sediment from entering the reservoir and reducing the storage capacity. The trap has an approximate capacity of 23,000 cubic meters and is emptied every eight to ten years (Cieslewicz 2004). The discontinuity in bedload transport caused by the dam and gravel bin trap has led to a decrease in availability of small substrate to aquatic organisms downstream of the reservoir (Figure 1-3; Lobb 2016; Figure 1-4).

On December 14, 2005, the upper reservoir's dam at the Taum Sauk Hydroelectric Facility failed, allowing nearly one billion gallons of water to rush down Proffit Mountain, which resulted in a large amount of damage to terrestrial and aquatic habitat, nearly eliminating the fish community in the main river downstream of the upper reservoir (Combes and Dunnaway 2009). Beginning on December 20, 2005, fish and habitat sampling by Missouri Department of Conservation (MDC) began to monitor the impact of the flood throughout the EFBR. Initially, large amounts of fine sediments were deposited within the river downstream from the lower reservoir, but the fine sand and silt moved downstream of the study area by 2007, returning the river to a similar state before the flood event (Combes and Dunnaway 2009). In 2010, a new upper reservoir was completed constructed of roller compacted concrete.

The EFBR downstream from the Lower Taum Sauk Reservoir has been monitored by the MDC for instream habitat, substrate size and distribution, aquatic invertebrate communities, and fish communities to maintain licensing for Ameren through the Federal Energy Regulatory Commission (FERC). The river downstream of the lower reservoir is considered substrate-altered through continuous bed movement and lack of bedload replacement. Therefore, the lack of small substrate may affect the biological community of the East Fork Black River.

The fish community of the EFBR is similar to other southern flowing drainages of the Ozark Highlands where many fishes in this stream require silt-free gravel, low turbidity, and high velocity habitat. Due to prevalence of low turbidity, many species in this stream are believed to be sight feeders (Pflieger 1997). In the intensive sampling by MDC for two years following the flood event in 2005, 57 species were sampled in the East Fork Black River downstream of Taum Sauk Reservoir (Combes and Dunnaway 2009). Hornyhead Chubs occur on the EFBR and many other streams throughout the Ozark region (Pflieger 1997; Combes and Dunnaway 2009). Nest associates (species that use HHC constructed mounds for spawning) of the HHC that occur in the East Fork Black River include Bleeding Shiner, Striped Shiner, Carmine Shiner *Notropis percobromus*, and Ozark Minnow (Vives 1990; Pflieger 1997; Combes and Dunnaway 2009).

The West Fork Black River (WFBR) and Big Creek (BGCK) of the St. Francis River system are both fifth order streams and were added for the second field season of this study when HHC spawning mounds were scarce in the EFBR. Both the WFBR and BGCK are located in the Ozark Highlands and flow south into the Mississippi River Lowlands. Big Creek joins the St. Francis, and the WFBR meets the Middle Fork Black River to create the Black River 2.5 km before the confluence of the Black River and the EFBR.

Our study goal was to help conservation agencies determine management actions that may benefit native stream fishes where disturbances have altered habitats, including substrate, wetted width, depth, gradient, and velocity. Our objective was to determine how the lack of small substrate in the EFBR may influence spawning habitat selection of HHCs.

Objective 1: Determine spawning habitat characteristics for Hornyhead Chubs in the East Fork Black River.

Hornyhead Chubs may select spawning habitat at both the mesohabitat and microhabitat spatial scales. As used in this document, the mesohabitat scales defines the stream area delineated longitudinally by low velocity pools. This scale was used to delineate riffle-run complexes that are available to HHCs for the selection of a mound site within flowing water habitat (Figure 1-5). Hornyhead Chubs may also select spawning locations for specific habitat characteristics within a given mesohabitat to construct spawning mounds, and thus, we also determined microhabitat selection of spawning mounds within a mesohabitat. We define the microhabitat scale as the area within one meter of HHC spawning mounds.

We addressed the following questions:

1) Do substrate size distribution, water temperature, gradient, depth, area, stream width, mesohabitat length, distance from the dam, or the presence of habitat structure differ among mesohabitats with and without HHC spawning mounds?
2) Do substrate size distribution, stream width, depth, velocity, canopy cover, or distance to the bank differ at the microhabitat scale for the location of mounds within a mesohabitat?

Approach

Prior to searching for HHC spawning sites, 20 riffle-run complexes (i.e., mesohabitats) were defined within a 6.3 km study area downstream of Lower Taum Sauk Reservoir. We sampled each mesohabitat for HHC spawning mounds, substrate size and distribution, gradient, depth, area, stream width, and distance from the dam to determine which characteristics best predicted the presence of Hornyhead Chub spawning mounds (Table 1-1).

Mound searches were conducted systematically by surveying riffle/run mesohabitats with two people approximately every 10 days from mid-April through the end of June 2017 and 2018, or until no active spawning activity was observed for two consecutive search periods. The stream channel was split in half and the observers (wearing polarized glasses) started at the downstream end of the mesohabitat and moved upstream, while maintaining a constant pace at each site. Search time was recorded by the time spent searching a riffle-run complex and divided by the area of the mesohabitat to standardize the effort (per area) used to search for mounds. All located spawning mounds were marked using a GPS unit and habitat characteristic measurements were recorded. At the location of found HHC spawning mounds, water depth, velocity, stream wetted width, canopy cover, distance to the closest bank, distance to the nearest upstream or adjacent habitat structure (i.e., presence/absence of woody debris greater than 1 m in length and 0.15 m in diameter (Wohl et al. 2010), boulders, macrophytes, or other stabilized objects creating velocity shelter), mound dimensions, and distance to other present mounds were measured (Table 1-1). These characteristic measurements defined the microhabitat surrounding the spawning mound.

In addition to measuring habitat at each HHC spawning mound, substrate, depth, stream wetted width, and canopy cover density were measured from between 20 and 120 random points in each mesohabitat, related to the measured area (Table 1-2).   A metal cross of a 60 x 60 cm was be used to select five substrate particles from each random point (Figure 1-6; Litvan et al., 2010). The first piece of substrate touched when a finger was placed at each indicated point was measured. Depth was measured using a wading rod with 2 cm increments. A tape measure and Sonin® electronic distance measuring tool were used to measure stream wetted width. The percent canopy cover was measured using a concave spherical densitometer at each random point (Lemmon 1956). Stream surface gradient for each mesohabitat was measured using a self-leveling laser and a stadia rod. Measurements were taken at each end of the mesohabitat and the thalweg length was used to calculate the gradient. The boundaries of the riffle-run mesohabitats were defined by observing substrate deposition, depth, water velocity, and water surface disturbance.

We randomly selected seven out of 29 spawning mounds to be collected from the LEFBR in 2017 when it was that they were based on minimal fish activity and the presence fine sediment collecting on previously clean substrate. Mounds were collected using a small trowel with a small net held immediately downstream to collect drifting substrate. Collected substrate was dried prior to being separated using sieves. Mass was measured for each size class, and mass of 20 individual particles from each size class to calculate the number of particles.

All mesohabitats within 4 km downstream of the dam were surveyed, and alternating riffle-run habitats for the remaining study length of river were surveyed. This was based on the preliminary data that Lower Taum Sauk Reservoir Dam has the strongest effect on the substrate size and particle-size distribution within the first 4 km downstream of the reservoir (Lobb 2016).

During the spring of 2018, only one spawning mound was located in the East Fork Black River downstream of the Lower Taum Sauk Reservoir leading to a shift in sampling strategy. In addition to replicating 2017 sampling on the Lower East Fork Black River, we surveyed mesohabitats identified using the same criteria in nearby streams of the West Fork Black River, the East Fork Black River upstream from Taum Sauk Reservoir, and Big Creek (Figure 1-1). Each of the additional sites was searched twice for

Hornyhead Spawning mounds, and mesohabitat measurements were collected in addition to microhabitat measurements in the presence of spawning mounds.

Data Analysis

We analyzed the mesohabitat scale using Generalized Linear Models (GLMs) with a Bayesian framework in the programs R and RStudio to determine which habitat characteristics best predicted the presence of Hornyhead Chub spawning mounds. The variables used were based on characteristics found to be relevant in other studies of *Nocomis* spawning site selection (Vives 1990; Wisenden et al. 2009), or that we believed may affect suitability for Hornyhead Chub spawning sites (Table 1-1). Generalized Linear Models are based on logistic regression, which is a flexible method appropriate for situations where continuous variables can analyze habitats or situations and calculate the probability of a positive response (that is, presence of a spawning mound). A global model was used to compare which variables have the highest influence on site selection and included mean depth, mean wetted width, and mean canopy cover from the random points, in addition to distance from Lower Taum Sauk Reservoir, area of mesohabitat, length of mesohabitat, water surface gradient, and 50^{th} percentile size of sampled substrate particles (D_{50}). Prior to running the model, a correlation analysis was completed with all variables, and highest value for r was 0.38, therefore, no variables were removed. JAGS (Just Another Gibbs Sampler) package was used in R to operate the Bayesian framework using uninformative prior probability distributions ($\bar{x} = 0, \pm 0.001$). Parameter outputs were interpreted using 95^{th} percentiles as guidelines for posterior distributions.

Discrete choice analysis within a Bayesian framework was used to compare which parameters affect the microhabitat site selection for Hornyhead Chub spawning mounds. Discrete choice selection models, based in linear regression, were used when comparing habitat selection with the assumption that individuals gain satisfaction from the selection of given resource (Cooper and Millspaugh 1999; Edge et al. 2020). Data collected from the location of the mounds were compared to three random points within the same mesohabitat to determine microhabitat selection of Hornyhead Chub spawning sites.

The discrete choice model used included depth, velocity, canopy cover density, presence of velocity shelters, and wetted width. Depth and velocity were included as quadratic relationships to determine if there is a selected range of values for spawning habitat. As with the GLM, JAGS package was used in R to operate the Bayesian framework using uninformative prior probability distributions ($\overline{x} = 0, \pm 0.001$). Parameter outputs were interpreted using 95th percentiles as guidelines for posterior distributions.

Results

We conducted 8 HHC spawning mound surveys in 2017 and 10 surveys in 2018 at 19 mesohabitats on the Lower EFBR starting when water temperatures reached 14 degrees C until active spawning mounds were not observed for two consecutive weeks. Active spawning mounds were observed in water temperatures ranging from 16 C to 27

C. Hornyhead Chub spawning mound surveys were conducted from April 2017 through November 2018 in the Lower East Fork Black River, and from June 2018 through November 2018, data were collected in the Upper East Fork Black River, West Fork Black River and Big Creek. During the 2017 field season, 29 Hornyhead Chub spawning mounds were located in the LEFBR, and measurements were taken at 15 spawning mound microhabitats. During the 2018 field season only 1 spawning mound was located on the Lower EFBR, but additional surveys located 6 mounds on the Upper EFBR, 31 on the WFBR, and 4 on BGCK (Table 1-3).

Mesohabitat Scale

During the 2017 field season, HHC spawning mounds were found in 3 of the 17 mesohabitats surveyed on the LEFBR. For the 2018 field season, spawning mounds were found at 1 of the 17 mesohabitats surveyed in the LEFBR. In addition, 1 of 2 mesohabitats had spawning mounds present in the WFBR, 2 of 3 mesohabitats had spawning mounds present in BGCK, and 1 of 2 mesohabitat in the UEFBR (Table 1-3). For our full study, HHC spawning mounds were present at 7 out of 26 mesohabitats surveyed.

In the LEFBR, the substrate size and gradient (Figure 1-7: $r = -0.981$, $n = 19$) were unrelated in comparison to mesohabitats on the UEFBR, WFBR, and BGCK (Figure 1-7: $r = 0.815$, $n = 7$). In addition, depth and gradient were not strongly related in the LEFBR (Figure 1-7: $r = -0.300$, $n = 19$) compared to the typical streams (UEFBR, WFBR, BGCK; Figure 1-7: $r = -0.732$, $n = 7$).

At the mesohabitat scale, mean stream depth and substrate size were the most influential habitat characteristics for predicting the presence of a Hornyhead Chub spawning mound when data from all streams were included (Figure 1-8A). In the LEFBR, none of the measured habitat characteristics were influential at the mesohabitat scale, and for BGCK and WFBR (other streams), mean depth and substrate size were the most influential for the presence of HHC spawning mounds (Figure 1-8B and 1-8C). Mesohabitats in all streams had a mean depth less than 0.25 m the probability of HHC spawning bounds being present increased with amounts of small substrate in comparison to the mean value. None of the measured habitat characteristics were of high importance in the LEFBR at the mesohabitat scale (Figure 1-8C). There is a difference in available substrate size for mesohabitats with mounds present compared to mounds absent between in mesohabitats with less substrate between sizes of 8 mm to 64 mm (Figure 1-9).

Microhabitat Scale

In 2017, microhabitat measurements were recorded at 15 of the 29 HHC spawning mounds in the LEFBR. For 2018, measurements were recorded at 6 of the mounds identified on the WFBR. Hornyhead Chub mounds were constructed at depths between 0.11 m and 0.63 m, and at velocities between 0.00 and 0.49 m/s. The mean depth at mounds was 0.35 m ± 0.03 m (± standard error), and average velocity was 0.17 m/s ± 0.015 m. Distance to nearest banks was 2.59 m ± 0.37 m (range: 0.45 m, 5.90 m), and channel mean wetted width was 14.79 m ± 1.26 m (range: 7.23 m, 27.60 m). Mean percent canopy cover for spawning mounds was 41% ± 7% (range: 0%, 80%).

The discrete choice models determined that in all streams (EFBR and WFBR data combined), depth, velocity, presence of velocity shelter and the distance to bank were the most important microhabitat characteristics (Figure 1-10). Based on the relative probability results, Hornyhead Chubs were most likely to create spawning mounds at microhabitats with depths of 0.25 m to 0.45 m, velocities 0.10 m/s to 0.35 m/s, downstream of velocity shelters, and a less than 2 m from the nearest bank (Figure 1-11).

The microhabitat location of spawning mounds in the Lower EFBR was influenced by depth, velocity, the presence of velocity shelters, and wetted width (Figure 1-10). Spawning mounds in the Lower East Fork Black River were most likely to be found at depths of 0.20 m to 0.35 m, velocities 0.10 m/s to 0.30 m/s, downstream of velocity shelters, and stream wetted widths of 7 m to 11 m (Figure 1-11). The distance to the nearest bank was not influential for mounds located on the LEFBR. Microhabitat measurements were only taken at 6 spawning mounds on the WFBR creating a large confidence interval with the discrete choice model results. The results from this small dataset indicate that none of the covariates were significantly inmportant (Figure 1-10).

Based on mass of substrate grain sizes, 8 mm to 23 mm were the dominant substrate in HHC spawning mounds (Figure 1-12). The count of grain size classes showed that 16 mm grains make up more than 30 % of spawning mounds closely followed by 11.2 mm grains. The remaining substrate was made up of 8 mm and 23 mm particles (Figure 1-13).

Discussion

Our results suggest that HHC selection for spawning mound could be occurring at both the mesohabitat and the microhabitat scale. Fishes may need to minimize the risk of three key threats when selecting spawning habitat: desiccation, deoxygenation, and predation. *Nocomis* fishes construct spawning mounds to decrease these risks but in doing so add another criteria: prevent nest deconstruction (Peoples et al. 2014). Therefore, *Nocomis* spp, including HHC may select sites based on several criteria dictated at the microhabitat measurements (Lobb and Orth 1988; Vives 1990; Wisenden et al. 2009; Peoples et al. 2014), but also multiple spatial scales (Peoples et al. 2014).

<u>Mesohabitat</u>

We found HHC spawning mounds in 6 of the 21 mesohabitat samples in all streams. Our results suggest similar patterns where HHC congregate in certain riffle-run habitat for spawning, and the riffle-run mesohabitats on the LEFBR with spawning mounds present were between 2.0 and 2.4 km downstream of the dam. The mesohabitat distance from the dam on the LEFBR ranged from 0.05 km to 5.6 km.

Peoples et al. (2014) noted that River Chub *Nocomis micropogon* spawning mounds were often found in groups on stretches of the Cheoah River of North Carolina. Chub spawning mounds are often relatively close to each other (Vives 1990; Peoples et al. 2014), but not adjacent to one another as frequently found with *Lepomis* species (Pflieger 1997).

The first limiting factor for HHCs to construct spawning mounds is most likely the temperature spawning range. Our results found that HHC began constructing spawning mounds at about16 C and continued until about 26 C, which is consistent with Vives (1990) and Wisenden et al. (2009) that found spawning mounds constructed from 16 C to 26 C. Following water temperature, suitable spring flow that last one week or more may provide preferred habitat to allow HHCs to construct mounds and spawn before multiple high flow events that can destruct mounds or lower water levels that may desiccate eggs (Peoples et al. 2014).

The mesohabitat scale revealed two important habitat characteristics, shallower mean depth and smaller substrate, best predicted the presence of HHC spawning mounds when data was included from the LEFBR, UEFBR, WFBR, and BGCK, but this pattern was not evident when only the LEFBR was included. This contrasts with the results of Peoples et al. (2014) that found River Chubs nest sites at the mesohabitat scale were dependent on gradient and shallower depth in addition to the average number of outcrops from the bank that decrease flow velocity. The discrepancy between these two studies may be related to Peoples et al. (2014) defining mesohabitats as a habitat type (i.e. pool, run, riffle, and glide) rather than fast flowing habitat excluding pools. In addition, depth and substrate distribution are frequently related to the stream gradient or water surface slope (Beschta 1979; Keller and Swanson 1979; Keller and Tally 1979). Our results suggest that with increased gradient in a riffle-run habitat lead to a substrate distribution with larger particles and a decrease in mean depth. Therefore, depth and substrate distribution are not the first limiting habitat factor, but gradient was possibly the strongest habitat indicator for the presence of HHC spawning mounds at the mesohabitat scale similar to River Chub spawning habitat in Cheoah River (Peoples et al. 2014). However, gradient was possibly not observed as a significant indicator because we measured gradient using only two points rather than multiple points at a fixed distance and allowing gradient variance to be used as a habitat characteristic.

It is likely that substrate size and depth were not observed as significant indicators in the LEFBR because of substrate deprivation caused by Tom Sauk Dam immediately upstream of our study sites. Gradient, substrate distribution, depth, and wetted width are related (Frissell et al. 1986), and in substrate-altered habitat, it may influence the relationship between the remaining habitat characteristics (Kondolf 1997). Therefore, substrate may be important but likely driven by the gradient and water velocity. With the Taum Sauk Dam reducing substrate movement on the LEFBR, gradient may be difficult to measure as an influential habitat characteristic without further research on limiting habitat factors.

<u>Microhabitat</u>

At the microhabitat scale across all streams, HHCs generally selected spawning locations at intermediate depths, lower velocities, and downstream of velocity shelters. These results were relatively consistent across all streams except in the LEFBR, where distance to bank was not a significant predictor. We are not confident in reasoning for this, but it may involve higher inclined banks from erosion making depth and velocity more consistent in cross sections. Our results fit the hypothesis that chubs may minimize multiple threats; i.e., spawning mounds must be constructed in high enough velocity to remove small substrate and provide oxygen, but not fast enough velocity to destruct the spawning mound (People et al. 2014).

Hornyhead Chubs constructed mounds in microhabitats of the East and West Fork Black River with increased depth and higher velocities relative to available habitat within studied riffle-run complexes, which is inconsistent with results from Vives (1990) and Wisenden (2009), and in studies of River Chubs and Bigmouth Chubs, mounds were primarily found in more shallow and slower habitat (Lobb 1988; Peoples 2014). In our study, we did not include pool habitat, and the EFBR is a larger stream than those in previous HHC research possibly explaining differences in results. Even though studies have found differences between available and used habitat, the ranges of habitat characteristic values are similar. This is likely related to stream size and gradient.

At the microhabitat scale, it is uncertain if depth or velocity is more important, but other studies have suggested that velocity is most important to provide oxygen for eggs (Wisenden et al. 2009). If suitable velocity is not present, velocity shelters provide protected habitat from higher velocities and increased flow that frequently occur. Hornyhead Chubs constructed spawning mounds in our study at velocities and depths similar to previous studies of multiple *Nocomis* species (Lobb and Orth 1988; Vives 1990; Wisenden et al. 2009; Peoples et al. 2014; Peoples et al. 2016) (Table 1-4). This supports that habitat preferences are not relative to available habitat, but HHCs are dependent on specific habitat characteristics and ranges for successful construction of spawning mounds and the same is also likely for recruitment.

