HABITAT SELECTION AND MOVEMENT BY SPOTTED BASS AND SHORTHEAD REDHORSE DOWNSTREAM OF A HYDROPEAKING DAM IN MISSOURI

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by
ELISA NERI BAEBLER
Dr. Craig P. Paukert, Thesis Supervisor
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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

HABITAT SELECTION AND MOVEMENT BY SPOTTED BASS AND SHORTHEAD REDHORSE DOWNSTREAM OF A HYDROPEAKING DAM IN MISSOURI

Presented by Elisa N. Baebler,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Dr. Craig Paukert (Advisor)

Dr. Amanda Rosenberger

Dr. Christopher Wikle

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Habitat Selection and Movement by Spotted Bass and Shorthead Redhorse Downstream of a Hydropeaking Dam in Missouri

Elisa N. Baebler

Craig P. Paukert, Thesis Advisor

ABSTRACT

Flow alteration caused by hydropeaking dams may disrupt the natural flow regime and impact physical habitat and biological community, thus threatening the health of freshwater ecosystems. Life history strategies of fish evolved with their environments, including mobility to access habitats for feeding, spawning, refuge, and rearing. However, behavioral responses among species to artificially extreme flow and the influence of spatial and temporal scale, are not clearly understood. We used radio telemetry (from April 2016 to June 2017) to determine the habitat selection and daily and seasonal movement of two native fishes downstream of a hydropeaking dam on the Osage River, Missouri, where river stage may fluctuate up to 5 m daily. We selected two fishes from different habitat and spawning guilds, Spotted Bass (*Micropterus punctulatus*) and Shorthead Redhorse (*Moxostoma macrolepidotum*), that are common throughout the Midwestern United States and Canada and represent diverse life history strategies of riverine fishes. We used a Bayesian discrete choice analysis to determine seasonal and flow-related habitat selection and linear regression to evaluate predictors of movement rate of fishes. We determined flow to be "steady" or "fluctuating" based on the range of discharge measured during the 24-hour period prior to a fish location, where the threshold corresponded to minimum or maximum daily discharge being within (steady) or exceeding (fluctuating) 30% of the mean daily flow. Fluctuating flow corresponded to increased movement rate of Spotted Bass and Shorthead Redhorse and selection of slower velocity (<0.5 m/s) nearshore habitat by Spotted Bass. Shorthead Redhorse did not select specific velocity during fluctuating flow, yet used fast velocities (>1 m/s) during steady flow. Both Spotted Bass and Shorthead Redhorse selected moderate depth (1.5 – 4.0 m) with submerged cover during both steady and fluctuating flow. Spotted Bass movement rate peaked when 3-day average discharge was 500 m^3/s, which occurred during consecutive days of hydropeaking or flood management at the dam. This discharge occurred or was exceeded during 25% of the study period, primarily during spring and summer, but did not occur during winter. Smaller adult Spotted Bass had greater movement rates than larger bass, whereas increased movement rate of Shorthead Redhorse was related to increased barometric pressure and Julian day. Both Spotted Bass and Shorthead Redhorse movement rates were greatest during spring (10 – 23˚C) and differed among seasons. The mean longitudinal dispersal by Spotted Bass and Shorthead Redhorse was approximately 20 and 30 rkm, respectively, although 50% and 60% of Spotted Bass and Shorthead Redhorse, respectively, made movements between 5 and 91 rkm from the tagging location. Spotted Bass and Shorthead Redhorse selected similar habitats among steady and fluctuating flow regimes, however, both species responded to flow disturbance by moving more during fluctuating flow than during steady flow, presumably to relocate to suitable habitat. These effects occurred on a short timescale (10 hours to 3 days) and should be could be considered when informing ecologically-sustainable river management in highly flow-altered systems.

GENERAL INTRODUCTION

The health and longevity of freshwater ecosystems and their biodiversity is threatened by flow alterations, pollution, overexploitation, habitat degradation, invasive species, and climate change (Murdoch et al. 2000; Dudgeon et al. 2006). Hydrologic alteration, which is commonly caused by regulated water releases from hydroelectric dams, is among these threats and impairs the river ecosystem, while impacts vary in severity and type (Poff and Hart 2002; Couto and Olden 2018). However, humans depend on hydroelectric energy as a source of non-fossil fuel power. Hydropower accounts for nearly one fifth of all electricity production globally, and the demand is increasing with emerging economies worldwide (Zarfl et al. 2015). This presents a need to better understand freshwater ecology so that science can mitigate the loss and damage caused by hydrologic alteration as society meets socioeconomic needs such as clean energy production, water storage, irrigation, and flood control.