Once spawning temperature and flow conditions are met, gradient is likely to be the next important habitat characteristic at the mesohabitat scale for the presence of *Nocomis* spawning mounds (Frissell et al. 1986; Peoples et al. 2016). However, we found that gradient was not an influential habitat characteristic in our models, but substrate size and distribution is likely related to water surface gradient in Ozark streams that are not substrate-altered. The substrate used to construct spawning mounds must be available but the gravel sizes used in spawning mounds may not have to be the primary sizes of substrate within a mesohabitat. If so, gradient may be more limiting, and preferred substrate particles must be available to construct spawning mounds. Although, it is not required for substrate for construction of mounds to be the dominate substrate in a mesohabitat as spawning mounds have been observed on bedrock and sand if small gravel is available for chubs to construct mounds.

Conclusions and Management Recommendations

We found that HHC spawning mound site selection was based on multiple spatial scales. Once suitable temperatures occurred in spring (16 to 26 C), HHC selected sites in mesohabitats 10.5 and 11, 2.0 and 2.4 km from Taum Sauk Dam. Although distance from the dam was not a significant predictor on our models, sites closer to the dam retained lesser amounts of small substrate. Hornyhead Chub spawning mounds in the LEFBR were typically in mesohabitats with mean depth of 0.25 m or less, with mean wetted width near 11 m during summer flow. Therefore, mesohabitats that meet these criteria may be suitable locations for substrate additions, if these sites do not have substrate of 8 to 23 mm. In the LEFBR the mesohabitat 1.26 km downstream of Taum Sauk Dam is the only site that had suitable depths, and gradient if of importance and may be limited by substrate distribution. Even though the first riffle-run mesohabitat meeting criteria other than substrate size is 1.26 km downstream of Taum Sauk Dam, access limitations may only allow substrate to be placed within the first 0.55 km. Based on our study, substrate of sizes classes 8 mm to 23 mm is dominant in HHC spawning mounds, and therefore should be of focus when adding substrate to the system in order to aid lithophilic spawning fishes.

References

Berkman, H. E. and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes. 18(4):285-294.

Bunn, S. E. and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492–507.

Cieslewicz, P. 2004. Black River watershed inventory and assessment. Missouri Department of Conservation, Jefferson City, MO.

Combes, M. and S. Dunnaway. Assessment of aquatic resources in East Fork Black River after Upper Taum Sauk Reservoir Dam breach. Missouri Department of Conservation, Jefferson City, MO.

Edge, E. N., C. P. Paukert, M. D. Lobb, B. H. P. Landwer, and T. W. Bonnot. 2020. Seasonal selection of habitat by Spotted Bass and Shorthead Redhorse in a regulated river in the Midwest, USA. River Research and Applications (July 2019):1–10.

Ellis, L. E., and N. E. Jones. 2014. Longitudinal trends in regulated rivers: a review and synthesis within the context of the serial discontinuity concept. Environmental Reviews 21:136-148.

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience. 52(6):483–498.

Frissell, C., W. Liss, C. Warren, and M. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management. 10(2):199–214.

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59(3):507–515.

Hamann, E.J., B. P. Kennedy, D.C. Whited, and J.A. Stanford. 2014. Spatial Variability in Spawning Habitat Selection by Chinook Salmon (*Oncorhynchus tshawytscha*) in a Wilderness River. River Research and Applications 30:1099–1109.

Heggenes, J., J. L. Bagliniere, and R. A. Cunjak. 1999. Spatial niche variability for young Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) in heterogeneous streams. Ecology of Freshwater Fish 8(1):1–21.

Johnston, C. E. and L. M. Page. 1992. The evolution of complex reproductive strategies in North American minnows (Cyprinidae). Pages 600-621 in R. L. Mayden, editor. Systematics, Historical ecology, and North American freshwater fishes. Stanford University Press, Stanford, California.

Kondolf, G. M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21(4):533–551.

Kondolf, G. M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129:262-281.

Lobb, D. and D. J. Orth. 1988. Microhabitat Use by the Bigmouth Chub Nocomis platyrhynchus in the New River, West Virginia. American Midland Naturalist 120(1):32-40.

Manny, B. A., E. F. Roseman, G. Kennedy, J. C. Boase, J.M. Craig, D. H. Bennion, J. Read, L. Vaccaro, J. Chiotti, R. Drouin, and R. Ellison. 2015. A scientific basis for restoring fish spawning habitat in the St. Clair and Detroit Rivers of the Laurentian Great Lakes. Restoration Ecology 23(2):149-156.

Maurakis, E., W. Woolcott, and M. Sabaj. 1991. Reproductive-behavioral Phylogenetics of Nocomis Species-groups. American Midland Naturalist 126(1):103.

McManamay, R. A., B. K. Peoples, D. J. Orth, C. A. Dolloff, and D. C. Matthews. 2015. Isolating causal pathways between flow and fish in the regulated river hierarchy. Canadian Journal of Fisheries and Aquatic Sciences 72(11):1731–1748.

Merz, J. E. and L. K. Ochikubo Chan. 2005. Effects of gravel augmentation on macroinvertebrate assemblages in a regulated California river. River Research and Applications 21:61–74.

Merz, J. E. and J. D. Setka. 2004. Evaluation of a spawning habitat enhancement site for Chinook Salmon in a regulated California river. North American Journal of Fisheries Management 24:2, 396-407.

Paukert, C. P. and D. L. Galat. 2010. Warmwater Rivers. Pages 699-736 *in* W. A. Hubert and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Peoples, B. K., R. A. McManamay, D. J. Orth, and E. A. Frimpong. 2014. Nesting habitat use by river chubs in a hydrologically variable Appalachian tailwater. Ecology of Freshwater Fish 23:283-289.

Peterson, J. T. and C. F. Rabeni. 2001. Evaluating the efficiency of a one-square-meter quadrat sampler for riffle-dwelling fish. North American Journal of Fisheries Management 21:76-85.

Pflieger, W. L. 1997. The Fishes of Missouri. Missouri Department of Conservation, Jefferson City, MO.

Poff, L. N., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47(11):769–784.

Pohl, M. M. 2002. Bringing down our dams: trends in American dam removal rationales. Journal of the American Water Resources Association 38(6):1511–1519.

Richards, K. 1982. Rivers: Form and process in alluvial channels. University Press, Cambridge, Great Britain.

Smith, T. A. and C. E. Kraft. 2005. Stream Fish Assemblages in Relation to Landscape Position and Local Habitat Variables. Transactions of the American Fisheries Society 134(2):430-440.

Vadas, R. L., and D. J. Orth. 2000. Habitat use of fish communities in a Virginia stream system. Environmental Biology of Fishes 59(3):253–269.

Vives, S. P. 1990. Nesting ecology and behavior of hornyhead chub Nocomis biguttatus, a keystone species in Allequash Creek, Wisconsin. American Midland Naturalist 124(1):46–56.

Ward, J. V, and J. A. Stanford. 1983. The Serial Discontinuity Concept of Lotic Ecosystems. Pages 29 – 42 *in* T. D. Fontaine, S. M. Bartell, editors. Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, Michigan.

Wisenden, B. D., A. Unruh, A. Morantes, S. Bury, B. Curry, R. Driscoll, M. Hussein, and S. Markegard. 2009. Functional constraints on nest characteristics of pebble mounds of breeding male hornyhead chub Nocomis biguttatus. Journal of Fish Biology 75:1577-1585.

Whitney, J. E., R. Waters, and J. A. Holloway. 2020. Muddying the waters : investigating the generality of silt-resistance in mound-building Nocomis spp . using hornyhead chub (Nocomis biguttatus) and redspot chub (Nocomis asper). Environmental Biology of Fishes.

Zeug, S. C., K. Sellheim, C. Watry, B. Rook, J. Hannon, J. Zimmerman, D. Cox, and J. Merz. 2014. Gravel augmentation increases spawning utilization by anadromous salmonids: a case study from California, USA. River Research and Applications 30:707–718.

Zimmermann, A. E. and M. Lapointe. 2005. Intergranular flow velocity through salmonid redds: sensitivity to fines infiltration from low intensity sediment transport events. River Research and Applications 21:865-881.

Tables & Figures

Table 1-1. Habitat characteristics measured (acronym and units) at the mesohabitat and microhabitat scales to determine Hornyhead Chub spawning site selection. A dash indicates the specific parameter was not measured at that scale.

	Scale	
Habitat Variable	**Mesohabitat**	**Microhabitat**
Distance from Dam	D (km)	-
Mesohabitat Area	$\bar{x}$ (m^2)	-
Stream Width	$\bar{x}$ (m)	x (m)
Depth	$\bar{x}$ (m)	d (m)
Velocity	-	v (ms^{-1})
Gradient	h %	-
Substrate	Distribution Curve	-
Velocity Shelter	-	Presence of velocity shelter
Canopy Cover	$\bar{x}$ (%)	Canopy Cover (%)
Distance to Bank	-	D (m)

Table 1-2. Habitat characteristics were measured in riffle-run mesohabitats on the Lower East Fork Black River (LEFBR), East Fork Black River (EFBR) upstream of Taum Sauk Reservoir, Big Creek (BGCK), and the West Fork Black River (WFBR) in 2017 and 2018. The number of random points was based on the size of the habitats with a minimum of 20 points and a maximum of 120 points. Mesohabitats 10.5 and 11.5 were labeled differently because they were side channels that run adjacent to the main channel of the East Fork Black River.

Mesohabitat	Stream	Area (m^2)	Habitat Points
1	LEFBR	620	20
2	LEFBR	4550	83
3	LEFBR	1160	20
5	LEFBR	1870	33
6	LEFBR	1930	35
7	LEFBR	1100	20
8	LEFBR	6840	120
9	LEFBR	2060	37
10	LEFBR	3170	57
10.5	LEFBR	2140	38
11	LEFBR	3670	66
11.5	LEFBR	4770	87
12	LEFBR	6550	120
13	LEFBR	2750	49
14	LEFBR	2440	44
16	LEFBR	940	20
18	LEFBR	2450	44
20	LEFBR	4680	85
21	UEFBR	2610	49
22	UEFBR	1800	35
23	WFBR	2540	47
24	WFBR	1660	32
25	BGCK	2610	48
26	BGCK	2560	48
27	BGCK	3460	63

Table 1-3. Searches revealed 29 Hornyhead Chub Spawning mounds in the Lower East Fork Black River in 2017. In 2018, the Upper East Fork Black River, West Fork Black River, and Big Creek, Missouri were added to the study, and an additional 42 Hornyhead Chub spawning mounds were located. Microhabitat measurements were recorded at 15 randomly selected spawning mounds in 2017 and seven spawning mounds in 2018.

	Spawning Mounds Found		Spawning Mounds Measured	
Stream	2017	2018	2017	2018
Lower East Fork Black River	29	1	15	1
Upper East Fork Black River	-	6	-	0
West Fork Black River	-	31	-	5
Big Creek	-	4	-	1

Table 1-4. Microhabitat habitat characteristics recorded at *Nocomis* spawning mounds in other studies.

			Depth (m)		Velocity (m/s)	
Study	Species	Mounds	Mean (SD)	Range	Mean (SD)	Range
Peoples et al. 2014	*N.micropogon*	78	0.42 (0.14)	0.19-0.96	0.22(0.01)	0.02-0.70
Lobb and Orth 1988	*N. platyrhynchus*	90	0.38 (-)	0.15-0.75	0.33(-)	0.07-0.69
Peoples et al. 2016	*N. leptocephalus*	7	0.35 (0.08)	-	0.006 (0.0004)	-
Vives 1990	*N. bigguttatus*	85	0.431 (0.01)	0.09-0.71	0.18 (0.075)	0.02-0.36
Wisenden et al. 2009	*N. bigguttatus*	13	0.354 (0.05)	-	0.38 (0.02)	-
This study	*N. bigguttatus*	22	0.33 (0.14)	0.11-0.63	0.14 (0.02)	0.04-0.49

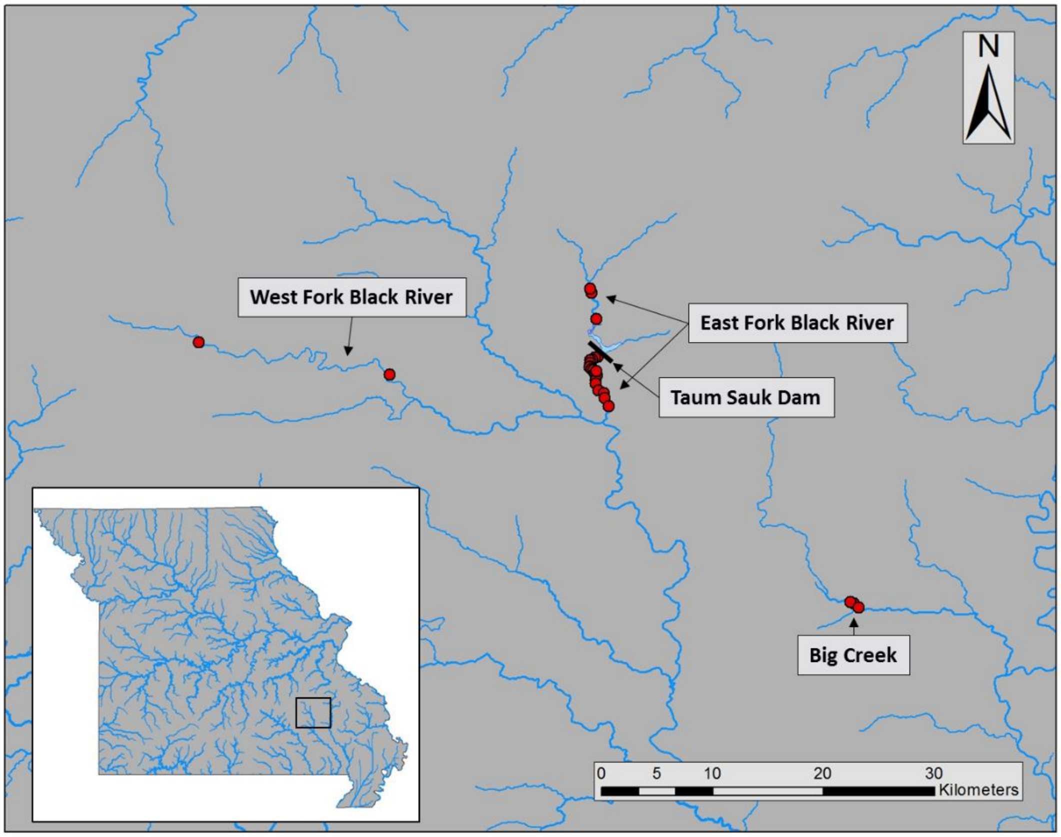

Figure 1-1. Map of Missouri, USA and the streams included in this study. The red dots indicate study mesohabitats; the black dark line indicates Taum Sauk Dam on the East Fork Black River.

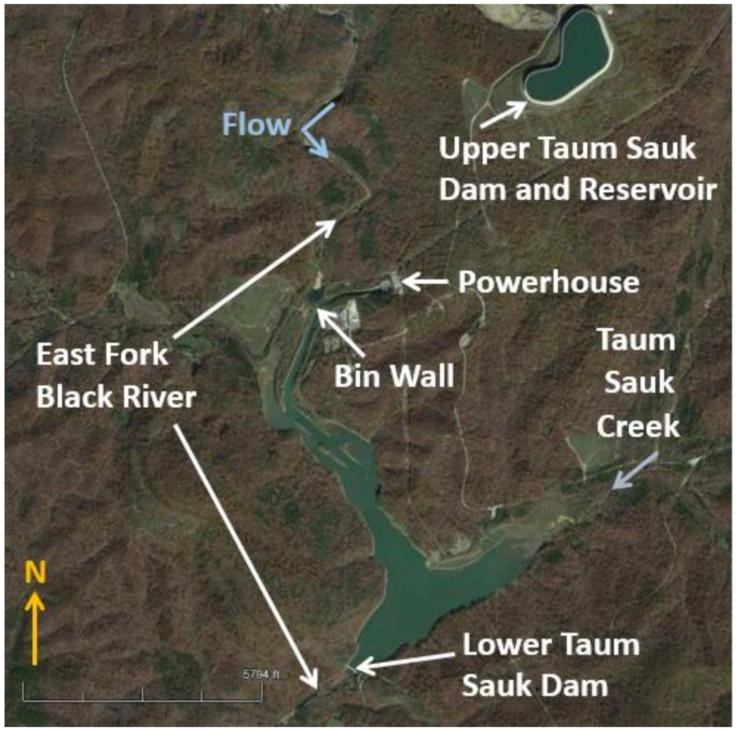

Figure 1-2. Map of Taum Sauk Project Facilities located on the East Fork Black River and Taum Sauk Creek, Missouri (reprinted from Lobb 2016)

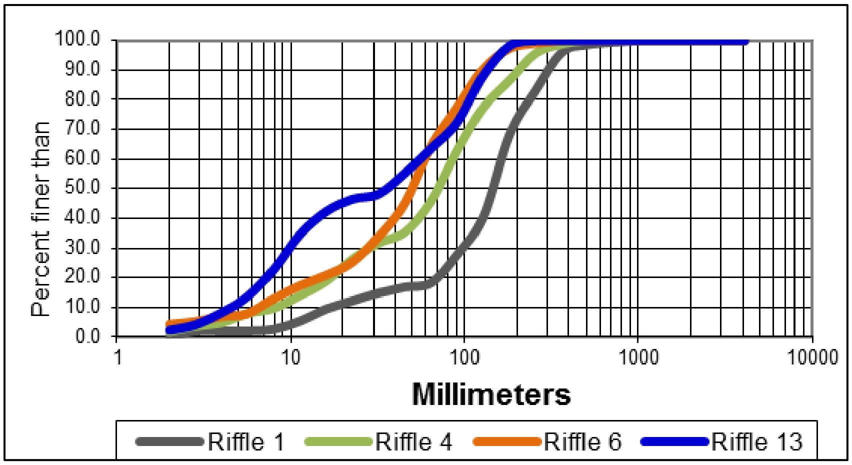

Figure 1-3. Cumulative particle size distribution at four riffles (Figure 1-4) downstream of the lower Taum Sauk Reservoir sampled in 2015 by the Missouri Department of Conservation (reprinted from Lobb 2016). Riffles were 0.49 km, 0.74 km, 1.26 km, and 2.43 km downstream of Taum Sauk Dam, respectively.

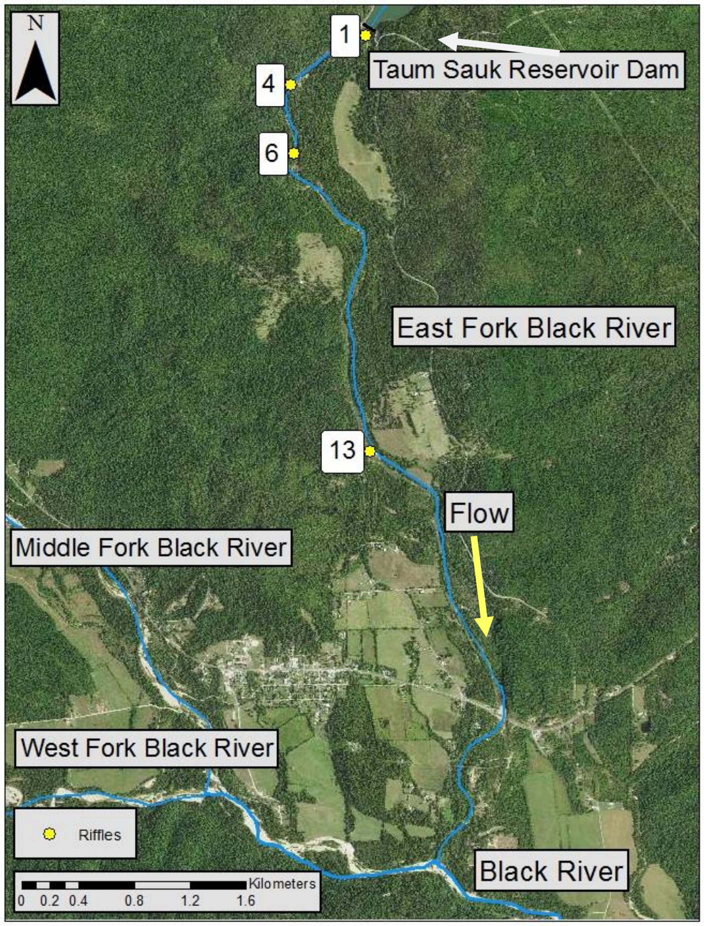

Figure 1-4. Map of the four riffle reaches (1, 4, 6, and 13) where particle sizes were measured by the Missouri Department of Conservation in 2015 (reprinted from Lobb 2016).

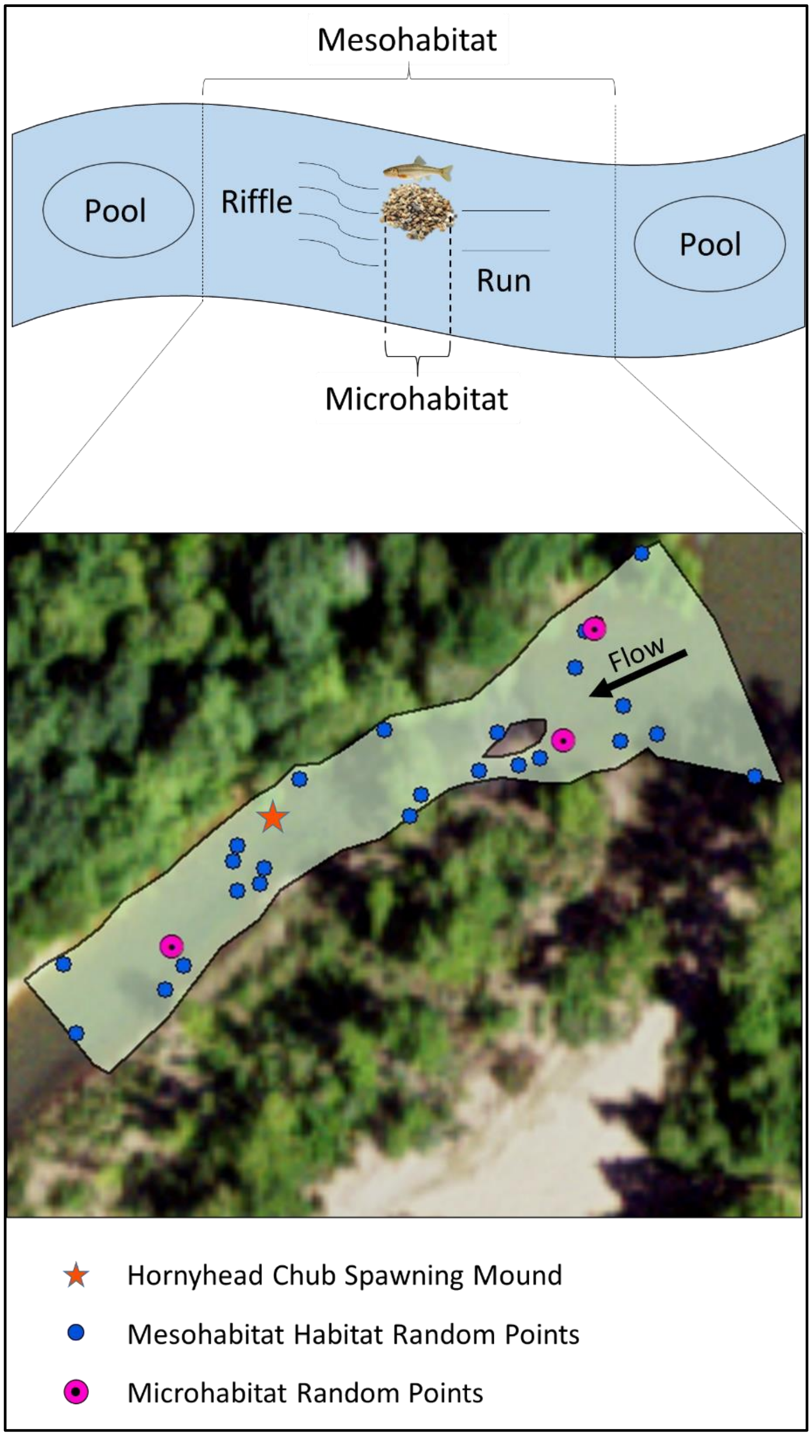

Figure 1-5. Schematic of the sampling approach to determine habitat characteristics of Hornyhead Chub spawning mounds. Mesohabitats were separated by pools (top panel). Within defined mesohabitats, depth, stream width, canopy cover, and five substrate samples were collected at random points to describe the mesohabitat (bottom panel); area and water surface gradient were measured for the whole mesohabitat. When Hornyhead Chub spawning mounds were located, variables were measured at the mound and at three randomly selected points to compare to the microhabitat selection.

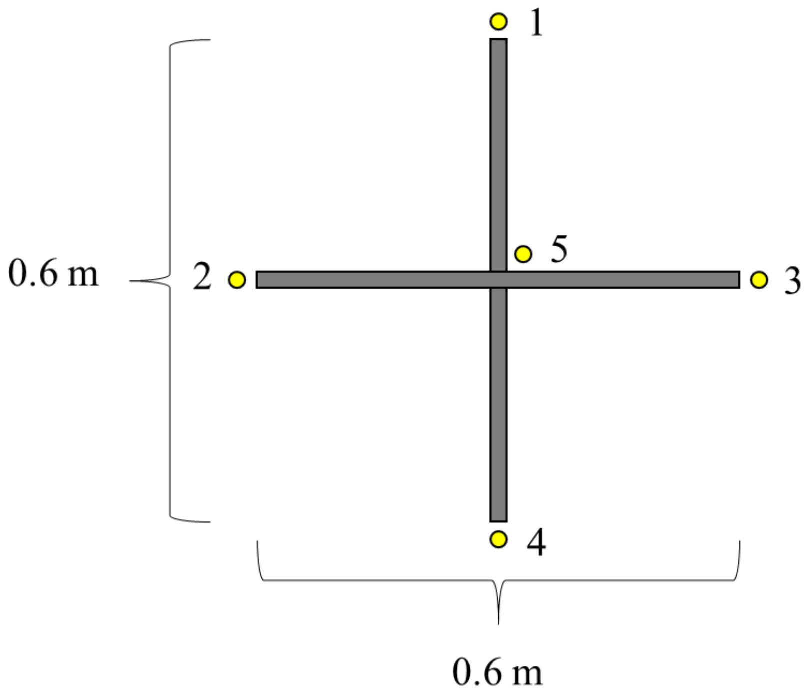

Figure 1-6. Metal cross used for selecting substrate at random habitat measurement points. The yellow dot was where the first piece of substrate that one came in contact with was measured and recorded (Litvan et al., 2010).

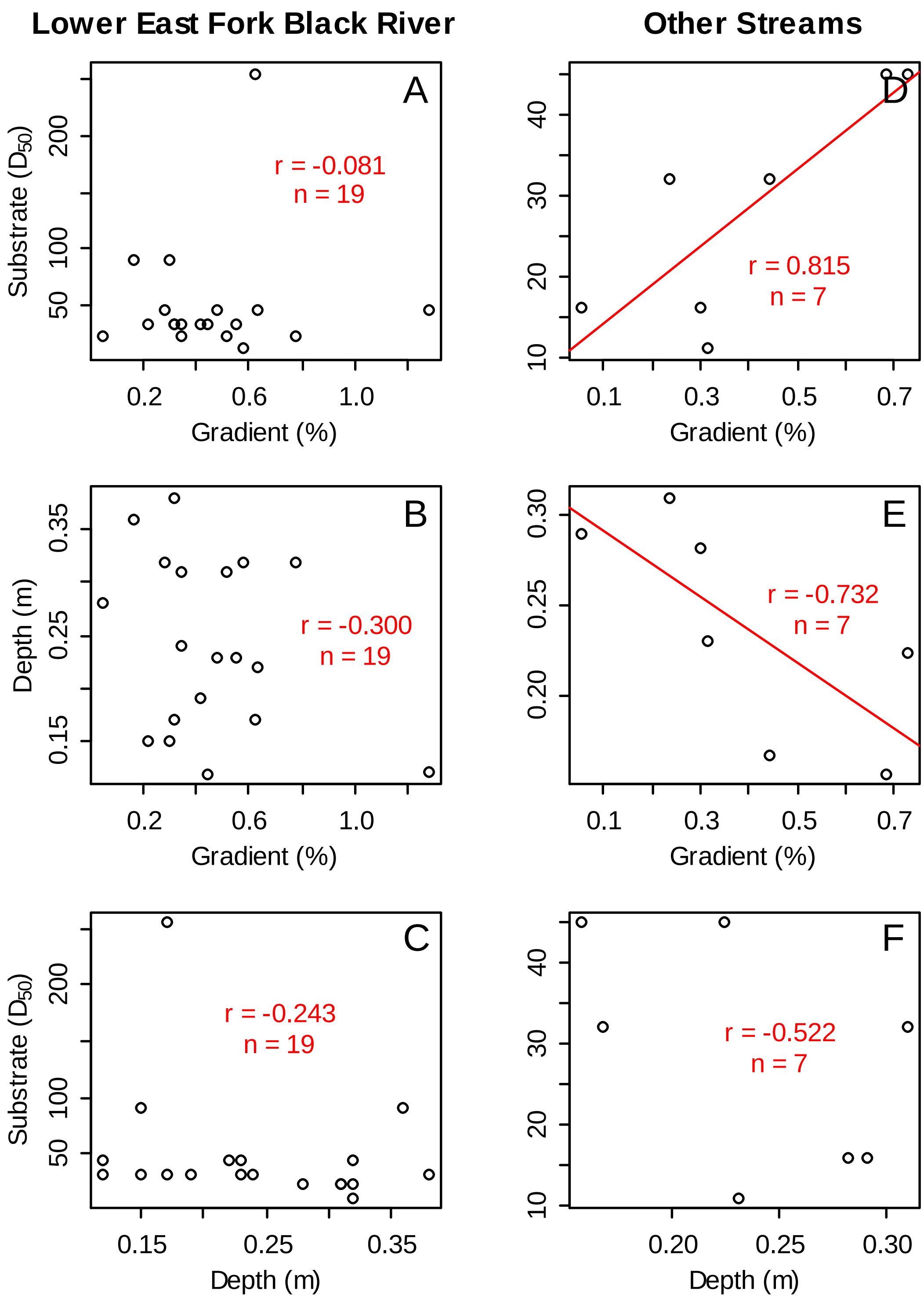

Figure 1-7. The relationship between habitat characteristics at the mesohabitat scale is shown in plots A, B, and C for the Lower East Fork Black River, a substrate-altered stream, and relationships for the West Fork Black River and Big Creek in plots D, E, F, streams that are not substrate-altered. Substrate (D_{50}) is the 50th percentile values for all particles measured within a mesohabitat.

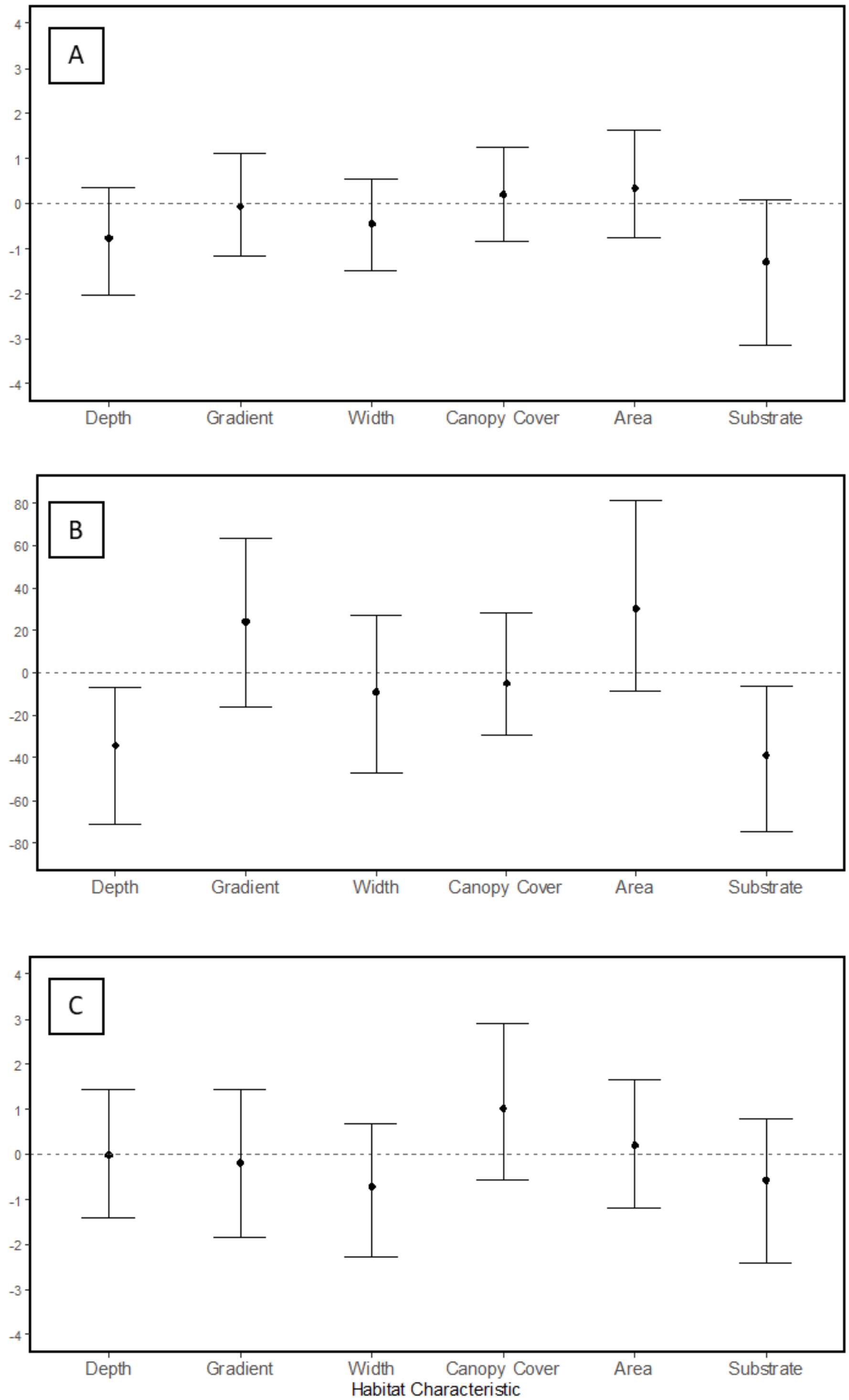

Figure 1-8. The standardized coefficients (y-axis) for the general linearized model (GLM) predicting Hornyhead Chub spawning mound presence for habitat variables at the mesohabitat scale. Plot A includes outputs from mesohabitat models in all streams. Plot B displays the outputs for other streams (West Fork Black River, Upper East Fork Black River, and Big Creek), and Plot C for the Lower East Fork Black River.

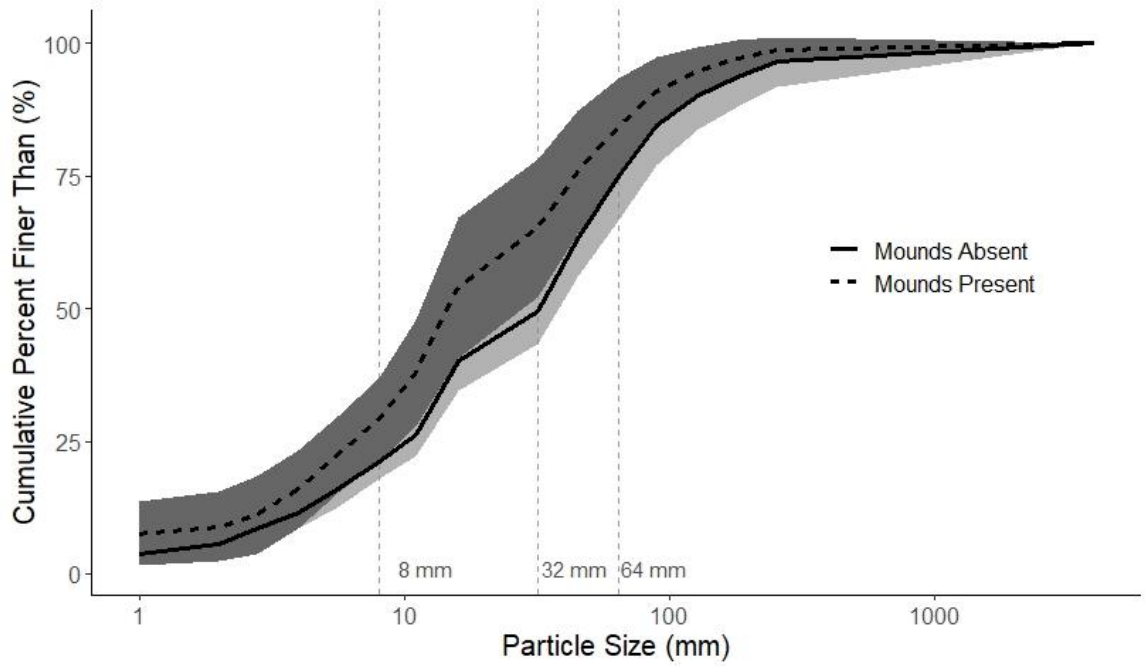

Figure 1-9. Cumulative particle size distribution plots for mean substrate values of mesohabitats with Hornyhead Chub spawning mounds present (n = 7) and absent (n = 19). Standard Error marked by shaded areas surround the lines for mean cumulative percent values. Mesohabitats were located in the Lower East Fork Black River, Upper East Fork Black River, West Fork Black River, and Big Creek, Missouri.

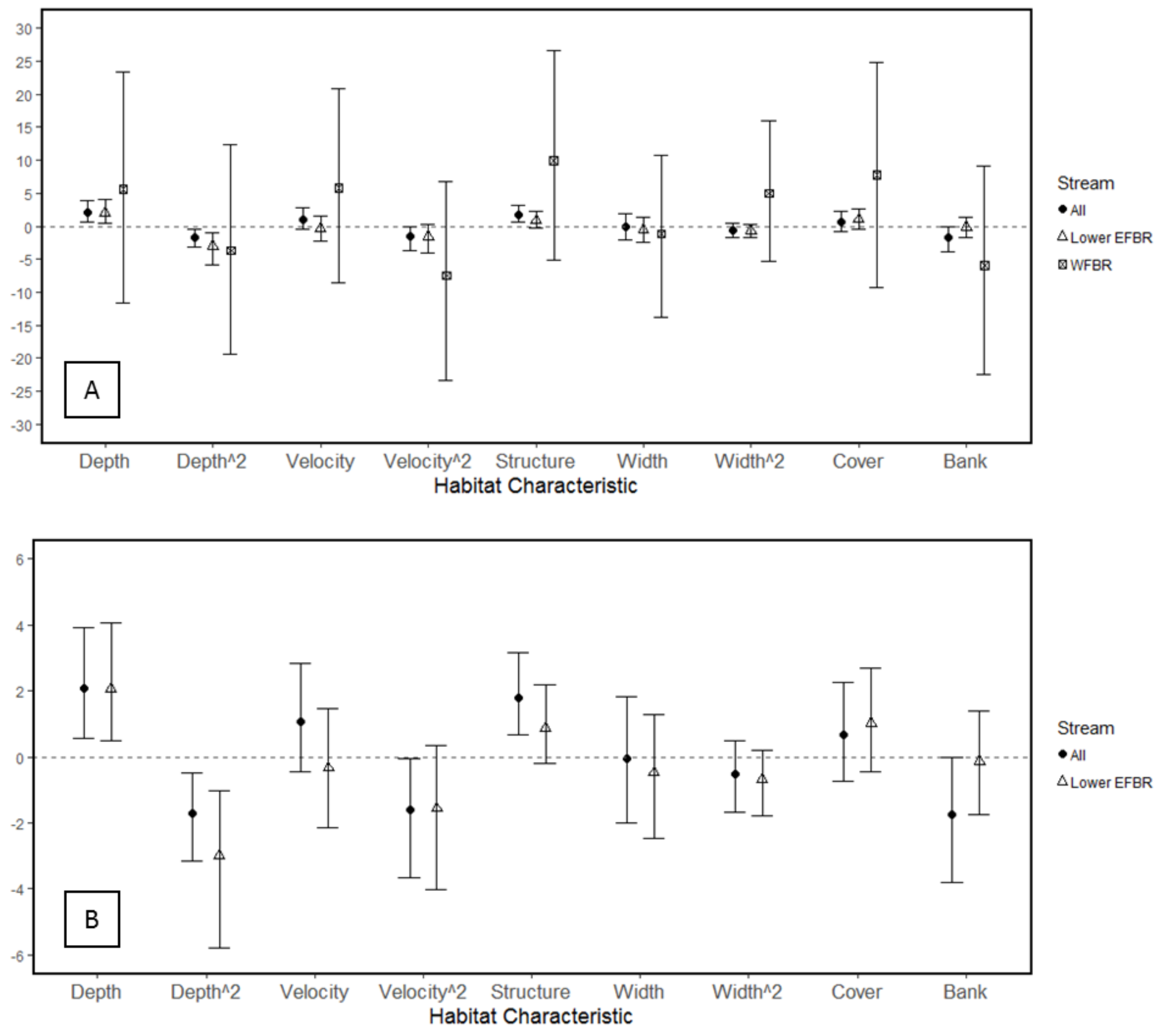

Figure 1-10. Standardized coefficients (y-axis) for Hornyhead Chub spawning mound microhabitat selection results from a discrete choice model with a Bayesian Framework. Plot A includes results from mounds found in all mesohabitats including the Lower East Fork Black River (LEFBR), and those grouped in other streams including The Upper East Fork Black River, West Fork Black River, and Big Creek. Plot B only includes results from mesohabitats in all stream sections and those from the Lower East Fork Black River to view at a finer scale.