The last few decades have seen a push to develop a better understanding of ecological flow relationships to guide instream flow recommendations in hydrologically altered systems and in future climate change scenarios (Richter et al. 2003; Poff et al. 2010). Altered streamflow caused by hydropeaking dams is often characterized by short-duration and high-magnitude discharge peaks designed to produce electricity, which diverges from natural streamflow variability and predictability on a daily scale (Magilligan and Nislow 2005). Flow is also altered on a seasonal scale by lessening the magnitude of flood flows and increasing the time required to pass water through the system (Dudgeon et al. 2006; Mims and Olden 2013). Similarly, drought events, which would naturally cause extreme low flows, are buffered by increased discharge from the dam. This unnaturally altered flow regime affects flora and fauna in the river ecosystem. Life history strategies are highly predictive of species' responses to environmental patterns and disturbance (Mims and Olden 2013), and species with different life histories may respond differently to altered flow. Synthesizing the scientific understanding of the ecological effects of flow degradation and restoration on individual species and guilds promotes a pathway to developing recommendations for sustainable river management (Webb et al. 2015; Chen and Olden 2018).

Life history strategies of fish evolved with their environments, including mobility to access habitats for feeding, spawning, refuge, and rearing. Movement patterns and habitat selection of fishes are indicative of the necessary resources and environmental conditions for their survival and growth. Streamflow, water temperature, and season are associated with fish movement (Albanese et al. 2004; Lyon et al. 2010; Westhoff et al. 2016; Macnaughton et al. 2016), although this is not always the case (Paukert et al. 2004; Earley and Sammons 2015). Therefore, daily and seasonal alterations to flow, temperature, and habitat availability, due to hydropeaking dams, may impact the behavior of riverine fish. However, in regulated rivers, environmental cues other than flow regime may assume greater importance in cueing fish migration and spawning behavior due to the misalignment of timing between those life history events and flows (Jones and Petreman 2015).

Researchers have used multiple methods to document movements and habitat use of fish; among these tools is telemetry. Coupled with habitat assessments, river modeling, and records of extrinsic environmental factors, telemetry can be used to identify which habitats are important for meeting the needs of the species. Meta-analyses across study systems and organisms at a population level show variable relationships between flow and movement (Taylor and Cooke 2012; Comte and Olden 2017). Discharge has been positively related to both migratory and non-migratory movements (Paukert and Fisher 2001; Taylor and Cooke 2012; Reinfelds et al. 2013); however, daily flow fluctuation in regulated rivers may hinder synchronicity of spawning migrations to suitable flows (Lallaman 2012). Flow regime can also influence dispersal and small scale movements of fish to find food, shelter, and rearing resources (Weisberg and Burton 1993; Schwartz and Herricks 2005). Despite the growing understanding of the influence of flow on fish movement and habitat, there are many relationships yet to be uncovered (Murchie et al. 2008).

Cooke et al. (2012) outlined major themes hindering conservation of river fish, among them, limited basic fish life history information and limited understanding of fish and flow relationships. Within this specific arena, Murchie et al. (2008) identified additional knowledge gaps pertaining to flow effects on fish and habitat including information on non-salmonids, integrating interdisciplinary methods (including telemetry and habitat modeling), examining physical variables that co-vary with flow (such as temperature and dissolved oxygen), and observing fish responses during dynamic flow. To maintain ecologically informed recommendations for flow regime in altered systems, further investigation is warranted, therefore, our study addressed some of these research needs in a highly regulated riverine system.

This study used radio telemetry to determine the habitat selection and daily and seasonal movement of native fishes downstream of a hydropeaking dam, complimenting existing projects on the Osage River, Missouri examining the impact of regulated flow on fish community, water quality, and physical habitat conducted by the Missouri Department of Conservation (Farless et al. 2018). The purpose of our study is to inform ecologically-sustainable river management in the highly flow-altered system, including to sustain populations of native fishes and critical habitat. We selected two fishes from different guilds, Spotted Bass (*Micropterus punctulatus*) and Shorthead Redhorse (*Moxostoma macrolepidotum),* that are common on the Osage River, and represent diverse life history strategies of riverine fishes. Additionally, these fish have socioeconomic value as either sportfish or to local culture, and are common throughout the United States and Canada.

Objectives

The objectives of this study are:

1. To determine how selection of riverine habitat (i.e., depth, velocity, submerged cover, substrate, distance to land, temperature, and dissolved oxygen) by Spotted Bass (*Micropterus punctulatus*) and Shorthead Redhorse (*Moxostoma macrolepidotum)* is influenced by fish species, streamflow, and season.
2. To determine how Spotted Bass and Shorthead Redhorse movement relates to streamflow and season.

Site Selection

We used the Osage River below Bagnell Dam as the study site. The Osage River Basin encompasses approximately 39,000 km^2 in eastern Kansas and central Missouri.

The basin is characterized by karst topography and average precipitation of 100 cm per year. The lower Osage River flows 131 river kilometers (rkm) from Bagnell Dam, which creates the 220 km^2 Lake of the Ozarks, to the Missouri River (Figure 1-1). As the third largest river in the state, the Osage River is an important recreational fisheries resource where anglers spent an estimated 394,600 hours fishing during 75,650 visits annually (Haverland 1990).