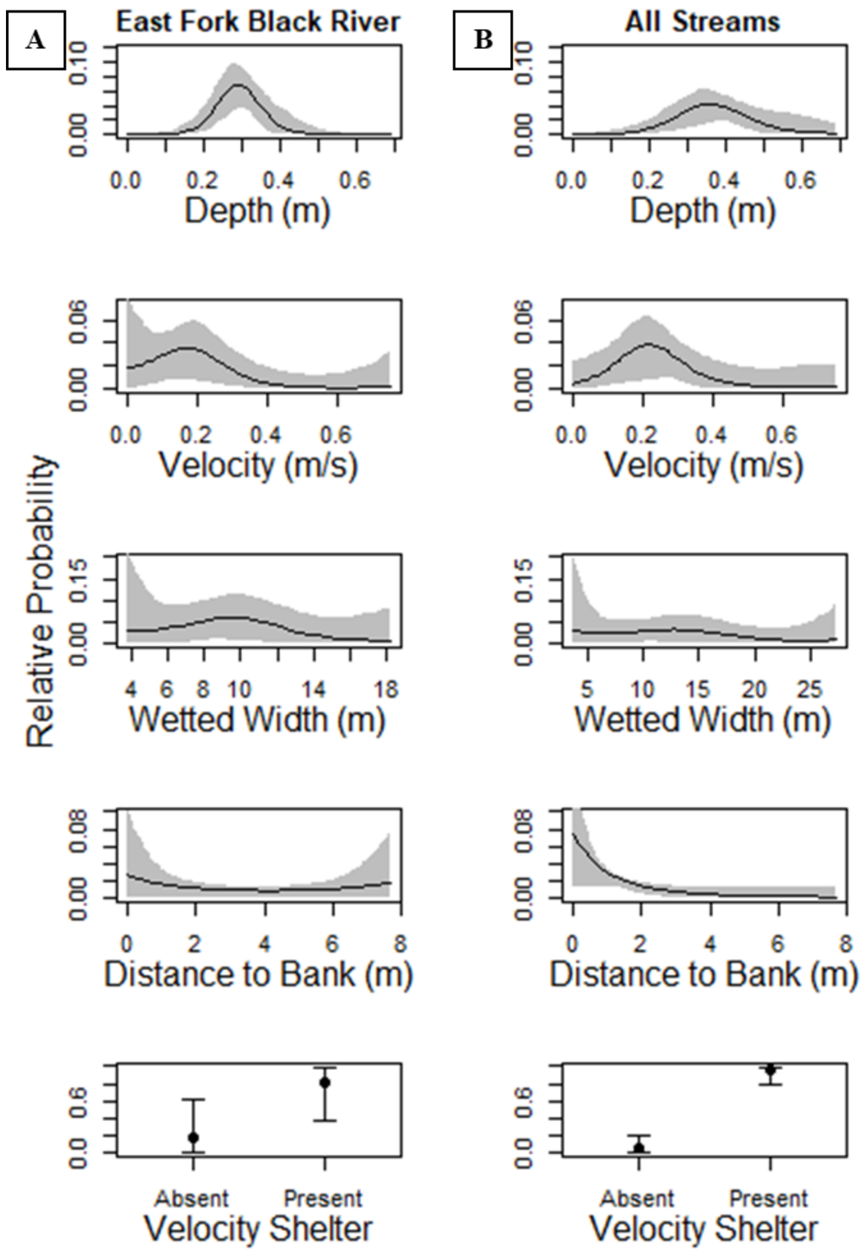

Figure 1-11. Relative probability for Hornyhead Chub spawning microhabitat characteristics in the Lower East Fork Black River downstream of Taum Sauk Reservoir (A) and all steams combined (Lower East Fork Black River, West Fork Black River and Big Creek) (B). The shaded gray area and error bars for velocity shelter represent the 95th percentile error for relative probability.

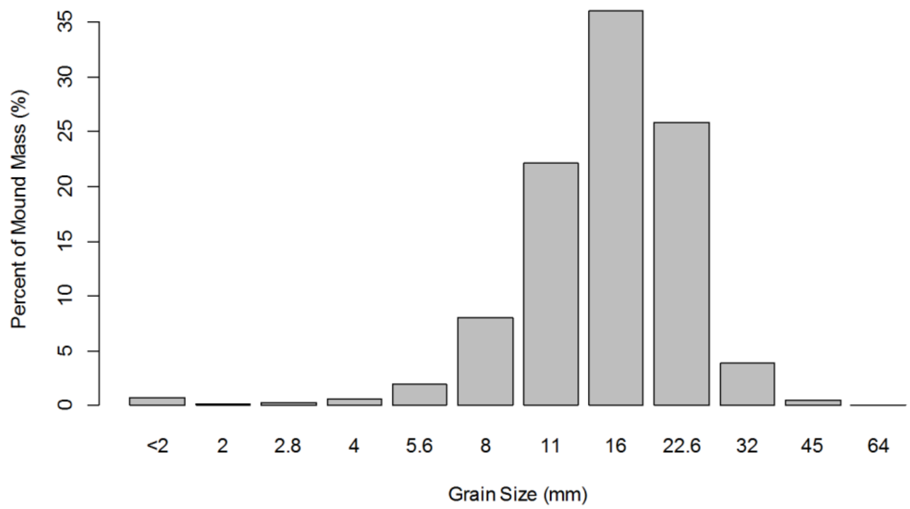

Figure 1-12. Substrate size composition averaged from six randomly selected Hornyhead Chub spawning mounds collected in 2017 from the Lower East Fork Black River, Missouri.

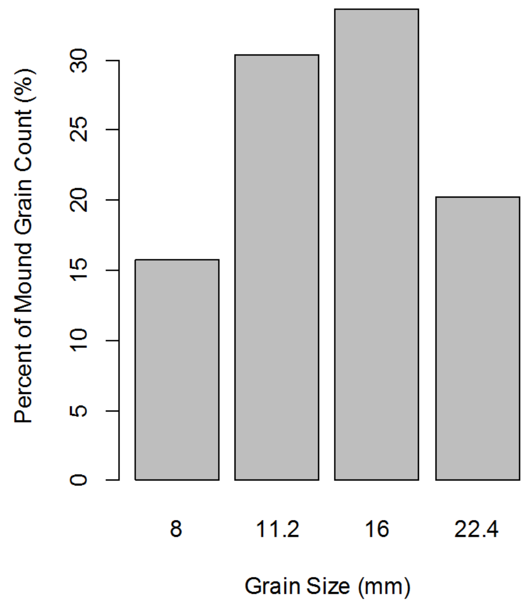

Figure 1-13. Seven spawning mounds collected in 2017 and substrate was separated into size groups using sieves, and weighed by group. Within each group, 20 particles were randomly selected and weighed to estimate the number of particles within each group. Based on gape size, it is assumed that Hornyhead Chubs can collect substrate between 8 and 32 millimeters in diameter; therefore, we distributed four substrate size groups to identify what substrate grain size is potentially of most importance to the construction of Hornyhead Chub Spawning mounds.

CHAPTER TWO

Fish Communities of Riffle-Run Habitat in the East Fork Black River, Missouri

John D. Brant and Craig P. Paukert

Abstract

Fish communities are frequently driven by habitat characteristics and niches that are created by physical features in freshwater streams. However, dams often influence downstream habitat including substrate size distribution, the presence of woody debris, water temperature, and dissolved oxygen. Due to the high variation in streams that are not dammed, it is often difficult to isolate individual habitat characteristics that limit fish diversity and life history downstream of dams. Therefore, determining what management actions can improve available habitat can be challenging. To determine influential habitat characteristics in a substrate-altered stream, we sampled fish communities at 14 riffle-run habitats (separated by pools > 1 m depth with low velocities) and measured habitat characteristics within 6.4 km downstream of Taum Sauk Reservoir in the Lower East Fork Black River of Missouri. Fish were sampled using backpack electrofishing, and prepositioned grid electrofishing in riffle-run habitats from August to October of 2017 and 2018. Measured habitat characteristics included reach area, water depth, wetted width, substrate size, canopy cover, water surface gradient, and distance downstream from Taum Sauk Dam. Hill number diversity indices were used to describe the diversity fish in three different groups: the overall fish community, fishes sampled with prepositioned electrofishing grids, and Hornyhead Chub *Nocomis biguttatus* (hereafter "HHC") and spawning associates. We used generalized linear models in a Bayesian

framework to determine which habitat characteristics were most influential to diversity in our three groups if fish. Increased reach area, smaller substrate sizes, and increased distance from Taum Sauk Dam were related to an increase in the overall fish community diversity. Fishes sampled with propositioned electrofishing grids were most influenced by depth, and HHC spawning associated species diversity was influenced by area and substrate size distribution. Presence of increased small substrate was related to greater fish diversity in multiple groups suggesting that substrate size is a limiting fish diversity in the East Fork Black River downstream of Taum Sauk Reservoir. Therefore, addition of substrate downstream of Taum Sauk Reservoir may create more heterogeneous habitat and increase fish diversity.

Introduction

Freshwater streams are highly dynamic ecosystems that are influenced by internal and external environmental factors including precipitation, geomorphology, and surrounding land cover and vegetation along with additional factors (Allan 2004). As water flows downstream, it continuously transports substrate, nutrients, and organisms (Vanotte et al., 1980), shaping landscapes through erosion and deposition allowing streams to meander but stay within dynamic equilibrium (Vanotte et al., 1980). Aquatic and terrestrial species biologically compete and sometimes even alter the habitat of streams by moving structure and influencing ecosystem processes (Vanotte et al., 1980). On a short time scale (e.g. one or two years), these changes are miniscule, but over extensive lengths of time, streams may have shifts in habitat characteristics leading to a change in aquatic biota (Rahel 2010).

Streams and aquatic organisms have been heavily influenced and degraded through anthropogenic activity at multiple scales (Allan 2004; Dudgeon et al. 2006). Humanity has influenced streams through changes in land use, introducing and eradicating species, and creating barriers that isolate imperiled ecosystems (Wang et al. 2001; Dudgeon et al. 2006; Wohl 2006). Streams continue to develop and change as they grow into larger bodies of water, but dams hinder this process and influence the change that naturally occurs (Ward and Stanford 1983). Dams cause shifts in aquatic communities not only through separating populations but by influencing habitat through shifts in temperature and flow regimes, restricting the amount of woody debris flowing downstream, and stopping substrate movement (Ward and Stanford 1983; Kondolf 1997; Allan 2004).

All dams trap substrate to some degree, alter stream bed movement, and interrupt the continuity of substrate transport (Kondolf 1997). Streams below reservoirs are often referred to as “hungry water” because the substrate load is low, and excess energy typically moves substrate from the stream bed below the reservoir until equilibrium is met where no more of the stream bed can be moved or the banks have eroded (Kondolf 1997). Streams below impoundments have a change in bedload, and the available habitat becomes more homogeneous (Kondolf 1997). Therefore, fishes that require specific substrate sizes to meet their life history requirements may be affected by dams and segmented streams (Ellis and Jones 2013; McManamay et al. 2015). Longitudinally, a change in substrate size and distribution is often observed (Ward and Stanford 1983), and as the distance from the dam increases, streams regain diverse habitat and aquatic communities (Ward and Stanford 1983).

Fish community diversity is strongly driven by habitat complexity because many species fill niches within specific habitat types (Gorman and Karr 1978). Aquatic organisms depend on variation in habitat parameters including substrate, presence of secondary channels, temperature regime, size of area, and available cover for protection, foraging, and spawning (Gorman and Karr 1978; Johnston and Page 1992; Peterson and Rabeni 2001; Merz and Chan 2005; Kondolf et al. 2008; Zueg et al 2014). In particular, substrate size is a critical component for lotic fishes which many species depending upon for spawning and foraging (Berkman and Rabeni 1987). Without specific substrate requirements met, populations frequently decrease in numbers or become extirpated (Berkman and Rabeni 1987).

Benthic and lithophilic spawning fishes, which are common in the Ozark streams, are dependent substrate size, distribution, and embeddedness to meet their life history requirements (Smith and Kraft 2005; Wisenden et al. 2009, Manny et al. 2015). Longitudinal shifts in biotic communities and physical habitat changes have been documented in multiple streams, but the distance at which diversity increases is dependent on multiple factors including but not limited to watershed size, flow release from impoundments, and gradient (Bunn and Arthington 2002; Ellis and Jones 2014). Within the East Fork Black River downstream of Taum Sauk Reservoir, we are uncertain at what distance from the dam the fish diversity and habitat return to a state they may sustain in the absence of the dam. Our objective was to determine what habitat characteristics are related to fish diversity within riffle-run habitat of the East Fork Black River downstream of Taum Sauk Reservoir dam and recommend management actions to reduce the influence of the dam. Our hypothesis is that fish diversity will increase with distance from Taum Sauk reservoir and substrate size distribution.

Methods

Study Site

This study was conducted on the East Fork of the Black River (EFBR), a fifth order stream that flows 32 km from the St Francis Mountains within the Ozark Highlands of Missouri (Figure 2-1). Streams of Ozark Highlands are typically pristine, have low turbidity, carry small loads of silt, have high gradient, and hold high biodiversity. The watershed of the EFBR covers 246 km^2 and the land use is primarily forest and woodlands with a small amount of grasslands in river bottoms along with glade complexes occurring throughout the St. Francis Mountains (Cieslewicz 2004). The EFBR flows into the Black River, a seventh order Ozark stream and continues through the Ozark Highlands and Mississippi Lowlands of Missouri and Arkansas before joining the White River of the Mississippi River drainage.

Taum Sauk Reservoir on the EFBR and Clearwater Reservoir on the main stem of the Black River occurring 25 km downstream of the EFBR confluence are the only impoundments in the Missouri portion. Taum Sauk Reservoir is located immediately upstream of our study area on the EFBR and is operated as a pump storage facility constructed in 1963 and operated by Ameren Missouri Electric Company. An upper reservoir, 230 m higher in elevation, stores water to generate electricity. Outflow of Lower Taum Sauk Reservoir is intended to match the inflow from the Upper East Fork Black River (UEFBR) and Taum Sauk Creek, but outflow does not achieve the rate of variation in flow or temperature of inflowing water (Cieslewicz 2004). A small dam upstream of the Lower Taum Sauk Reservoir creates a gravel bin trap (Figure 1-2) to prevent coarse sediment from entering the reservoir and reducing storage capacity. The coarse sediment trap has an approximate capacity of 23,000 cubic meters and emptied every eight to ten years (Cieslewicz 2004). Lower Taum Sauk Reservoir creates a break in bedload transport and has led to a decrease of available small substrate in the EFBR downstream of the dam (Chapter 1: Figure 1-3; Lobb 2016; Figure 1-4).

The Missouri Department of Conservation (MDC) and Missouri Department of Natural Resources (DNR) have monitored the EFBR since a dam failure upstream of the Lower Taum Sauk Reservoir causing a catastrophic flow event 2005. This anthropogenic caused event resulted in large amounts of terrestrial and aquatic habitat damage upstream of Taum Sauk Reservoir (Combes and Dunnaway 2009). Immediately following the event, increased amounts of fine sediment were deposited in the LEFBR, but the fine substrate shifted downstream by 2007 returning the river to a similar state prior to the flood event in 2005 (Combes and Dunnaway 2009). The Missouri DNR and MDC have monitored the EFBR for water quality, instream habitat, substrate size and distribution, aquatic invertebrate communities, and fish communities to maintain licensing for Ameren through the Federal Energy Regulatory Commission (FERC).

The EFBR hosts a similar fish community to other south flowing Ozark Highland streams. Many of these fishes require silt free gravel, low turbidity, and higher velocity habitat. In relation to habitat requirements, many species of Ozark Streams are believed to be site feeders (Pflieger 1997). Following the flood event of 2005, MDC conducted sampling for two years in all habitats leading to a collection of 57 species collected downstream of Taum Sauk Reservoir (Combes and Cunnaway 2009).

In chapter one, the HHC spawning habitat requirements were studied to understand habitat characteristic limitations for this species. This was done to understand if (or how) the lack of substrate in the LEFBR may affect HHC and affiliated nest associated species. In this chapter, our objective was to determine what habitat characteristics influence fish communities within riffle-run habitats of the East Fork Black River.

Sampling Methods

We sampled fishes in a 6.4 km stretch of the East Fork Black River downstream of Taum Sauk Reservoir in 14 riffle-run mesohabitats from late August through early October in 2017 and 2018. Reach boundaries were defined by large pools greater than one meter deep separating high velocity habitat. The fast flowing, or riffle- run, habitats were identified by canoeing the 6.4 km stretch three times in March and April 2017. Fish sampling occurred when water temperatures were 24 to 21 C (in 2017) and 27 to 25 C (in 2018). Most fish were identified and immediately released once sampling of a reach was complete, but as needed, formalin was used as a preservation agent to transfer and identify fish in a lab setting.

Electrofishing prepositioned grids were used to sample fish on or near the stream bed using benthic habitat. These grids were constructed using one-inch PVC pipe, aircraft cable for the cathode and anode, and 7.6 meters of cable to connect the grid to the electrofishing control box (Figure 2-2). Between 5 and 20 grid samples of two square meters were collected at each reach in proportion to the area size (Table 2-1). Electrofishing grid sampling was limited to habitat with flowing water less than 0.5 m deep because fish immobilization was inconsistent at greater depths. Alternating Current (AC) was used for prepositioned grid electrofishing to prevent collection of specimens from outside of the grid due to fish taxis associated with Direct Current (DC) (Fisher and Kessler 1987; Weddle and Kessler 1993). The depth and electric current restrictions were determined in a preliminary experiment to minimize fish mortality and maximize immobilization for all sized fish.

The protocol followed for sampling using prepositioned electrofishing grids consisted of placing grids at randomly selected points within the area of a reach and collecting habitat measurements at the location of each individual grid. Habitat characteristics measured were depth, velocity, 10 substrate particles were measured using a metal cross (Chapter 1; Figure 1-6) at two locations in the grid, canopy cover using a concave forestry densiometer, wetted width, and distance to the nearest bank (Table 2-2). Following habitat measurements, the grids were left undisturbed for twenty minutes to allow fish to return. Grids were individually connected to the control box to provide constant AC at 80 watts. One person controlled the electrofishing control box while another individual quickly positioned them self at the downstream end of the grid spreading a 1.8 m high and 1.8 m wide beach seine with 3.2 mm mesh to catch fish drifting downstream while immobilized. A third individual used a dip net to catch fish that were drifting away from the seined and collected fish that were trapped on the stream bed. Once all fish were collected from the two square meter area, the electricity was turned off, and fish were identified to the species and total length measurements were collected. Prepositioned electrofishing grids were only used at 14 reaches due to low flow levels, and the three reaches not sampled did not have habitat less 0.5 meters deep and velocity fast enough to carry immobilized fish into the seine.

Backpack electrofishing was conducted using two Midwest Lake Electrofishing Systems (MLES) XStream units. As recommended by Rabeni et al. (2009), settings used included 60 Hz pulsed DC with a duty cycle of 15% and a voltage of 220-280 to achieve current of 2-5 amps. Voltage started at 220 for all sites, but if current did not stay between 2-5 amps, voltage was adjusted (Rabeni et al. 2009). Two individuals operated backpacks and nets while a third crew member assisted in netting fish. The crew started at the downstream end of each mesohabitat and worked their way upstream while electrofishing. Once a mesohabitat was sampled, fish were identified to the species and total length measurements were recorded before fish were released or preserved for reference specimens. Water conductivity was measured and voltage settings were adjusted based on standard protocol for backpack electrofishing (Rabeni et al. 2009). Capture per unit effort (CPUE) was measured by the number of fish collected in the time that the electrofishing backpacks were operated. To test our detection of species with our selected gear, seining was conducted in 2018 to confirm that species in deeper runs were not being missed by only using backpack and prepositioned electrofishing. No additional species were sampled only by using a beach seine in 2018. The seining effort was not standard across all reaches because of habitat limitations, and therefore, fishes collected while seining were not included in the data analysis.

Habitat characteristics were measured and used to describe reach scale habitat at a different spatial scale from the individual grid locations included depth, canopy cover, wetted width, and surface gradient. As described in the first chapter, depth (m), canopy cover (% cover), wetted width (m), and substrate size (mm) were measured at 20 to 120 random points in relation to water surface area of the corresponding reach (Table 2-2, Table 2-1), and the mean value of metrics measured at the random points was used to summarize habitat. Stream surface gradient (slope) was measured at the reach scale using a self-leveling laser and stadia rod for elevation changes and the thalweg length for distance.

A flow meter staff with was used to measure stream depth, a tape measure and Sonin® electronic distance measuring tool were used to measure wetted width. Canopy cover was estimated using a spherical concave densiometer (Lemmon 1956), a metal cross of a 60 x 60 cm was used to select five substrate particles (Figure 1-6; Litvan et al. 2010). The first piece of substrate touched when a finger is placed at each indicated point was measured on the intermediate axis. Substrate distribution was calculated by creating a cumulative substrate size distribution plot (example in Figure 1-3) and taking the integral to determine area beneath the distribution curve. A larger value indicates more small particles. Distance from Taum Sauk Reservoir was measured using GIS software and stream distance.

Data analysis:

We used Hill numbers, the effective number of species (Montoya-Ospina et al. 2020), as diversity indices to compare fish communities across reaches in the Lower East Fork Black River, and values were calculated separately for three groups of fishes: the overall fish community sampled using backpack electrofishing, HHC spawning associates (Striped Shiners *Luxilus chrysocephalus*, Bleeding Shiners *L. zonatus*, Ozark Minnows *Notropis nubilus*, and Carmine Shiners *N. percobromus*) sampled with backpack electrofishing, and the benthic fish community sampled with prepositioned grid electrofishing. Hill numbers are the effective number of species or as species equivalents since their values represent the minimum number of equally distributed species to meet the same level of diversity (Chao et al., 2014). The response variable, *D,* is the minimum number of species that meets the same level of diversity based on the order *q*. *S* is the number of species in the assemblage being evaluated, and *p* is the relative abundance for the number of species included. The order of *q* determines the sensitivity to species relative abundance.

$$^{q}D = \left(\sum_{i=1}^{S} p_i^q\right)^{1/(1-q)}$$

When *q* = 0 the response, *D*, is equivalent to species richness being sensitive to rare species. The order *q* = 1 weighs species by their proportions without favoring common or rare species. The response can be interpreted as an effective number of typical species and is mathematically equivalent to the exponential of Shannon entropy

(Chao et al., 2014). Therefore, subsequent notation will be based on the emphasis of the estimate: $D_{\text{rare weighted}}$ species will represent ${}^{0}D$, diversity weighted for rare speices, and ${}^{1}D$ will be represented by $D_{\text{equal weighted}}$, diversity weighted equally.

Hill numbers for $D_{\text{rare weighted}}$, and $D_{\text{equal weighted}}$, were used as response variables in generalized linear models (GLM) with habitat characteristics as the covariates in a Bayesian framework with uninformative priors. Models run with $D_{\text{rare weighted}}$ as the response variable will be referred to as the rare species model, and models with $D_{\text{equal weighted}}$ as the response variable as the equal diversity model. $D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$ variables were calculated for the overall community, HHC spawning associates, and the fish sampled using prepositioned electrofishing grids. For the overall community and HHC spawning associates, the Hill number values were calculated at the reach scale. Diversity values calculated with samples collected using prepositioned grids combined the data from all grids within a reach, and the number of grids sampled was proportional to the reach size.

All statistical models used mean depth, mean wetted width, mean canopy cover, water surface gradient, water surface area, substrate size distribution, and distance from the Taum Sauk Reservoir Dam as covariates (Table 2-3). The 50^{th} percentil (D_{50}) was used to represent substrate size for the reaches. Rare species models were run for the overall fish community, HHC spawning associates, and fishes sampled with propositioned electrofishing grids. If the 95 percent credible interval did not include 0, or nearly did not, the habitat characteristics was defined as influential.

Results

On the LEFBR, 19 riffle-run habitats were identified as study reaches in the main channel. Of these 19 reaches, 14 were sampled for fish were sampled using backpack electrofishing and prepositioned electrofishing grids as previously described, and two side-channel habitats were sampled with backpack electrofishing. We collected a total of 24,015 fish of 45 species using multiple sampling gears in 2017 and 2018 combined. In 2017 and 2018, 41 species were sampled, but not all species were sampled both years (Appendix 2). Bleeding Shiner, Longear Sunfish *Lepomis megalotis*, Largescale Stoneroller *Campostoma oligolepis*, and Rainbow Darter *Etheostoma caeruleum*, were the dominant species sampled in riffle-run reaches of the LEFBR making up 78% of the fishes sampled in 2017 and 53% in 2018 (Appendix 2; Appendix 3; Appendix 4).

Habitat Characteristics

Habitat characteristics were measured at the 14 riffle-run study reaches and the two side-channels that remained connected to the main channel throughout the study (Figure 2-3). The 14 reaches on the main channel were included in our analysis, but we excluded the two side-channel reaches from further analysis because they included pool habitat at the time when fish were sampled. Reach area was highly variable across all 14 reaches with a mean of 3000 ± 2000 m^2 (± standard deviation) and a range of 600 m^2 to 6800 m^2. The largest median substrate size was 255 mm at reach 12, 2.7 km downstream of the dam, and the reach median substrate sizes ranged from 11 mm to 440 mm with a standard deviation of 58 mm. Wetted width was variable across all reaches with a mean value of 15 ± 4.5 m. Reach 14 had the greatest mean depth of 0.38 m, but across all reaches, depth was similar (mean = 0.24 ± 0.12 m). Reach 16 had the highest gradient of 1.28 %, and the mean value for all reaches was 0.48 ± 0.28 %. As described in Chapter 1, gradient and substrate size distribution were more strongly correlated in additional studied streams of the same region (i.e., West Fork Black River, Upper East Fork Black River, and Big Creek) that are not considered substrate-altered in comparison to the LERBF (Figure 1-7). Canopy cover percentage varied from 7 to 59% and a mean value of 25 ± 10 % for the LEFBR.

Overall Fish Community

The mean value of $D_{\text{rare weighted}}$ across all 14 reaches for the overall fish community was 22.3 (range: 11, 32) (Table 2-4) and increased with reach area and smaller substrate size for both 2017 and 2018 (Figure 2-4). For $D_{\text{equal weighted}}$ in 2018, diversity increased with increased substrate distribution, reach area, and a decrease in the distance from the Lower Taum Sauk Reservoir Dam (Figure 2-4). However, these patterns for $D_{\text{equal weighted}}$ were not evident in 2017.

Fishes sampled with propositioned electrofishing grids

In August and September of 2017 and 2018, 29 fish species were sampled using prepositioned electrofishing grids at 14 reaches. The mean value of $D_{\text{rare weighted}}$ across all reaches for fishes sampled with propositioned electrofishing grids was of 3.7 (range 2.3 to 6.3) (Table 2-5).

In 2017, Hill Numbers $D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$ were not related to mean depth, mean wetted width, canopy cover, reach gradient, reach area, substrate distribution, and distance from Taum Sauk Dam (Figure 2-5). However, $D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$ diversity values in 2018 increased with a decrease in mean depth at the reach scale (Figure 2-5). Darters, particularly those of the genus *Etheostoma*, made up 32% and 44% of fishes sampled using prepositioned electrofishing grids in 2017 and 2018, respectively. Rainbow Darters were sampled in all reaches making up 25% and 39% of fish sampled using prepositioned electrofishing grids in 2017 and 2018, respectively.

Hornyhead Chub Spawning Associates

In 2017 and 2018, HHC and four associated nest species (Striped Shiner, Bleeding Shiner, Ozark Minnow, and Carmine Shiner) were sampled in the Lower East Fork Black River. In 2017, all five nest associated species were sampled together at reach 11, 2.43 km downstream of Taum Sauk Reservoir, where 10 HHC spawning mounds were located, but in 2018, all five associated species, including HHCs, were not sampled together at any reach. Bleeding Shiners were sampled at 13 of 14 reaches being absent at the reach immediately downstream of the dam (50 m), and Striped Shiners were found at 12 of 14 sampled reaches. Ozark Minnows were sampled at 12 of 14 reaches, and their highest abundance occurred within the reach 11, where HHC spawning mounds were located (see Chapter 1). Carmine Shiners were the least sampled of the four associated spawning species; in 2017 they were sampled at four out of 14 reaches followed by only one individual sampled in 2018.

The number of HHC nest associated species, $D_{\text{rare weighted}}$, sampled in 2017 increased with distance from the dam, whereas in 2018, $D_{\text{rare weighted}}$ values increased with the availability of small substrate, and increased area of sampled reaches (Table 2-6; Figure 2-6). For $D_{\text{equal weighted}}$ values, increased distance from Taum Sauk Reservoir led to increased affiliated spawning fishes diversity in 2017, and in 2018, increased amounts of small substrate and reach area led to higher HHC spawning affiliated fishes diversity (Figure 2-6).

Discussion

Overall Fish Community

Our results found that rare species weighted diversity (^0D or $D_{\text{rare weighted}}$) in riffle-run reaches of the LEFBR was related the reach area, substrate size distribution, and the distance to the Lower Taum Sauk Reservoir Dam. Larger reach areas increase the probability of habitat heterogeneity by providing more niches for species to occupy (Schlosser 1999; Nogués-Bravo and Araújo 2006) and the same pattern may be occurring in the LEFBR. The other habitat characteristic influential in both 2017 and 2018 was substrate size. Increased fine substrate in fast flowing habitat led to a decrease in fish diversity likely caused by filling interstitial spaces and creating homogenous habitat (Casatti et al., 2006). However, our results are contrary of what was found by Casatti et al. (2006), likely because the LEFBR is described as a substrate-altered stream, and an increase of relatively small substrate includes gravel of various sizes potentially providing increased heterogeneous spawning habitat. The pattern of substrate-altered streams frequently creates homogenous habitat of larger substrate (Kondolf 1997) possibly leading to a decrease in species richness in our study. Decreased distances to the dam on the East Fork Black River increased equally weighted species richness contrary to other studies that have shown diversity increases with increased distances from dams (Stanford and Ward 2001; Ellis and Jones 2014). However, these studies typically represent large river reaches below dams. Study reach was a maximum of 5.6 km from the dam and thus represented a relatively small spatial scale, which may have led to the different conclusions than that of Ward and Stanford (2001) and Ellis and Jones (2014).

Both species diversity indices (rare and equally weighted) in riffle-run habits were not related to depth, gradient, wetted width, and canopy cover in both sampling years. Mean depth was not related to the overall species diversity in the LEFBR, but multiple studies have found contrasting results that depth was related to fish communities and habitat selection (Pavlov 1989; Lobb and Orth 1991; Lamouroux et al. 1999; Senay et al. 2017. The exclusion of pools led to a narrow range of reach mean depth values in riffle run habitats ($\bar{x}$ = 0.24 m; SD = 0.08; range 0.12 – 0.38, n = 14) which likely lead us to be believe that mean depth is not a limiting primary habitat characteristic on the LEFBR when focused on riffle run habitat. Although gradient, which we used as a surrogate for water velocity (Yochum et al. 2012), can be influential on fish habitat selection (Facey and Grossman 1992; Peoples et al. 2014), our study found that surface gradient for the riffle run habitats was not related to fish diversity in the LEFBR.

Fishes sampled with propositioned electrofishing grids

Species diversity of fishes sampled with prepositioned grids weighted for increased with shallower mean depths at the reach scale in samples from 2018 for both used indices, increase in $D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$, but no relationships were found between species diversity and measured habitat characteristics in 2017. Darters made up a large portion of the fish sampled using prepositioned electrofishing grids and was potentially related to the relatively low diversity of fishes sampled with this method. *Etheostoma sp*. are abundant in riffle and run stream habitat with heterogeneous substrate that provides interstitial spaces for protection from high water velocity, protection from predators, and preferred prey (Kessler et al., 1995). Rainbow Darters, a generalist species (Pflieger 1997), were sampled in all reaches making up 25% and 39% of fish sampled using prepositioned electrofishing grids in 2017 and 2018, respectively. At the reach scale, depth and gradient were correlated (r = -0.732) indicating that shallower riffle-run habitat frequently often has a higher water velocity. However, our measurement of gradient was based on only two points: the defined upstream and downstream locations of each reach and thus does not account for variation of gradient within the riffle-run habitat. Without taking elevation changes at more points throughout the length of reaches, velocity variation may not be accurately represented. For future studies, variation of gradient at the reach scale may be captured by taking multiple elevation measurements within a reach.

Hornyhead Chub and Associated Spawning Fishes

The most abundant of Hornyhead Chub associated spawning fishes was the Bleeding Shiner and was present at all reaches except for the first reach 50 m downstream of the dam, where neither Hornyhead Chubs nor any associated spawning species were sampled. Bleeding Shiners are abundant in midsize streams (Pflieger 1997) suggesting that they may be a generalist species. Striped Shiners prefer habitat with slower flowing water (Pflieger 1997), suggesting that they may be less abundant in the studied riffle-run reaches. Therefore, Bleeding Shiners and Striped Shiners may not be the best indicator of quality spawning habitat for lithophilic spawning fishes, but species such as Ozark Minnows and Carmine Shiners may be more particular in spawning habitat selection because they frequently do not occur at as high of densities as Bleeding Shiners, and they are well distributed in mid-sized streams in the Ozarks (Pflieger 1997) such as the LEFBR. Understanding the importance of lithophilic spawning fishes preferred habitat is of interested because of their potential decrease of abundance in substrate-altered streams (Chapter 1).

Hornyhead Chub nest associated species $D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$ values increased in 2017 with distance from Taum Sauk dam, whereas in 2018, an increase of both diversity values was related to larger reach area and increased substrate size distribution. The different influential habitat characteristics for 2017 and 2018 is difficult to explain because the composition of fish communities highly varies on a regular basis in midsized streams (Grossman and Sabo 2010), and even different sampling crew members (which occurred in our study) may influence sampling (Hardin and Connor 1992). As previously discussed about the overall fish community, reach area may create habitat diversity and leading to an increase in fish diversity (Schlosser 1999; Nogués-Bravo and Araújo 2006) which was observed among HHC spawning associates in 2018.

Substrate may be a limiting habitat characteristic for these lithophilic spawning fishes that are dependent on substrate size, flowing water, and protection from predation for successful recruitment and presence (Gorman 1988; Lobb and Orth 1991; Mueller et al. 2014). As discussed in Chapter 1, gradient and substrate size were correlated in non-substrate-altered streams suggesting gradient may have a stronger relationship to HHC and associated fishes diversity than our analysis suggests. With this conclusion, substrate may be a limiting habitat characteristic in the LEFBR, but in non-substrate limited streams, habitat for HHCs and associated spawning fishes may be limited by the depth and gradient.

Conclusions and Management Recommendations

Our results showed that fish community diversity in riffle-run habitats of the Lower East Fork Black River were related to increase substrate size distribution and larger reach area. Because substrate was correlated with gradient in non- substrate-altered streams, we could not discern if species diversity was linked more to gradient or substrate. Nonetheless, our results suggest at least one of these variables is important in fish species diversity. Further research with more detailed gradient measures may be useful to tease out these patterns. Adding substrate of the same sizes related to HHC spawning mounds (8 mm to 23 mm; Figure 1-12 and Figure 1-13) to the stream may help minimize the limiting factor of substrate distribution.

References

Allan, J. D. 2004. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. Annual Review of Ecology, Evolution, and Systematics 35(1):257–284.

Bunn, S. E. and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492–507.

Casatti, L., F. Langeani, A. M. Silva, and R. M. C. Castro. 2006. Stream fish, water and habitat quality in a pasture dominated basin, southeastern Brazil. Brazilian Journal of Biology 66(2 B):681–696.

Chao, A., C. H. Chiu, and L. Jost. 2014. Unifying Species Diversity, Phylogenetic Diversity, Functional Diversity and Related Similarity/Differentiation Measures Through Hill Numbers. Annual Review of Ecology, Evolution, and Systematics 45(1):1–28.

Cieslewicz, P. 2004. Black River watershed inventory and assessment. Missouri Department of Conservation, Jefferson City, MO.

Combes, M., and S. Dunnaway. 2009. Assessment of aquatic resources in East Fork Black River after Upper Taum Sauk Reservoir Dam breach. Missouri Department of Conservation, Jefferson City, MO.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Leveque, R. J. Naiman, A. H. Prieur-Richard, D. Soto, M. L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81:163–182.

Ellis, L. E., and N. E. Jones. 2013. Longitudinal trends in regulated rivers: a review and synthesis within the context of the serial discontinuity concept. Environmental Reviews 21:136-148.

Facey, D. E., and G. D. Grossman. 1992. The relationship between water velocity, energetic costs, and microhabitat use in four North American stream fishes. Hydrobiologia 239(1):1–6.

Fisher, W. L., and R. K. Kessler. 1987. Benthic fish sampler for use in riffle habitats. Transactions of the American Fisheries Society 12(3): 291–301.

Gorman, O. T. 1988. The dynamics of habitat use in a guild of Ozark minnows. Ecological Monographs 58(1): 1–18.

Hardin, S., and L. L. Connor. 1992. Variability of Electrofishing Crew Efficiency, and Sampling Requirements for Estimating Reliable Catch Rates. North American Journal of Fisheries Management 12(3):612–617.

Harvey, B. C. 1991. Interactions among Stream Fishes: Predator-Induced Habitat Shifts and Larval Survival. Oecologia. 87(1):29–36.

Kessler, R. K., A. F. Casper, and G. K. Weddle. 1995. Temporal Variation in Microhabitat Use and Spatial Relations in the Benthic Fish Community of a Stream. The American Midland Naturalist. 134(2):361–370.

Kondolf, G. M. 1997a. Application of the pebble count notes on purpose, method, and variants. Journal of the American Water Resources Association. 33(1):79–87.

Kondolf, G. M. 1997b. Hungry water: effects of dams and gravel mining on river channels. Environmental Management. 21(4):533–551.

Kondolf, G. M., J. G. Williams, T. C. Horner, and D. Milan. 2008. Assessing physical quality of spawning habitat. American Fisheries Society Symposium 65:1–26.

Lamouroux, N., J. M. Olivier, H. Persat, M. Pouilly, Y. Souchon, and B. Statzner. 1999. Predicting community characteristics from habitat conditions: Fluvial fish and hydraulics. Freshwater Biology 42(2):275–299.

Lemon, P. E. 1956. A Spherical Densitometer for Estimating Forest Overstory Density. Forest Science 2(1):314–320.

Litvan, M. E., R. J. Distefano, K. J. Walker, and X. Gao. 2010. A Recreational Fishery for Longpincered Crayfish, Orconectes longidigitus (Faxon), in Table Rock Lake, Missouri, USA: Effects of Environmental Factors on Trapping Success. Freshwater Crayfish 17:91–101.