This river is the site of several scientific studies and restoration efforts concerning the influence of flow regime and physical habitat on aquatic biodiversity. Missouri Department of Conservation conducted multi-year evaluations of fish community, physical habitat, and water quality throughout the Osage River downstream of Bagnell Dam (Farless et al. 2018) and have assessed hydrologic connectivity of habitats inhibited by navigational structures historically intended to direct flow (Lobb and Lueckenhoff 2013). The US Fish and Wildlife Service implemented a reintroduction of Pink Mucket, a federally endangered freshwater mussel that was historically found in the Osage River. Additionally, the Osage River is used by sturgeon and paddlefish and studies have assessed movement and habitat suitability of these large river fishes (Lallaman 2012; Moore 2016). Our research will contribute to the growing knowledge of aquatic ecology, streamflow alteration, and habitat dynamics as they vary spatially and temporally on the Osage River.

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CHAPTER ONE

Influence of Streamflow and Season on Habitat Selection by Spotted Bass and Shorthead Redhorse on the Osage River, Missouri

Elisa N. Baebler and Craig P. Paukert

Abstract

Downstream of hydropeaking dams, water depth and velocity fluctuate rapidly, which may lead to short-term changes in physical habitat supporting aquatic organisms. While some fish species have been extirpated from flow-regulated systems, other species flourish, which may be related to the persistence of critical habitats complementary to these life histories. We used radio telemetry to determine the influence of season and streamflow on the habitat selection of two common, native fishes downstream of Bagnell Dam in central Missouri from April 2016 to June 2017. We studied Spotted Bass (*Micropterus punctulatus*), which are nest-guarding, sight feeding, habitat generalists and Shorthead Redhorse (*Moxostoma macrolepidotum)*, which are fluvial dependent, migratory, and benthic feeders. Bayesian discrete choice analyses determined habitat selection from used and available habitats among season and flow regime. Spotted Bass selected moderate depth near submerged cover in all seasons, slow velocity during spring and summer, and near-bank habitat in all seasons except spring. Shorthead Redhorse preferred moderately deep and faster flowing habitat during spring and summer and used slow velocities and shallow depths during winter. Additionally, we evaluated habitat selection during steady and fluctuating flows, based on 24-hour discharge prior to fish location. “Fluctuating” flow occurred when the maximum, or minimum, discharge during the 24-hour time period exceeded 30% of the mean discharge; conversely, flow was considered “steady” if discharge remained within 30% of the mean. Spotted Bass used slow velocity in both fluctuating and steady flow, whereas, Shorthead Redhorse preferred fast velocity (>1.0 m/s) in steady flow but did not select velocity during fluctuating flow. Flow pattern and season influence habitat used by Spotted Bass and Shorthead Redhorse and suggest that available resources may vary among environmental conditions and therefore, flow and seasonality should be considered for river management that supports native fishes of different guilds.

Introduction

Natural flow regimes are critical in shaping and maintaining healthy aquatic ecosystems, however, human dependence on water resources has led to major alterations to rivers that change natural flow. Dams and impoundments are the chief cause of these alterations (Magilligan and Nislow 2005), although water withdrawals and diversions may lead to similar consequences for aquatic ecosystems (Beasley and Hightower 2000; Kingsford 2000; Poff and Hart 2002). Systems with natural flow regimes maintain more biodiversity and structural resilience following disturbances than systems with man-made hydrologic and structural alterations (Junk et al. 1989; Power et al. 1996). Dams change the natural flow regimes of rivers by controlling the magnitude, frequency, duration, rate of change, and timing of water discharge in streams (Poff et al. 1997; Magilligan and Nislow 2005). Consequently, dams also alter the thermal regime, sediment transport, channel connectivity, and biotic composition of the river, which can have deleterious effect on native aquatic biota (Bunn and Arthington 2002; Carlisle et al. 2011; Wohl et al. 2015; Bhattacharya et al. 2016).

Suitable habitat for aquatic organisms may be particularly altered as a result of regulated streamflow managed by hydropeaking dams, which generate electricity during elevated energy demand, releasing high magnitude discharge peaks for short durations of time. Downstream of hydropeaking dams, water depth and velocity fluctuate rapidly, which may lead to short-term fluctuations in physical, chemical, and biological habitat that support aquatic organisms (Poff et al. 1997; García et al. 2011). The change in available habitat due to rapid fluctuation in flow can affect the distribution and persistence of fishes in regulated streams (Bain et al. 1988). On a broader timescale, dams reduce the variability and seasonality typical of downstream discharge by lessening the magnitude of flood flows and increasing the time required for water to pass through the system (Dudgeon et al. 2005; Mims and Olden 2013). Conversely, the effects of drought events, that normally cause extreme low flows, are mitigated by increased discharge of water from the dam. Thus, the altered flow regimes may promote unnaturally buffered conditions on an annual or decadal basis, while introducing artificial and extreme conditions daily. These deviations from natural processes can interfere with the availability of suitable habitat for meeting life history requirements of biota and eventually aquatic community structure.