Lobb, D. 2016. Habitat use and distribution of lithophilic spawning and riffle fishes in the East Fork Black River study proposal. Missouri Department of Conservation, Jefferson City, MO.

Lobb, M. D., and D. J. Orth. 1991. Habitat Use by an Assemblage of Fish in a Large Warmwater Stream. Transactions of the American Fisheries Society 120(1):65–78.

Montoya-Ospina, D. C., E. Orlando López-Delgado, V. Hevia, and F. A. Villa-Navarro. 2020. Effects of habitat structural complexity on diversity patterns of neotropical fish assemblages in the Bita River Basin, Colombia. Limnologica 80(2020):125743.

Nogués-Bravo, D., and M. B. Araújo. 2006. Species Richness, Area and Climate Correlates. Global Ecology and Biogeography. 15(5):452–460.

Pavlov, D. S. 1989. Structures assisting the mitigations of non-salmonid fish: USSR. FAO Fishes Technical paper 308. Rome.

Peoples, B.K., R.A. McManamay, D.J. Orth, and E.A. Frimpong. 2014. Nesting habitat use by river chubs in a hydrologically variable Appalachian tailwater. Ecology of Freshwater Fish 23:283-289.

Pflieger, W. L. 1997. The Fishes of Missouri. Missouri Department of Conservation, Jefferson City, MO.

Rabeni, C. F., J. Lyons, N. Mercado-Silva, and J. T. Peterson. 2009. Warmwater Fish in Wadeable Streams. Pages 43–58 *in* S.A. Bonar, W.A. Hubert, D.W. Willis, editors. Methods for Sampling North American Freshwater Fishes. American Fisheries Society, Standard Bethesda, Maryland.

Rahel, F. J. 2010. Homogenization, Differentiation, and the Widespread Alteration of Fish Faunas. Pages 311–326 *in* K. B. Gido, and D. A. Jackson, editors. Community ecology of stream fishes: concepts, approaches, and techniques. American Fisheries Society Symposium 73, Bethesda, Maryland.

Senay, C., Z. E. Taranu, G. Bourque, C. J. Macnaughton, G. Lanthier, S. Harvey-Lavoie, and D. Boisclair. 2017. Effects of river scale flow regimes and local scale habitat properties on fish community attributes. Aquatic Sciences 79(1):13–26.

Vannote, R. L., G.W. Minshall, K. W. Cummins, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130–137.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. Environmental Management 28(2):255–266.

Ward, J. V. and J. A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. In Dynamics of Lotic Ecosystems. Pages 29–42 in Fontaine, T. D., and Bartell S. M., editors. Ann Arbor Scientific Publishers: Ann Arbor, Michigan.

Weddle, K. G. and R. K. Kessler. 1993. A square-metre electrofishing sampler for benthic riffle fishes. Freshwater Science 12(3):291–301.

Wisenden, B. D., A. Unruh, A. Morantes, S. Bury, B. Curry, R. Driscoll, M. Hussein, and S. Markegard. 2009. Functional constraints on nest characteristics of pebble mounds of breeding male hornyhead chub Nocomis biguttatus. Journal of Fish Biology 75:1577-1585.

Wolman, M. G. 1954. A method of sampling coarse river bed material. Transactions, American Geophysical Union 35:951–956.

Wohl, E. 2006. Human impacts to mountain streams. Geomorphology 79(3–4):217–248.

Tables & Figures

Table 2-1. Habitat characteristics summary for reaches sampled downstream from Taum Sauk Dam in the East Fork Black River, Missouri during 2017 and 2018. Reaches were defined by riffle-run habitat separated by large pools greater than one meter deep, therefore areas ranged in size. Number of habitat points and electrofishing grids sampled were dependent on reach area. NA represents that prepositioned electrofishing grids were not used as a sampling method because appropriate habitat was not available for effective sampling. Median substrate size, mean (± 1 SD) depth, wetted width, and canopy cover are reported.

Reach	Distance From Dam (km)	Area (m^2)	Habitat Points	Electrofishing Grids	Median Substrate (mm)	Mean Depth (m)	Mean Wetted Width (m)	Mean Canopy Cover (%)	Gradient (%)
1	0.05	620	20	5	90	0.36 ± 0.26	16 ± 2	13 ± 15	0.17
2	0.22	4550	83	14	22.6	0.32 ± 0.26	17 ± 9	15 ± 18	0.78
3	0.55	1160	20	6	45	0.32 ± 0.18	11 ± 4	35 ± 18	0.29
5	0.96	1870	333	7	45	0.22 ± 0.20	15 ± 8	34 ± 20	0.63
6	1.26	1930	35	7	32	0.19 ± 0.21	13 ± 6	34 ± 23	0.42
7	1.43	1100	19	5	38.5	0.15 ± 0.15	16 ± 2	18 ± 10	0.22
8	1.61	6840	120	20	22.6	0.24 ± 0.24	11 ± 4	17 ± 21	0.52
10	2.09	3170	57	10	32	0.23 ± 0.15	12 ± 6	32 ± 27	0.55
10.5	2.05	2140	38	NA	11	0.32 ± 1.28	11 ± 5	59 ± 26	0.58
11	2.43	3670	66	12	32	0.17 ± 0.10	9 ± 2	26 ± 28	0.32
11.5	2.09	4770	87	NA	22.6	0.31 ± 0.24	9 ± 4	39 ± 22	0.35
12	2.77	6550	120	19	440	0.17 ± 0.14	13 ± 3	26 ± 21	0.62
13	3.31	2750	49	9	90	0.15 ± 0.12	21 ± 3	32 ± 20	0.30
14	3.98	2440	44	9	32	0.38 ± 0.23	15 ± 5	7 ± 13	0.32
16	4.53	940	16	5	45	0.12 ± 0.13	27 ± 2	46 ± 17	1.28
18	4.96	2450	44	NA	45	0.23 ± 0.18	21 ± 2	37 ± 23	0.48
20	5.63	4680	85	14	32	0.24 ± 0.16	15 ± 6	21 ± 24	0.35

Table 2-2. Habitat characteristics, abbreviations, and descriptions for variables included in generalized linear models describing habitat preferences for fish diversity in riffle run habitat reaches of the East Fork Black River, Missouri.

Parameter	Description
DEP	Mean water depth (m) measured at random points within each reach
WW	Mean of wetted widths (m) measured at random points within a given
SUB	Median value (D_{50}) of sampled substrate particles
DIST	The distance from the upstream boundary of the reach to the Lower Taum Sauk Reservoir Dam (m)
AREA	The area of the riffle run habitat reach (m^2)
GRAD	Gradient measured for the given reach using the water surface elevation change and thalweg distance (m/m, %)
CC	The mean percent of canopy cover measured with a forestry densiometer (%)

Table 2-3. Generalized Linear Models used to predict how species richness focused on rare species (${}^{0}D$ or $D_{\text{rare weighted}}$) or weighted equally among species (${}^{1}D$ or $D_{\text{equal weighted}}$) for each fish community types were related to influential habitat characteristics Lower East Fork Black River, Missouri. Abbreviations and descriptions for variables are provided in Table 2-2.

Fish Community	Hill Numbers	Generalized Linear Model
Overall Fish Community	$D_{\text{rare weighted}}$, $D_{\text{equal weighted}}$	ß1(DEP) + ß2(GRAD) + ß3(WW) + ß4(CC) + ß5(AREA) + ß6(SUB) + ß7(DIST)
Fish Sampled using Prepositioned Grids	$D_{\text{rare weighted}}$, $D_{\text{equal weighted}}$	ß1(DEP) + ß2(GRAD) + ß3(WW) + ß4(CC) + ß5(AREA) + ß6(SUB) + ß7(DIST)
Hornyhead Chub Spawning Associates	$D_{\text{rare weighted}}$, $D_{\text{equal weighted}}$	ß1(DEP) + ß2(GRAD) + ß3(WW) + ß4(CC) + ß5(AREA) + ß6(SUB) + ß7(DIST)

Table 2-4. The overall fish community diversity values sampled using backpack electrofishing in the fall of 2017 and 2018 on the East Fork Black River, Missouri. Hill numbers diversity ^{0}D ($D_{\text{rare weighted}}$) and ^{1}D ($D_{\text{equal weighted}}$) represent the effective number of species required to achieve the same diversity value. Calculated values with decimals were rounded to the nearest whole number for simplicity of interpretation.

Reach	$D_{\text{rare weighted}}$		$D_{\text{equal weighted}}$	
	2017	2018	2017	2018
1	11	12	6	6
2	28	28	10	8
3	18	19	8	6
5	18	23	8	7
6	23	22	7	6
7	20	15	9	5
8	25	28	5	8
10	25	21	7	7
10.5	29	26	9	8
11	24	24	7	7
11.5	32	32	11	9
12	23	25	7	8
13	21	17	7	6
14	21	18	9	6
16	19	16	6	6
20	26	26	6	7

Table 2-5. The fish diversity values sampled using prepositioned grid electrofishing in the fall of 2017 and 2018 on the East Fork Black River, Missouri. Hill numbers diversity ^0D ($D_{\text{rare weighted}}$), and ^1D ($D_{\text{equal weighted}}$) represent the effective number of species required to achieve the same diversity value. The number of two square meter grids was dependent on the reach area (Table 2). Calculated values with decimals were rounded to the nearest whole number for simplicity of interpretation.

	$D_{\text{rare weighted}}$		$D_{\text{equal weighted}}$	
Reach	2017	2018	2017	2018
1	3	3	3	2
2	4	3	3	2
3	4	2	3	2
5	6	3	4	3
6	4	2	3	2
7	4	4	3	3
8	5	3	4	3
10	6	2	4	2
11	5	4	4	3
12	4	3	3	2
13	5	4	4	3
14	5	3	4	2
16	3	3	2	3
20	3	3	3	2

Table 2-6. Hornyhead Chubs and spawning associated species diversity values sampled using backpack electrofishing in the fall of 2017 and 2018 on the East Fork Black River, Missouri. Hill numbers diversity ${}^{0}D$ ($D_{\text{rare weighted}}$), and ${}^{1}D$ ($D_{\text{equal weighted}}$), represent the effective number of species required to achieve the same diversity value. Calculated values with decimals were rounded to the nearest tenth place because the range of effective number of species only ranges from 1 to 4. Spawning associates include Bleeding Shiners, Striped Shiners, Ozark Minnows, and Carmine Shiners.

	$D_{\text{rare weighted}}$		$D_{\text{equal weighted}}$	
Reach	2017	2018	2017	2018
1	0	0	NA	NA
2	2	3	1.4	2.4
3	3	2	1.7	1.0
5	2	3	1.2	1.9
6	2	2	1.2	1.3
7	4	3	2.4	2.0
8	3	3	1.4	1.7
10	3	3	1.4	1.5
10.5	4	4	3.0	3.7
11	5	4	2.1	1.6
11.5	4	4	2.5	3.4
12	3	2	1.4	1.2
13	3	3	1.3	1.0
14	4	2	2.1	1.4
16	4	2	2.1	1.0
20	4	4	2.5	1.7

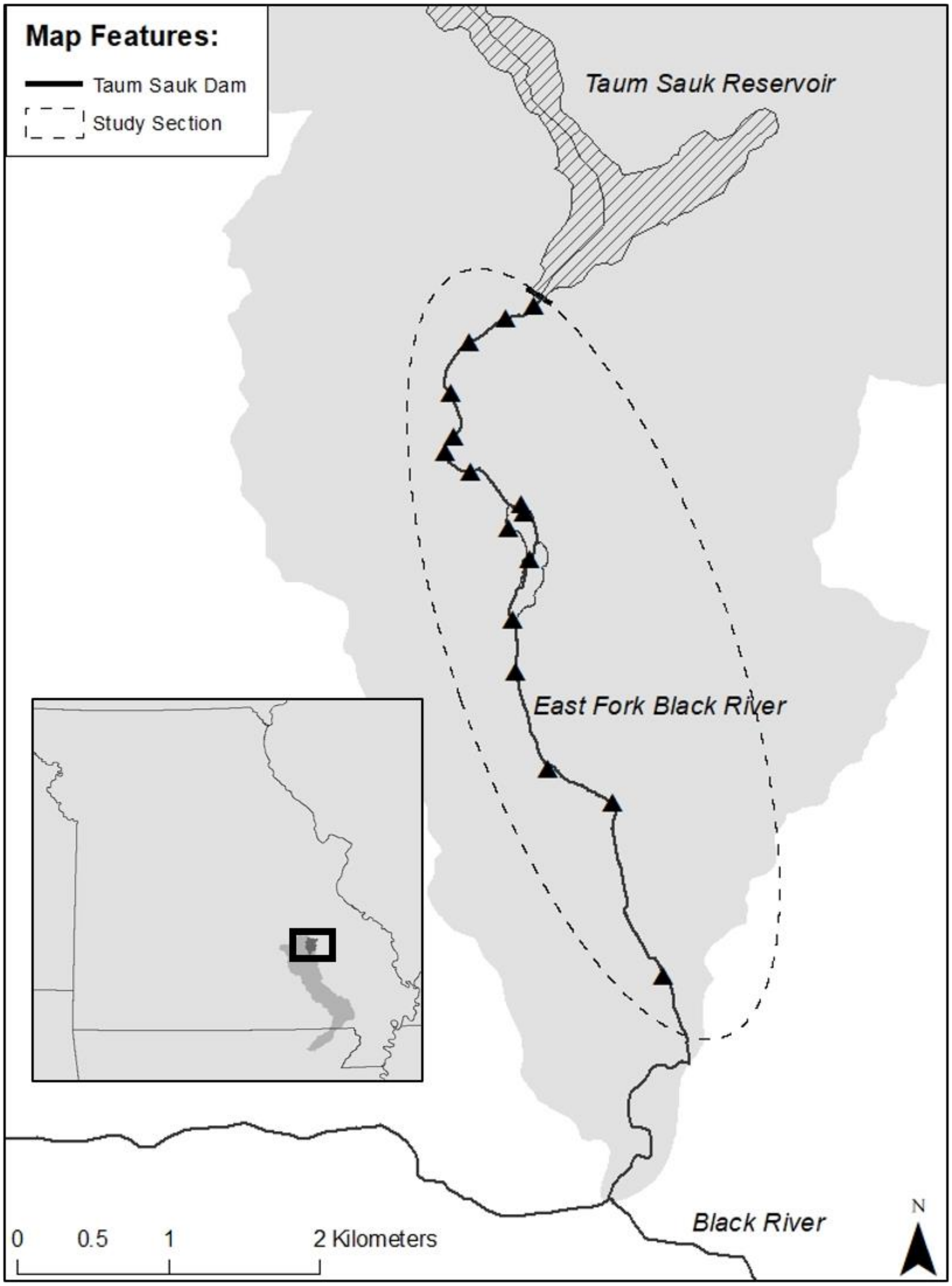

Figure 2-1. The East Fork Black River and watershed (shaded gray), Missouri, flow south and drain into the Black River and further, the Arkansas River. Our study section covered 6.4 km downstream of the Taum Sauk Lower Reservoir Dam.

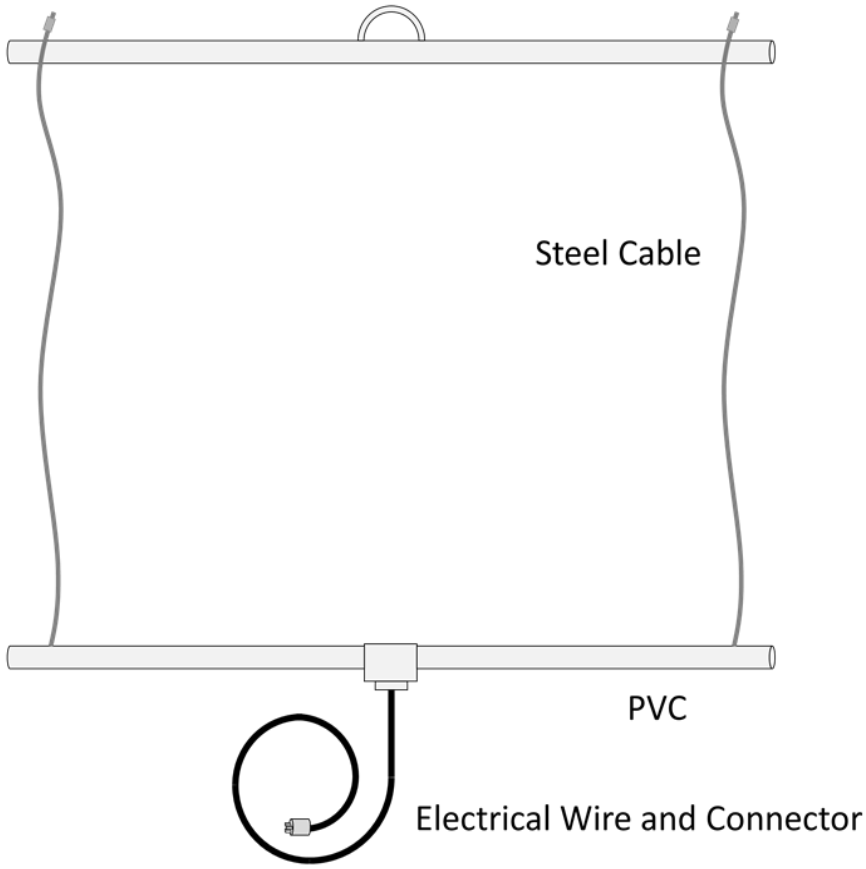

Figure 2-2. Prepositioned electrofishing grid design used to sample fishes in stream flowing habitat less than 0.5 m in depth on the East Fork Black River, Missouri. The dimensions of the grid were 2 x 1 meters and constructed with steel aircraft cable, 1-inch PVC pipe, two wire electric cable, and a connector for attachment to the electrofishing control box.

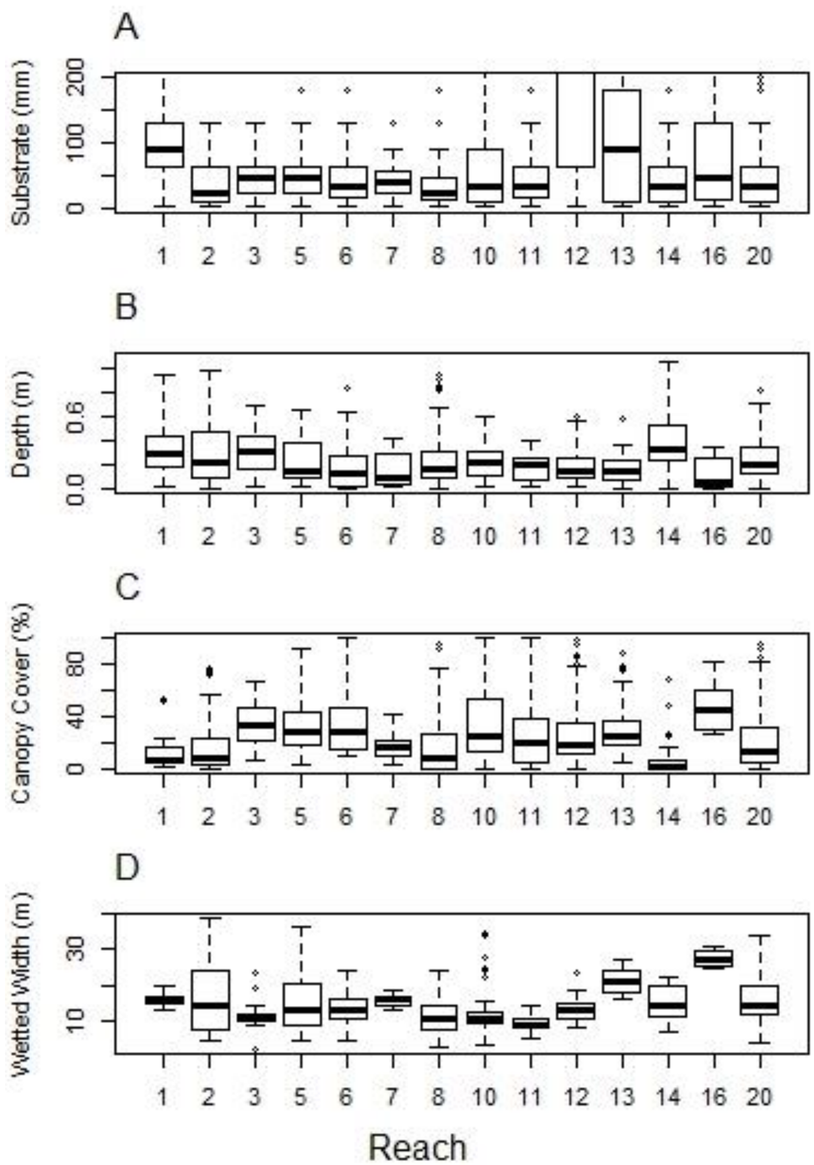

Figure 2-3. Box plots of substrate size, depth, canopy cover, and wetted width collected at 14 reaches in the East Fork of the Black River, 2017-2018. The lower and upper boundaries of the box represent the 25^{th} and 75^{th} precentiles (Q_{25} and Q_{75}), and the thick bar within the box dipslays the median (Q_{50}). The upper and lower whiskers display the maximum and minimum values calculated in the following equations using the Interquartile Range (IQR): Minimum value = Q_{25} – 1.5*IQR, and Maximum value = Q_{75} + 1.5*IQR. Dots outside of the range are individual samples outside the IQR. The y-axis scale excludes higher values for visual scales, but values are shown in Table 2-. Substrate particles (mm), depth (m), canopy cover (%), and wetted width (m) were measured at 20 to 120 random points relative to area size of 14 riffle run habitat areas identified within the 6.4 km stretch of the East Fork Black River, Missouri.