In addition to causing hydrodynamic fluctuations, dams may alter the downstream water temperature and dissolved oxygen because they may release water from the hypolimnion (i.e., deeper, colder layer of reservoirs), which can have implications on fish spawning cues, metabolism and development (Lehmkuhl 1974; Weisberg and Burton

1993; Olden and Naiman 2010; Farless et al. 2018). Temperature and oxygen conditions below hypolimnetic release dams reflect seasonal stratification and mixing of the upstream reservoir, which may result in rivers with warmer water temperature during winter and cooler, less oxygenated water during summer. Since fish respond to temperature, stream flow, diel period, and other environmental cues to guide their seasonal movements, altered thermal and flow regimes may impact the timing of fish migration in rivers below hydropeaking dams (Bunn and Arthington 2002).

Artificial conditions created downstream of dams may promote habitat for some types of fishes over others. Species that are habitat specialists are more likely to be influenced by disturbance and habitat availability than habitat generalists who use a range of habitats and thus may be more successful in altered rivers (Travnichek et al. 1995; Devictor et al. 2008; Wilson et al. 2008; McManamay and Frimpong 2015). Decades of persistent flow alteration has resulted in an abundance of habitat generalists and extirpation of habitat specialists that rely on slow and shallow habitats along stream margins below some hydropeaking dams (Bain et al. 1988; Mims and Olden 2013). Despite these effects to fish community, when considered at daily or seasonal time scale, the influence of flow management schedules on fish behavior is largely unknown (Arthington et al. 2006; Murchie et al. 2008; Capra et al. 2017).

Our objective was to determine seasonal and flow-dependent habitat selection for two species of native fish with different life histories that are abundant in a flow regulated river. Spotted Bass (*Micropterus punctulatus*) are habitat generalists (Goclowski et al. 2013) that tend to use relatively low velocity reaches and are in greatest abundance in pool habitat with gravel substrate and submerged cover (Lobb and Orth

1991; Horton and Guy 2002). Spotted Bass are nest builders that typically spawn between 14˚ and 23˚C on nests guarded by males for several weeks until eggs hatch (Warren 2009). As opportunistic predators, Spotted Bass typically feed on small fish and crayfish, yet may shift their diet to terrestrial insects when available (Churchill and Bettoli 2015). Generally, Spotted Bass are considered relatively sedentary with home ranges 600 – 12,000 m^2 (Horton and Guy 2002), although they may make upstream migrations to spawn and then overwinter in lower gradient habitat (Warren 2009). Shorthead Redhorse (*Moxostoma macrolepidotum)* are fluvial dependent (habitat specialists) and are found in high velocity riffles with gravel substrate where they feed on benthic aquatic insects (Harbicht 1990; Pflieger 1997). Shorthead Redhorse sometimes migrate upstream to gravel shoals in the main channel or into tributaries for spawning when temperatures are 10˚ to 16˚C (Curry and Spacie 1984; Harbicht 1990; Reid 2006). Movements are generally localized with the exception for spawning and post-spawning migrations (Bunt and Cooke 2001; Fisk II et al. 2015) up to 32 km (Harbicht 1990). The life histories of Spotted Bass and Shorthead Redhorse differ from one another in spawning and rearing, feeding, and observed habitat use (Pflieger 1997), yet are representative of common native fish present in regulated rivers in the Midwestern US.

We hypothesized that habitat selection by Spotted Bass and Shorthead Redhorse would be related to seasons and flow regime. We expected that Spotted Bass would use submerged cover and deeper pools (Lobb and Orth 1991) in addition to multiple habitat types since they are known to be habitat generalists (Goclowski et al. 2013), and that Shorthead Redhorse would select gravel riffle habitat, particularly during spring and summer (Sule and Skelly 1985). We expected that both Spotted Bass and Shorthead

Redhorse would use deeper and slower habitat to reduce energy expenditure during winter when water temperatures are colder (Harbicht 1990; Horton and Guy 2002). Additionally, we expected that stronger habitat selection would occur during steady flows due to the opportunity for fish to seek out and occupy preferred resources; conversely, we expected less habitat selection during fluctuating flows due to changing habitat conditions associated with fluctuating flow.

Methods

Study Site

The Osage River Basin extends through eastern Kansas and central Missouri, encompassing approximately 39,000 km^2 and characterized by karst topography and average precipitation of 100 cm per year. The lower Osage River flows from Bagnell Dam (38˚ 12’ 5.40” N, -92˚ 37’ 20.99” W; river km-131), which creates the 220 km^2 Lake of the Ozarks, through the eastern portion of the basin, covering 131 river kilometers (rkm) until it joins the Missouri River (Figure 1-1). Bagnell Dam operates as a hydroelectric power facility releasing water from the hypolimnion of Lake of the Ozarks to the Osage River downstream. Typical management of the dam is driven by hydroelectric power generation needs but also accommodates flood control, recreation, and environmental flow requirements. Hydropeaking at Bagnell Dam, a method for producing electricity, may result in discharge rising from 25 m^3/s to more than 1,000 m^3/s within an hour (Figure 1-2). Mean daily discharge ranged from 28 m^3/s (exceeded 95% of time) to 1,143 m^3/s (exceeded 5% of time) from 2007 through 2017 (USGS gage 06926000).

We selected an 8 rkm river reach located 13 rkm downstream of Bagnell Dam as our primary focus reach (rkm-110 to 118) due to diverse macro-habitat and available bathymetric and velocity data collected by the Missouri Department of Conservation from 2015 to 2018. This reach includes pool, glide, run, riffle complex, side channel, backchannel, and training structure habitats at low flows (25 – 31 m^3/s; Lobb and Lueckenhoff 2013). Within the focus reach, streamflow magnitude, rate of change, and timing closely mirrored outflows from the dam due to close proximity and lack of tributaries present upstream of the reach. Spotted Bass and Shorthead Redhorse were common within the focus reach (Farless et al. 2018).

Tagging Method

We collected Spotted Bass and Shorthead Redhorse within the focus reach using boat electrofishing from March 16 to 31 and November 16 to December 1, 2016 and implanted the fish with radio transmitters. Prior to surgery, fish were kept in an aerated live well which maintained a water temperature within 3˚C of the river temperature. Fish were weighed, measured for total length, visually inspected for signs of poor health (e.g., infection, injury, etc.) and examined to identify fish sex. Fish determined to be in poor health were released back into the river untagged. We identified sex for 14% of Spotted Bass and 54% of Shorthead Redhorse by observing ovaries within the body cavity (indicating female) and presence of tubercles on anal and caudal fins, specific to Shorthead Redhorse (indicating male). Due to the low rate of sex identified on study fish, it was not incorporated into the results. Fish were anesthetized using CO_2 and surgically implanted with a radio transmitter (Advanced Telemetry Systems, F1580) in the abdominal cavity anterior of the pelvic girdle. Radio transmitters had a battery life up to 441 days and weight of 3.6 g, which was less than 2% of body weight (Jepsen et al. 2002) of 92% of tagged Spotted Bass and all tagged Shorthead Redhorse. The transmitter's external radio antenna was 25 cm long and exited the fish posterior of the incision. Fish were held in aerated water for one to four hours post-surgery before being released near the capture site. All fish had regained equilibrium (i.e., upright swimming) before release.

In total, we fit 75 fish with radio transmitters. We tagged 37 Spotted Bass (24 in spring, 13 in fall) and 38 Shorthead Redhorse (25 in spring, 13 in fall). On average, tagged Spotted Bass had a total length of 295 ± 41 mm (range=218 – 399 mm) and weighed 365 ± 182 g and Shorthead Redhorse measured 389 ± 51 mm (range=265 – 451 mm) and weighed 614 ± 242 g.

Telemetry

We actively tracked fish from a boat using Lotek radio receivers (SRX 600) and five-element Yagi antennas during 1 to 7 days per month, between April 2016 and June 2017 in an attempt to locate each fish once per day. We searched the focus reach 1 to 2 times per month and additional segments of the 110 rkm distance from Bagnell Dam downstream to Lock and Dam 1 (located at rkm-19) every other month. We attempted to locate fish during steady and fluctuating flows in each season. To minimize temporal pseudoreplication, observations were typically spaced out by one week or month and were collected once per day at most, providing sufficient time for the fish to move to another area (Arthur et al. 1996). We searched all wetted habitats accessible by boat, including main channel, connected backchannels, side channels, and tributaries.

Generally, we began tracking fish at the upstream end of a reach and traveled downstream in the middle of the channel or in a zig-zag pattern between the banks. We tested the accuracy of our homing technique by navigating to tags deployed at a fixed location and measuring the distance between the estimated tag location and the true tag location using a global positioning system (GPS). Based on these results we estimated our accuracy to be within 3 m.