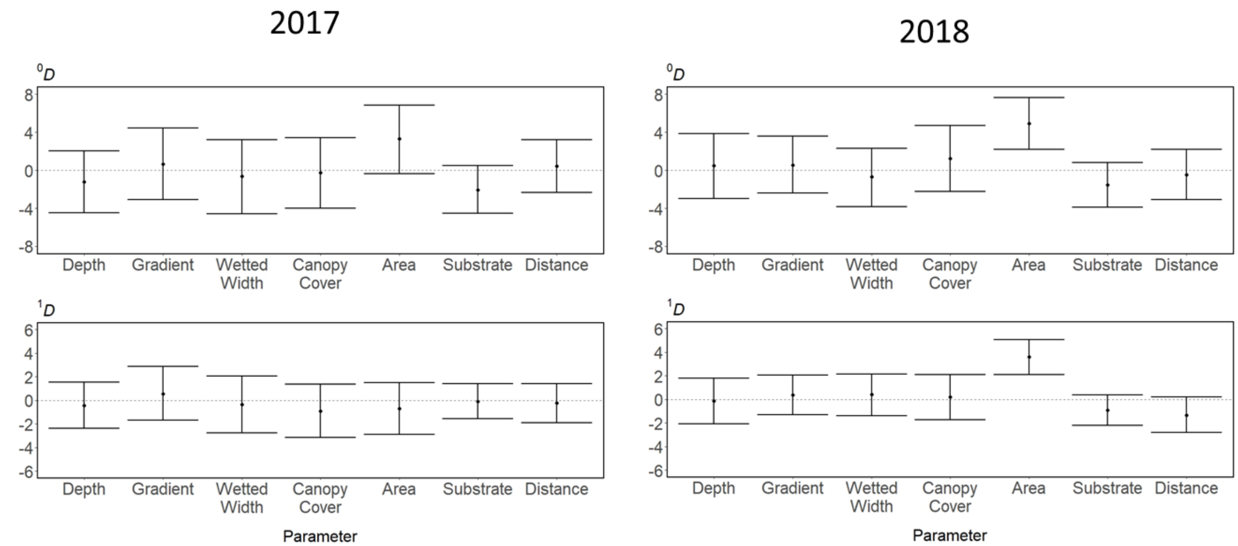

Figure 2-4. Mean and 95% credible intervals of the standardized coefficient for each habitat metric used to predict Hill numbers diversity indices ^0D ($D_{\text{rare weighted}}$) and ^1D ($D_{\text{equal weighted}}$). Generalized linear models (GLMs) using a Bayesian Framework were run to evaluate the effect of habitat characteristics on the overall fish community diversity in 14 reaches within the East Fork Black River, Missouri. Each reach was sampled annually using backpack electrofishing between August-October of 2017 and 2018. Standardized habitat characteristics values (mean depth (m), surface gradient (%), mean wetted width (m), mean canopy cover (%), substrate distribution, and distance from Taum Sauk Dam (m)) were predictor variables (i.e., parameters) in the GLMs for selected Hill numbers ($D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$; i.e. indices of diversity). A dashed line denotes a value of 0 for a parameter.

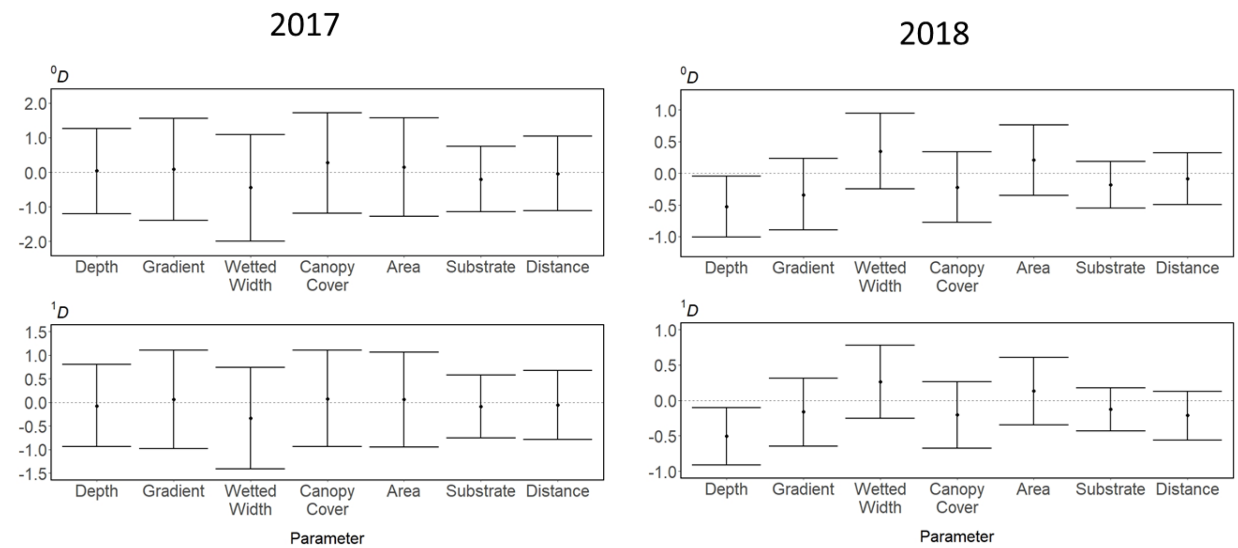

Figure 2-5. Mean and 95% credible intervals of the standardized coefficient for each habitat metric used to predict Hill numbers diversity indices ^0D ($D_{\text{rare weighted}}$) and ^1D ($D_{\text{equal weighted}}$). Generalized linear models (GLMs) using a Bayesian Framework were run to evaluate the effect of habitat characteristics on the fishes sampled with prepositioned electrofishing grid diversity in 14 reaches within the East Fork Black River, Missouri. Each reach was sampled annually using backpack electrofishing between August-October of 2017 and 2018. Standardized habitat characteristics values (mean depth (m), surface gradient (%), mean wetted width (m), mean canopy cover (%), substrate distribution, and distance from Taum Sauk Dam (m)) were predictor variables (i.e., parameters) in the GLMs for selected Hill numbers ($D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$; i.e. indices of diversity). A dashed line denotes a value of 0 for a parameter.

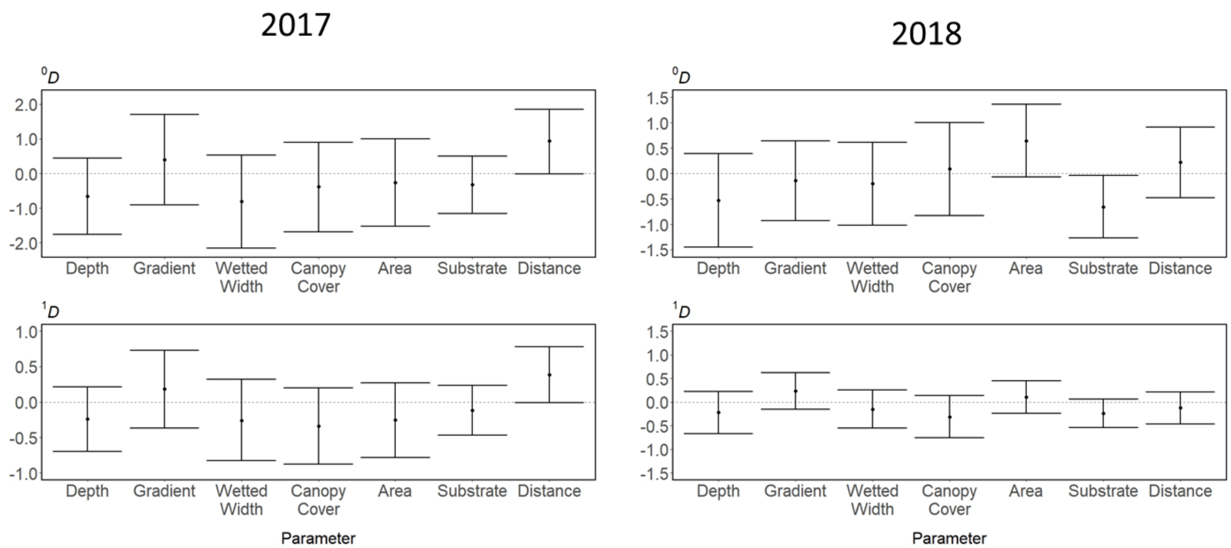

Figure 2-6. Mean and 95% credible intervals of the standardized coefficient for each habitat metric used to predict Hill numbers diversity indices ^0D ($D_{\text{rare weighted}}$) and ^1D ($D_{\text{equal weighted}}$), weighted for rare species and evenly weighted. Generalized linear models (GLMs) using a Bayesian Framework were run to evaluate the effect of habitat characteristics on the diversity of Hornyhead Chub and spawning associate fishes including Bleeding Shiner, Striped Shiner, Ozark Minnow, and Carmine shiner in 14 reaches within the East Fork Black River, Missouri. Each reach was sampled annually using backpack electrofishing between August-October of 2017 and 2018. Standardized habitat characteristics values (mean depth (m), surface gradient (%), mean wetted width (m), mean canopy cover (%), substrate distribution, and distance from Taum Sauk Dam (m)) were predictor variables (i.e., parameters) in the GLMs for selected Hill numbers ($D_{\text{rare weighted}}$ and $D_{\text{equal weighted}}$; i.e. indices of diversity). A dashed line denotes a value of 0 for a parameter.

CHAPTER THREE

General Conclusions and Management Recommendations

Lithophilic spawning fishes are highly dependent on substrate size and distribution along with other habitat characteristics for successful recruitment. These habitat characteristics are most likely to minimize the risk of three key threats to fish egg and larval survival: desiccation, deoxygenation, and predation (Peoples et al. 2014). Due to dependence on substrate, lithophilic spawning fishes and fish communities of riffle-run habitats were chosen to study for habitat limitations on the LEFBR downstream of Taum Sauk Reservoir.

<u>Management Implications of Key Findings</u>

The main focus for our chapter one was the Hornyhead Chub *Nocomis biguttatus* because this fish has been described as a keystone species (Vives 1990; Whitney et al. 2020) due to the spawning habitat they provide for multiple other small bodied fishes by gathering small silt-free gravel and providing protection from predators (Lobb and Orth 1988; Vives 1990; Peoples and Frimpong 2013; Hickerson and Walters 2019), and declines in their spawning mounds have been documented on the LEFBR.

At the microhabitat scale, Hornyhead Chubs had a preferred depth (0.20 m to 0.35 m) and velocity ranges (0.10 m/s to 0.30 m/s) for their spawning mounds, and they often find this habitat behind structure that provides protection from high water velocities. The main difference between the LEFBR and adjacent streams for HHC spawning mound microhabitat was that in adjacent streams spawning mounds were likely to be found closer to the stream banks. We believe this is because HHCs may typically be able to find their preferred depth and velocities closer to banks, but in substrate-altered streams such as the LEFBR, streams frequently have steeper banks due to erosion. However, HHC spawning mounds were still located in riffles that were not furthest from the dam, or had the greatest amounts of small substrate.

At the mesohabitat, or riffle-run reach, scale in the LEFBR, none of our measured habitat characteristics were related to the presence of HHC spawning mounds, but in the other studied streams, spawning mounds were found in mesohabitats with shallower mesohabitats and increased substrate distribution. Gradient was not influential in predicting the presence of HHC spawning mounds, but our measurement methods may have been limiting because we were not able to take variation within a mesohabitat into account. In non-substrate-altered streams that we added in 2018, there was a strong correlation ($r = -0.73$, $n = 7$) between gradient and substrate size. Therefore, if the required substrate sizes of 8 mm to 23 mm are available, gradient may be the most limiting habitat characteristics for HHCs to construct their spawning mounds. If HHCs are not able to construct their spawning mounds for successful recruitment, it is possible that other affiliated species including Bleeding Shiner *Luxilus zonatus*, Striped Shiner *L. chrysocephalus*, Carmine Shiner *Notropis percobromus*, and Ozark Minnow *N. nubilus*, will be also be influenced by the decrease in spawning habitat.

Reach 10, 2.1 km from Taum Sauk Dam is the first location where we located spawning mounds and sampled HHCs in an adjacent side channel (reach 10.5). Both adult and juveniles were sampled during community fish sampling at nearly all reaches downstream of where spawning mound construction had been observed but not upstream. This may indicate that even if gravel augmentations frequently occur, HHCs and associated spawning fishes may not repopulate reaches upstream because the Lower Taum Sauk Reservoir and Dam have separated populations upstream and downstream of the reservoir. Bleeding Shiner and Striped Shiner distribution was not dependent on the presence of HHC spawning mounds in the LEFBR, but only one Carmine Shiner was sampled upstream of reaches where spawning mounds were found. In addition, a single Carmine Shiner was sampled in 2018 when we only found HHC spawning mound in the LEFBR.

Small sized substrate was related to increased fish diversity. However, benthic species such as Rainbow Darters prefer habitat with increased heterogenic substrate distribution with interstitial spaces (Pflieger 1997). These gaps between large substrate allow fishes to find protection from higher velocities, but small substrate is still required for spawning and foraging habitat (Pflieger 1997). Therefore, even large substrate may also be important to maintain habitat diversity for all aquatic biota. When comparing cumulative substrate particle plots, 8 mm to 23 mm size particles occur in lesser amounts in reaches where HHC spawning mounds were not found indicating that substrate close to that size range may be of importance.

We found that small substrate sizes were related to increased fish diversity in the Lower East Fork Black River, but with the current analysis, it is difficult to isolate the most important substrate sizes. When looking at cumulative substrate particle plots, 8 mm to 32 mm size particles occur in lesser amounts at upstream locations. The addition of substrate in this range may help increase the substrate diversity.

Depth, wetted width, substrate size distribution and gradient were important in predicting the presence of HHC spawning mounds. These characteristics were then compared at mesohabitats where HHC spawning mounds were both present and absent to identify reaches with suitable habitat (Table 3-1). The presence of HHCs detected in fish community sampling was also included, and we assumed if HHCs were sampled in a reach without spawning mounds, preferred spawning habitat was not available. Reach 3, which is 0.6 km downstream of Taum Sauk Dam meets the preferred spawning habitat requirements, except that small substrate and shallow habitat is not available (Table 3-1). Both of these habitat characteristics might be influenced by substrate deprivation. Reach 8, which is 1.6 km downstream of the dam is suitable based on measured habitat characteristics (Table 3-1). At this reach, spawning mounds were not present, and HHCs were not detected. Hornyhead Chubs intentionally introduced into suitable habitat persist, however are not known to recolonize suitable habitat on their own following disturbance (Propst and Carlson 1986; Hickerson and Walters 2019). Furthermore, dams create physical barriers for HHCs and other small bodied streams fishes that prevent recolonization (Mammoliti 2002). Therefore, even though HHCs are present upstream of Taum Sauk Dam, the reservoir may have created isolated populations and prevents the recolonization of reaches with suitable habitat in the LEFBR. Movement from downstream populations may also be limited due to HHC's general lack of movement upstream (Hickerson and Walters 2019).HHCs need the presence of substrate that is 8 mm to 23 mm to construct spawning mounds, but we believe that the addition of all substrate sizes including 8 mm to 23 mm is important to add in future gravel augmentations to allow the transfer of energy from fast flowing water to substrate movement. Larger sizes of substrate should be added to provided interstitial spacing, or possibly, substrate could be added in smaller volumes at regular intervals to prevent creating a homogenous stream bed. Hopefully this may reduce the habitat alterations likely caused by water with high potential energy that has increased erosion and depletion of small substrate.

Future Research Questions

Our research on the Lower East Fork Black River occurred in the same stretch of river that the Missouri Department of Conservation has previously monitored and is pursuing regular gravel augmentations. Annual monitoring of HHC spawning mounds at the mesohabitat scale and continuing fish sampling in addition to future gravel augmentations may help determine if substrate size and distribution is the most limiting habitat characteristics for lithophilic spawning fishes within the East Fork Black River, and additional questions may include the following:

- How far do Hornyhead Chubs and other lithophilic spawning fishes of the East Fork Black River search for preferred spawning habitat?
- Is stream surface gradient an influential habitat characteristic if different metrics such as variation are used to predict the presence of Hornyhead Chub spawning mounds and fish diversity?
- Do fish diversity and habitat relationships vary seasonally?

Additional questions to guide habitat management related to substrate and lithophilic spawning fishes on the Lower East Fork Black River:

- Do other fishes rely on the presence of Hornyhead Chub spawning mounds in the East Fork Black River for successful recruitment?
- Will adding substrate downstream of Taum Sauk Reservoir overcome other habitat characteristics influenced by the presence of Taum Sauk Dam, and if so at what volume and frequency will substrate need to be added?
- Is habitat in the East Fork Black River different because of substrate deprivation or because of geological features?

References

Grossman, G. D. and J. L. Sabo. 2010. Incorporating Environmental Variation into Models of Community Stability: Examples from Stream Fish. Pages 407–426 *in* K. B. Gido, and D. A. Jackson, editors. Community ecology of stream fishes: concepts, approaches, and techniques. American Fisheries Society Symposium 73, Bethesda, Maryland.

Hickerson, B. T., and A. W. Walters. 2019. Evaluation of Potential Translocation Sites for an Imperiled Cyprinid, the Hornyhead Chub. North American Journal of Fisheries Management 39(1):205–218.

Lobb, M. D., and D. J. Orth. 1988. Microhabitat Use by the Bigmouth Chub Nocomis platyrhnchus in the New River, West Virginia. American Midland Naturalist 120(1):32.

Peoples, B. K., and E. A. Frimpong. 2013. Evidence of mutual benefits of nest association among freshwater cyprinids and implications for conservation. Aquatic Conservation: Marine and Freshwater Ecosystems 23(6):911–923.

Peoples, B. K., R. A. Mcmanamay, D. J. Orth, and E. A. Frimpong. 2014. Nesting habitat use by river chubs in a hydrologically variable Appalachian tailwater. Ecology of Freshwater Fish 23(2):283–293.

Vives, S. P. 1990. Nesting Ecology and Behavior of Hornyhead Chub Nocomis biguttatus, a Keystone Species in Allequash Creek, Wisconsin. American Midland Naturalist 124(1):46.

Whitney, J. E., R. Waters, and J. A. Holloway. 2020. Muddying the waters: investigating the generality of silt-resistance in mound-building Nocomis spp. using hornyhead chub (Nocomis biguttatus) and redspot chub (Nocomis asper). Environmental Biology of Fishes.

Tables

Table 3-1. Suitability of habitat characteristics Hornyhead Chub spawning mounds in studied reaches/mesohabitats of the Lower East Fork Black River, Missouri was determined based on comparison of characteristics where spawning mounds were present and absent. Reach 3 is believed to be adequate for HHC spawning habitat other than deep habitat and lack of small substrate. Reach 8 is believed to be adequate for HHC spawning habitat, but mounds were not present, nor were HHCs sampled within this reach. "-" represents that reaches were not sampled.