Habitat Measurements

A critical component of determining habitat selection is identifying both the habitat used by a fish and the available habitat. Therefore, we measured multiple habitat characteristics (i.e., depth, velocity, submerged cover, substrate, distance to nearest shore, water temperature, and dissolved oxygen; Table 1-1) at each fish location and three randomly selected locations (Harris et al. 2018). This collectively represented a “choice set” to be used in discrete choice modeling (see analytical procedures below; Cooper and Millspaugh 1999; Harris et al. 2018). Available habitat may change quickly on this river due to the hydropeaking operation (i.e., historic daily fluctuation in river stage up to 5.4 m; Bovee et al. 2004), therefore, we measured used and available habitats within an hour of each fish located. The locations of available habitat measurements were determined by selecting three sets of distances and bearings from a randomly generated list and navigating to those points relative to the fish location. All available habitat locations were within 100 m of the used location, based on maximum average movement rates over a 1 hour period (see Chapter 2 on Movement). Since the study focused on suitable habitat on the main stem of the Osage River, we collected all available habitat points in the main channel, even if a fish's used location was in a tributary. In those cases, available habitat points were based on a random distance and bearing, relative to the mouth of the tributary, instead of the fish location. All habitat measurements were collected in wetted stream channel.

Substrate Mapping

The focus reach was mapped using recreational-grade HumminBird side scan sonar (998C-SI) at approximately 1,420 m^3/s discharge and used to classify substrate at habitat points that we were not able to measure in-situ. Images were post-processed using SonarTRX (Honolulu, Hawaii) and visualized in ArcGIS where substrate classes were manually delineated into polygons (Table 1-2). We field validated 50 haphazardly placed points within the reach and compared those points to our substrate map to estimate accuracy. Eighty-six percent of the field verified points corroborated our substrate map. The majority of error occurred in areas classified as fine substrate on the map but were identified in the field as patches of gravel or a combination of rocky-coarse and fine substrate. Overall within the mapped reach, gravel was the most dominant substrate (fines=14.2%, gravel=80.3%, rocky-coarse=5.4%, bedrock=0.1%). In general, substrate in this river is steady, although there is contribution of fine sediment due to erosion of some banks and islands. Therefore, we expected steady bed material throughout the study.

Analysis

We applied Bayesian analysis to a discrete choice model to determine habitat selection of Shorthead Redhorse and Spotted Bass, using similar methods to resource selection assessments in both terrestrial (Cooper and Millspaugh 1999; Thomas et al. 2006) and aquatic ecology (Bonnot et al. 2011; Harris et al. 2018). The theory of discrete choice models is based on utility theory and therefore assumes that an individual gains utility from selecting particular resources (e.g., protection from predators, reduced energy expenditure, and increased foraging quality) and that an individual will choose the resource that provides maximum satisfaction relative to available options (Cooper and Millspaugh 1999). In our experiment, available habitat was defined as three micro-habitat conditions measured in proximity to the location where an individual fish was found, which collectively represented a "choice set". We assumed that the fish had no a priori knowledge of available habitat and, therefore, choice sets contained habitat that an individual could have sampled within an hour of being located and within 100 m of the used location. Different individuals could have different, overlapping, or identical choice sets depending on the individuals' distributions in the river over time (Cooper and Millspaugh 1999).

Models

We modeled habitat selection by Spotted Bass and Shorthead Redhorse in the context of season and streamflow using Bayesian discrete choice analysis. We partitioned season and streamflow by metrics that may serve as ecological cues for riverine fish. Seasonal determinations were based on water temperature: winter, < 10˚C; spring, rising from 10˚ to 23˚C; summer, > 23˚C; and fall, falling from 23˚ to 10˚C (Todd and Rabeni

1989; Goclowski et al. 2013). Flow categories were separated into *steady* and *fluctuating* flows based on discharge during a 24-hr period prior to each fish location. Flow was considered “steady” if the maximum and minimum discharge during the one day period of interest were within 30% of the mean flow. Conversely, we considered flows “fluctuating” when the maximum, or minimum, flow during the time period exceeded 30% of the mean discharge. We used discharge records from the nearest of three USGS stream gages, located at rkm-129 near Bagnell, MO (USGS 06926000), rkm-108 near Tuscumbia, MO (USGS 06926080), and rkm-55 near St. Thomas, MO (USGS 06926510) (Figure 1-1). We modeled selection in both, seasonal and flow contexts, since fish use habitats differently among seasons (Todd and Rabeni 1989; Matheney and Rabeni 1995), and we hypothesized that fish would use habitats differently between fluctuating and steady flows (Nesler et al. 1988; Capra et al. 2017).