Reach	Depth	Wetted Width	Substrate	Gradient	HHC Mounds?	HHC Sampled?
1	No	No	No	No	No	No
2	No	No	Yes	Yes	No	No
3	No	Yes	No	Yes	No	No
5	No	No	No	No	No	No
6	Yes	No	No	Yes	No	No
7	Yes	No	No	Yes	No	No
8	Yes	Yes	Yes	Yes	No	No
9	No	No	Yes	No	No	-
10	Yes	Yes	Yes	Yes	Yes	No
10.5	Yes	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	Yes
11.5	No	Yes	Yes	Yes	No	Yes
12	Yes	No	No	No	No	Yes
13	Yes	No	No	Yes	No	Yes
14	No	No	Yes	Yes	No	No
16	Yes	No	No	No	No	Yes
18	Yes	No	No	Yes	No	-
20	No	No	Yes	Yes	No	Yes

APPENDICES

Appendix 1. Fish species codes for fishes sampled in the riffle-run reaches of the Lower East Fork Black River, Missouri (August – October 2017).

Common Name	Scientific Name	Code Name
Ammocoete		AMMO
Banded darter	*Etheostoma zonale*	BDDR
Banded sculpin	*Cottus carolinae*	BDSP
Bigeye shiner	*Notropis boops*	BESN
Black redhorse	*Moxostoma duquesnei*	BKRH
Blackspotted topminnow	*Fundulus olivaceus*	BPTM
Bleeding Shiner	*Luxilus zonatus*	BDSN
Bluegill	*Lepomis macrochirus*	BLGL
Bluntnose minnow	*Pimephales notatus*	BNMW
Brindled madtom	*Noturus miurus*	BDMT
Brook silverside	*Labidesthes sicculus*	BKSS
Carmine Shiner	*Notropis percobromus*	CRMS
Central stoneroller	*Campostoma anomalum*	CLSR
Channel catfish	*Ictalurus punctatus*	CNCF
Chestnut lamprey	*Ichthyomyzon castaneus*	CNLP
Common carp	*Cyprinus carpio*	CARP
Creek chub	*Semotilus atromaculatus*	CKCB
Creek chubsucker	*Erimyzon oblongus*	CKCS
Fantail darter	*Etheostoma flabellare*	FTDR
Golden redhorse	*Moxostoma erythrurum*	GDRH
Grass pickerel	*Esox americanus vermiculatus*	GSPK
Green sunfish	*Lepomis cyanellus*	GNSF
Greenside darter	*Etheostoma blennioides*	GSDR
Hornyhead chub	*Nocomis biguttatus*	HHCB
Largemouth bass	*Micropterus salmoides*	LMBS
Largescale stoneroller	*Campostoma oligolepis*	LSSR
Logperch	*Percina caprodes*	LGPH
Longear sunfish	*Lepomis megalotis*	LESF
Longnose gar	*Lepisosteus osseus*	LNGR
Northern hog sucker	*Hypentelium nigricans*	NHSK
Northern studfish	*Fundulus catenatus*	NTSF
Ozark Chub	*Erimystax harryi*	OZCH
Ozark Madtom	*Noturus albater*	OZMT
Ozark minnow	*Notropis nubilus*	OZMW
Rainbow darter	*Etheostoma caeruleum*	RBDR
Redear sunfish	*Lepomis microlophus*	RESF
Redspotted Sunfish	*Lepomis miniatus*	RSSF
Shadow Bass	*Ambloplites ariommus*	SHBS
Smallmouth Bass	*Micropterus dolomieu*	SMBS
Spotted Bass	*Micropterus punctulatus*	STBS
Striped shiner	*Luxilus chrysocephalus*	SPSN
Telescope Shiner	*Notropis telescopus*	TLSN
Wedgespot Shiner	*Notropis greenei*	WSSN
White crappie	*Pomoxis annularis*	WTCP
Whitetail Shiner	*Cyprinella galactura*	WTSH
Yellow bullhead	*Ameiurus natalis*	YLBH

Appendix 2. Presence and absence of sampled fishes at defined mesohabitat locations in the East Fork Black River, Missouri, between Taum Sauk Reservoir Dam and Hwy 72. Detected species are represented by “x”, and species not detected “-“. Fish sampling took place in 2017 and 2018 using backpack electrofishing and grid electrofishing. Seining was added in 2018 to confirm that pelagic species were not undetected.

	Mesohabitat ID															
Spp Code	1	2	3	5	6	7	8	10	10.5	11	11.5	12	13	14	16	20
AMMO	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
BDDR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BDMT	-	-	-	-	-	-	x	-	x	x	x	-	-	-	-	-
BDSN	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BDSP	-	-	-	x	x	-	x	x	x	x	x	x	x	x	x	x
BESN	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BKRH	-	x	x	-	x	-	x	-	x	x	x	x	-	x	x	-
BKSS	-	x	x	x	x	x	x	x	x	x	x	x	x	x	-	x
BLGL	x	x	x	x	x	x	x	x	x	x	x	x	x	-	x	x
BNMW	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	x
BPTM	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
CARP	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CKCB	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-
CKCS	-	-	x	-	-	-	-	-	-	-	x	-	-	-	-	x
CLSR	-	x	x	x	x	x	x	x	x	x	x	x	x	x	-	x
CNCF	-	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-
CNLP	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
CRMS	-	-	x	-	-	x	-	-	-	x	-	-	-	x	-	-
FTDR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GDRH	-	x	-	-	x	-	x	-	-	-	-	-	-	-	-	-
GNSF	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x	x
GSDR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GSPK	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-
HHCB	-	-	-	-	-	-	-	-	x	x	x	x	x	-	x	x
LESF	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
LGPH	-	x	x	x	x	x	x	x	x	x	x	x	-	x	x	x
LMBS	x	x	-	x	x	x	x	x	x	x	x	x	-	x	-	x
LNGR	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LSSR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
NHSK	-	x	-	x	x	-	x	x	x	x	x	x	x	x	x	x
NTSF	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
OZCH	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x
OZMT	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
OZMW	-	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x
RBDR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
RESF	-	x	-	-	-	-	-	-	-	-	x	x	-	-	-	-
RSSF	x	x	-	-	-	-	x	-	x	-	x	-	-	x	x	x
SHBS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SMBS	x	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x
SPSN	-	x	x	x	x	x	x	x	x	x	x	-	x	x	x	x
STBS	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
TLSN	-	-	x	-	x	x	x	x	-	x	x	x	x	x	x	x
WSSN	-	-	-	-	-	-	x	-	-	x	-	-	-	-	-	x
WTCP	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-
WTSH	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	x
YLBH	-	x	x	x	x	x	x	x	x	x	x	x	-	-	x	x

Appendix 3. Fish community composition (spp. codes in Appendix 1) sampled in the East Fork Black River, Missouri (August – October 2017). Values displayed are the count of individuals for each species sampled using backpack electrofishing.

	Reach ID															
Spp Code	1	2	3	5	6	7	8	10	10.5	11	11.5	12	13	14	16	20
AMMO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BDDR	2	6	6	6	5	0	14	15	1	8	3	63	6	1	2	2
BDMT	0	0	0	0	0	0	1	0	1	1	2	0	0	0	0	0
BDSN	0	72	4	22	61	13	74	119	35	109	159	210	49	11	27	85
BDSP	0	0	0	0	0	0	3	1	0	0	1	0	1	1	0	7
BESN	0	6	3	1	3	7	0	2	6	6	12	1	4	0	2	1
BKRH	0	6	1	0	2	0	0	0	2	0	8	2	0	1	3	0
BKSS	0	24	2	0	0	0	3	1	0	0	9	0	0	0	0	0
BLGL	5	37	10	6	6	5	7	2	1	1	18	1	1	0	4	2
BNMW	1	39	0	0	3	14	7	2	14	3	59	6	6	0	0	0
BPTM	2	15	19	10	15	5	11	8	11	4	48	12	1	3	0	6
CARP	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CKCB	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
CKCS	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
CLSR	0	0	0	0	4	0	3	2	20	0	0	0	6	1	0	0
CNCF	0	6	0	0	1	0	0	0	0	0	0	0	0	0	0	0
CNLP	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
CRMS	0	0	1	0	0	4	0	0	0	1	0	0	0	1	0	0
FTDR	0	2	5	1	6	2	18	9	1	1	0	0	1	2	0	1
GDRH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GNSF	22	30	8	22	14	2	5	13	21	10	20	17	7	0	0	8
GSDR	9	12	4	3	12	4	17	17	3	31	9	92	16	3	3	6
GSPK	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0
HHCB	0	0	0	0	0	0	0	0	8	4	3	1	2	0	3	6
LESF	41	168	66	69	107	89	105	166	213	101	350	213	57	27	20	150
LGPH	0	7	0	0	3	6	9	3	8	19	15	14	0	3	3	7
LMBS	1	5	0	2	0	0	1	1	2	4	8	1	0	0	0	7
LNGR	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LSSR	1	285	34	145	298	75	746	200	163	415	382	763	302	43	111	474
NHSK	0	4	0	0	2	0	3	2	2	13	24	41	12	4	2	3
NTSF	0	8	1	1	5	4	16	4	6	0	29	19	1	5	0	1
OZCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OZMT	0	6	2	22	14	10	93	38	9	36	19	41	22	4	3	16
OZMW	0	0	0	1	0	3	7	10	4	36	69	22	1	1	2	30
RBDR	50	145	42	37	69	42	278	74	57	107	76	144	62	49	64	109
RESF	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
RSSF	0	2	0	0	0	0	0	0	2	0	2	0	0	1	0	0
SHBS	10	15	3	4	11	10	7	15	10	3	20	16	5	6	5	11
SMBS	0	7	1	5	7	2	6	3	2	4	19	24	3	7	3	8
SPSN	0	8	0	0	2	0	1	1	35	1	28	0	0	1	2	6
STBS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TLSN	0	0	0	0	0	2	0	0	0	7	29	7	0	0	4	2
WSSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WTCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WTSH	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1
YLBH	0	5	0	6	2	1	5	5	19	0	5	2	0	0	1	4

Appendix 4. Fish community composition (spp. codes in Appendix 1) sampled in the East Fork Black River, Missouri (August – October 2018). Values displayed are the count of individuals for each species sampled using backpack electrofishing.

	Reach ID															
Spp Code	1	2	3	5	6	7	8	10	10.5	11	11.5	12	13	14	16	20
AMMO	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
BDDR	0	6	0	1	2	3	7	13	0	9	0	36	7	0	2	2
BDMT	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
BDSN	0	6	1	12	16	1	37	54	15	36	131	61	21	9	13	65
BDSP	0	0	0	1	2	0	3	0	1	1	2	2	2	0	0	4
BESN	0	9	8	1	0	2	9	6	1	1	13	1	7	8	2	1
BKRH	0	2	1	0	0	0	5	0	1	2	13	2	0	1	0	0
BKSS	0	9	1	0	0	0	1	0	6	0	7	1	0	0	0	0
BLGL	68	67	4	2	4	1	9	1	2	0	13	1	0	0	1	0
BNMW	10	12	2	1	3	0	2	0	2	1	8	0	5	0	0	7
BPTM	5	23	2	24	1	0	11	5	16	3	16	5	6	7	3	3
CARP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CKCB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CKCS	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0
CLSR	0	0	0	1	1	0	6	0	1	0	13	2	1	0	0	3
CNCF	0	12	0	0	2	0	0	0	0	0	0	0	0	0	0	0
CNLP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CRMS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
FTDR	1	3	0	5	5	1	12	9	0	6	5	0	1	1	1	1
GDRH	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0
GNSF	28	28	9	15	0	1	11	6	13	1	26	15	1	2	4	3
GSDR	5	5	2	3	6	1	7	13	1	9	15	54	10	3	8	5
GSPK	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
HHCB	0	0	0	0	0	0	0	0	6	0	4	0	0	0	0	1
LESF	58	163	44	48	58	11	159	85	208	108	357	136	33	39	36	60
LGPH	0	1	1	2	3	0	2	4	1	6	7	8	0	1	2	11
LMBS	6	6	0	1	2	2	4	3	6	2	1	1	0	1	0	1
LNGR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LSSR	28	183	21	59	103	21	261	192	64	260	284	365	61	18	26	177
NHSK	0	8	0	2	1	0	1	8	1	4	10	12	0	3	0	2
NTSF	0	29	0	6	1	0	25	7	3	5	14	10	1	0	0	2
OZCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
OZMT	0	2	0	3	3	3	8	11	2	11	9	13	3	1	2	5
OZMW	0	1	0	0	1	1	2	3	15	2	17	1	0	0	0	3
RBDR	31	67	26	49	78	24	125	130	15	138	59	149	60	61	70	104
RESF	0	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0
RSSF	0	0	0	0	0	0	1	0	5	0	3	0	0	1	1	3
SHBS	3	10	3	11	8	2	2	14	2	11	14	14	7	10	2	9
SMBS	1	11	2	2	0	1	0	12	3	14	15	24	2	1	3	9
SPSN	0	9	0	6	0	0	4	1	20	2	21	0	0	0	0	1
STBS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TLSN	0	0	1	0	1	0	0	0	0	2	11	2	0	0	0	0
WSSN	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
WTCP	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
WTSH	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
YLBH	0	0	2	1	0	0	5	1	8	1	4	1	0	0	0	4

Appendix 5. Fish community composition (spp. codes in Appendix 1) sampled in the East Fork Black River, Missouri (August – October 2017). Values displayed are backpack electrofishing catch per unit effort (# fish/hour electricity on).

	Reach ID															
Spp Code	1	2	3	5	6	7	8	10	10.5	11	11.5	12	13	14	16	20
AMMO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BDDR	7	4	11	10	5	0	8	9	1	7	2	29	9	2	5	2
BDMT	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0
BDSN	0	53	7	35	66	20	41	71	35	95	98	98	77	22	65	84
BDSP	0	0	0	0	0	0	2	1	0	0	1	0	2	2	0	7
BESN	0	4	5	2	3	11	0	1	6	5	7	0	6	0	5	1
BKRH	0	4	2	0	2	0	0	0	2	0	5	1	0	2	7	0
BKSS	0	18	4	0	0	0	2	1	0	0	6	0	0	0	0	0
BLGL	16	27	18	10	7	8	4	1	1	1	11	0	2	0	10	2
BNMW	3	29	0	0	3	21	4	1	14	3	37	3	9	0	0	0
BPTM	7	11	33	16	16	8	6	5	11	3	30	6	2	6	0	6
CARP	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CKCB	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
CKCS	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
CLSR	0	0	0	0	4	0	2	1	20	0	0	0	9	2	0	0
CNCF	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0
CNLP	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
CRMS	0	0	2	0	0	6	0	0	0	1	0	0	0	2	0	0
FTDR	0	1	9	2	7	3	10	5	1	1	0	0	2	4	0	1
GDRH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GNSF	72	22	14	35	15	3	3	8	21	9	12	8	11	0	0	8
GSDR	29	9	7	5	13	6	9	10	3	27	6	43	25	6	7	6
GSPK	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
HHCB	0	0	0	0	0	0	0	0	8	3	2	0	3	0	7	6
LESF	134	124	116	110	116	134	58	99	211	88	217	99	90	54	48	149
LGPH	0	5	0	0	3	9	5	2	8	16	9	7	0	6	7	7
LMBS	3	4	0	3	0	0	1	1	2	3	5	0	0	0	0	7
LNGR	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LSSR	3	211	60	231	324	113	414	120	162	360	237	356	475	86	268	471
NHSK	0	3	0	0	2	0	2	1	2	11	15	19	19	8	5	3
NTSF	0	6	2	2	5	6	9	2	6	0	18	9	2	10	0	1
OZCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OZMT	0	4	4	35	15	15	52	23	9	31	12	19	35	8	7	16
OZMW	0	0	0	2	0	5	4	6	4	31	43	10	2	2	5	30
RBDR	163	107	74	59	75	63	154	44	57	93	47	67	98	98	155	108
RESF	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
RSSF	0	1	0	0	0	0	0	0	2	0	1	0	0	2	0	0
SHBS	33	11	5	6	12	15	4	9	10	3	12	7	8	12	12	11
SMBS	0	5	2	8	8	3	3	2	2	3	12	11	5	14	7	8
SPSN	0	6	0	0	2	0	1	1	35	1	17	0	0	2	5	6
STBS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TLSN	0	0	0	0	0	3	0	0	0	6	18	3	0	0	10	2
WSSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WTCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WTSH	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1
YLBH	0	4	0	10	2	2	3	3	19	0	3	1	0	0	2	4

Appendix 6. Fish community composition (spp. codes in Appendix 1) sampled in the East Fork Black River, Missouri, USA (August – October 2018). Values displayed are backpack electrofishing catch per unit effort (# fish/hour electricity on).

	Reach ID															
Spp Code	1	2	3	5	6	7	8	10	10.5	11	11.5	12	13	14	16	20
AMMO	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
BDDR	0	6	0	2	4	15	6	15	0	9	0	28	14	0	6	2
BDMT	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
BDSN	0	6	3	27	28	5	32	64	25	38	93	48	43	19	38	80
BDSP	0	0	0	2	4	0	3	0	2	1	1	2	4	0	0	5
BESN	0	9	24	2	0	10	8	7	2	1	9	1	14	17	6	1
BKRH	0	2	3	0	0	0	4	0	2	2	9	2	0	2	0	0
BKSS	0	9	3	0	0	0	1	0	10	0	5	1	0	0	0	0
BLGL	209	67	12	4	7	5	8	1	3	0	9	1	0	0	3	0
BNMW	31	12	6	2	5	0	2	0	3	1	6	0	10	0	0	9
BPTM	15	23	6	53	2	0	10	6	26	3	11	4	12	15	9	4
CARP	3	1	3	2	2	5	1	1	2	1	1	1	2	2	3	1
CKCB	3	1	3	2	2	5	1	1	2	1	1	1	2	2	3	1
CKCS	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0
CLSR	0	0	0	2	2	0	5	0	2	0	9	2	2	0	0	4
CNCF	0	12	0	0	4	0	0	0	0	0	0	0	0	0	0	0
CNLP	3	1	3	2	2	5	1	1	2	1	1	1	2	2	3	1
CRMS	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
FTDR	3	3	0	11	9	5	11	11	0	6	4	0	2	2	3	1
GDRH	0	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0
GNSF	86	28	27	33	0	5	10	7	21	1	18	12	2	4	12	4
GSDR	15	5	6	7	11	5	6	15	2	9	11	42	21	6	23	6
GSPK	3	1	3	2	2	5	1	1	2	1	1	1	2	2	3	1
HHCB	0	0	0	0	0	0	0	0	10	0	3	0	0	0	0	1
LESF	178	163	134	107	103	55	139	100	342	114	253	106	68	82	105	74
LGPH	0	1	3	4	5	0	2	5	2	6	5	6	0	2	6	14
LMBS	18	6	0	2	4	10	4	4	10	2	1	1	0	2	0	1
LNGR	3	1	3	2	2	5	1	1	2	1	1	1	2	2	3	1
LSSR	86	183	64	131	183	105	228	227	105	274	201	285	126	38	76	219
NHSK	0	8	0	4	2	0	1	9	2	4	7	9	0	6	0	2
NTSF	0	29	0	13	2	0	22	8	5	5	10	8	2	0	0	2
OZCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
OZMT	0	2	0	7	5	15	7	13	3	12	6	10	6	2	6	6
OZMW	0	1	0	0	2	5	2	4	25	2	12	1	0	0	0	4
RBDR	95	67	79	109	138	120	109	154	25	145	42	116	124	129	205	129
RESF	0	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0
RSSF	0	0	0	0	0	0	1	0	8	0	2	0	0	2	3	4
SHBS	9	10	9	24	14	10	2	17	3	12	10	11	14	21	6	11
SMBS	3	11	6	4	0	5	0	14	5	15	11	19	4	2	9	11
SPSN	0	9	0	13	0	0	4	1	33	2	15	0	0	0	0	1
STBS	3	1	3	2	2	5	1	1	2	1	1	1	2	2	3	1
TLSN	0	0	3	0	2	0	0	0	0	2	8	2	0	0	0	0
WSSN	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
WTCP	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0
WTSH	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
YLBH	0	0	6	2	0	0	4	1	13	1	3	1	0	0	0	5