Using the *JAGS* package in R (package version 4.3.0; Plummer 2003), we sampled Markov chain Monte Carlo simulations of the observed data (iterations=40,000; burn in=10,000; thin=10) and calculated the likelihood that the used habitat would be selected by a fish, given the available habitat. The discrete choice models tested whether Spotted Bass or Shorthead Redhorse selected locations with particular depth, velocity, submerged cover, and distance to land (Table 1-3) among different seasons and flow regimes, which were incorporated as random slope (equations 1-1 and 1-2). Covariates representing continuous variables (i.e., depth, velocity, and distance to bank) were standardized by mean and standard deviation. Submerged cover was a categorical variable representing presence or absence. Depth and velocity covariates were initially included as linear and quadratic terms (equation 1-1) because we hypothesized that fish may prefer a particular range of depths or velocities. However, when the quadratic velocity term was not predictive, we excluded the quadratic term from the model, yet kept the linear term (equation 1-2). Individual fish was incorporated as a random intercept to account for repeated sampling units and unique characteristics among fish, which could influence each individual's habitat selection. We assumed vague priors with normal distribution of μ (mean=0; variance=100) and uniform prior distribution of σ (min=0; max=10) for alpha and all betas, where $\alpha_i \sim \text{Normal}(\mu_\alpha, \sigma_\alpha^2)$ and $\beta_j \sim \text{Normal}(\mu_\beta, \sigma_\beta^2)$. Habitat covariates (Table 1-3) were represented in the following models, where U_{ijk} is the utility of a resource in observation *k* by individual fish *i*, α is a random intercept associated with each individual fish, and *j* is an index corresponding to season or flow category, where slope may vary according to season or flow category.

$$(1\text{-}1) \quad U_{ijk} = \alpha_i + \beta_{1j}D_{ik} + \beta_{2j}D_{ik}^2 + \beta_{3j}V_{ik} + \beta_{4j}V_{ik}^2 + \beta_{5j}C_{ik} + \beta_{6j}B_{ik}$$

$$(1\text{-}2) \quad U_{ijk} = \alpha_i + \beta_{1j}D_{ik} + \beta_{2j}D_{ik}^2 + \beta_{3j}V_{ik} + \beta_{4j}C_{ik} + \beta_{5j}B_{ik}$$

The probability of an individual choosing resource A rather than any of the other *n* resources available is written in the following terms (Cooper and Millspaugh 1999).

$$(1\text{-}3) \quad P_{ijk}(\mathrm{A}) = \frac{\exp(\mathrm{U_{ijk}})}{\sum_{\mathrm{A}\to\mathrm{n}} \exp(\mathrm{U_{ijk}})}$$

We evaluated the importance of posterior beta distributions for habitat selection based on mean and 95% credible intervals; however, we did not use the 95% credible interval as fixed criteria for importance. Instead, we considered the potential importance of each habitat variable in the context of the other habitat characteristics and ecological relationships. Likewise, comparison of relative probability curves among multiple seasons or flow regimes were made by visually assessing the shapes and behavior of the mean and 95% credible intervals of each distribution.

Additionally, we assessed how daily flow regime effected the habitat selection by Spotted Bass and Shorthead Redhorse during spawning seasons, since flow affects spawning conditions and movement in some fishes (Nesler et al. 1988; Catalano and Bozek 2015). To distinguish habitat selection associated with season and selection associated with stream flow, we modeled spring data using flow category (i.e. steady and fluctuating) as a random slope in equation 1-2. We used the same seasonal and flow partitioning used for the previously described models. Due to low sample sizes (Table 1-4), we did not model season and flow together for seasons other than spring.

Preliminary modeling indicated no selection for substrate and, therefore, it was not included in any of the discrete choice models. This allowed us to add fish locations that lacked substrate classifications, which increased the sample size by 6%. Temperature and dissolved oxygen were omitted from the models due to limited variation between used and available sites within each choice set (mean temperature difference = 0.14 ± 0.29 ˚C; mean dissolved oxygen difference = 0.18 ± 0.38 mg/L).

Validation

The accuracy of each of the six discrete choice models was evaluated using k-fold cross-validation where 80% of choice sets were randomly selected to ‘train’ a model and the remaining 20% of the data were held back to ‘test’ the model (Boyce et al. 2002). The cross-validation method was repeated ten times with 20% of data randomly withheld for testing each time. The number of occasions that the used location was more likely to be selected than the available locations, represented the percentage of correctly classified observations (Bonnot et al. 2011; Westhoff and Rabeni 2013). Given the four habitat options in each choice set, we would expect predictive success to occur 25% of the time, based on random chance alone.

Results

Sample Size and Tag Loss

Habitat selection results are based on 176 observations from 32 individual Spotted Bass and 103 observations from 25 individual Shorthead Redhorse located between rkm 24 and 129 (Table 1-4). Most study fish (86% of Spotted Bass and 100% of Shorthead Redhorse) were considered adults based on body length when tagged (Pflieger 1997). Four out of five Spotted Bass that were not considered adult size expelled their tag or died within the first 5 months of the study. Accordingly, those fish were not incorporated into the results. We estimated that the rates of mortality and transmitter expulsion were 46% for Spotted Bass and 29% for Shorthead Redhorse throughout the duration of the study. This rate is based on recovered transmitters and unrecovered submerged transmitters that were confirmed expelled. To investigate the tags in question, we tracked the signal without the antenna, using only a Bayonet Neill–Concelman cable, which limited the range of detection. We disturbed substrate and water by digging and prodding in an attempt to recover the tag or cause the fish to move. We only deemed tags “expelled” following a thorough search, often over several visits. In addition, one Spotted Bass and two Shorthead Redhorse were never located after they were initially implanted with a transmitter.

Seasonal Models

Spotted Bass selected specific depths and submerged cover in all seasons, while they selected velocity in only spring and summer, and distance to land in summer, fall, and winter (Figure 1-3). Although available depths in spring typically ranged from <1 to 5 m, Spotted Bass were twice as likely to select habitat 2.8 m deep as to select <1 m or >4.5 m deep (Figure 1-4). Spotted Bass also selected submerged cover and slower velocities relative to other habitats available during spring. Similar habitats were selected during the summer with the greatest likelihood of selecting 3.2 m depth, slower velocities and submerged cover near to the bank. In fall and winter, Spotted Bass used shallower depths with submerged cover nearer to the bank. For example, during winter, Spotted Bass were twice as likely to select 1.5 m deep water as 3 m deep water and 10 times more likely to select 1.5 m water than 4 m deep water. They were most likely to select 2.0 m depths during fall. Wetted width of the main channel ranged from 70 – 280 m in the focus reach, yet 80% of Spotted Bass observations were within 20 m of the bank, exhibiting a preference for habitat nearer to the bank. Model cross-validation correctly classified 67% of Spotted Bass locations according to the seasonal model (Table 1-5), which indicates a good predictive accuracy of the model compared to an uninformed model, which we expected to correctly predict the used location 25% of time.

Shorthead Redhorse selected specific velocity, submerged cover, and distance to bank among all seasons and selected for depth in seasons except fall (Figure 1-3). During spring, Shorthead Redhorse were most likely to select habitats 3.5 m deep with fast velocities. For example, during spring, they were five times as likely to use fast velocities of 1.5 m/s compared to 0.8 m/s. However, in summer Shorthead Redhorse selected for deep (5.5 m) habitats with velocities that were relatively average for that season (0.6 m/s). During fall they were most likely to select slower velocity of 0.3 m/s regardless of depth. In winter, Shorthead Redhorse selected slow velocities (0.4 m/s) but in shallow water, less than 2 m deep. Shorthead Redhorse selected habitat with submerged cover nearer to the bank compared to habitats available in all seasons. In particular, Shorthead Redhorse were closer to the bank during summer (19 ± 11 m), but used a wider range of habitats between the bank and mid-channel throughout the rest of the year (33 ± 23 m). Overall, Shorthead Redhorse tended to distribute across a wider range of distances from the bank than Spotted Bass, with 47% of locations measuring 30 – 90 m from the nearest land. Additional comparison of velocity and depth selection among seasons based on relative probability distribution curves with 95% credible intervals are in Appendix A (Figures A-1 and A-2). Model cross-validation classified 48% of Shorthead Redhorse locations correctly (Table 1-5). This percentage indicated a moderate predictive capacity of the model compared to the expected rate of 25% correctly classified by pure chance.

Flow Models

Both Spotted Bass and Shorthead Redhorse exhibited stronger selection for velocity during steady flow than fluctuating flow (Figures 1-5, 1-6, A-3, and A-4).

Spotted Bass selected slower velocity during steady flows (<0.5 m/s) than during fluctuating conditions, according to probability curves, which both skewed right, but had a steeper slope during steady flow (Figure A-3). In contrast, Shorthead Redhorse selected for fast velocities (>1.0 m/s) during steady flow but showed no velocity selection in fluctuating flows. During both steady and fluctuating flow, Spotted Bass and Shorthead Redhorse selected for habitat with submerged cover and mid-range water depths (1.5 – 4.0 m), although depths in the river reached 8 m or greater. Spotted Bass selected habitat closer to the bank during fluctuating flow only, as did Shorthead Redhorse during both steady and fluctuating flows. Model cross-validation correctly classified 64% of used locations for Spotted Bass and 45% for Shorthead Redhorse (Table 1-5).

Spring Flow Models

During spring steady flows, Spotted Bass most often selected 3 m depth, slow velocities (< 0.3 m/s) with submerged cover (Figures 1-7 and 1-8). They selected similar habitats during fluctuating flows but with shallower depth (1.5 m) despite mean sampled depth in spring of 3.1±1.6 m. Spotted Bass did not select for distance from the bank during either flow regime during spring. Shorthead Redhorse selected depths 3 m with high velocity (>1.5 m/s) near submerged cover and nearer to the bank (< 40 m) during steady spring flows. In contrast, during fluctuating flows, Shorthead Redhorse were most likely to select moderate depths (2 – 3 m) near submerged cover; however, they did not select for velocity or distance to bank. During steady flows in the spring, Spotted Bass used cover 95% of time and 74% of time during fluctuating spring flows. Comparatively, Shorthead Redhorse used cover 54% of time during steady flows in spring and 46% of time during fluctuating flows. The cross-validation correctly classified 72% of used locations by Spotted Bass, yet only 38% by Shorthead Redhorse in spring (Table 1-5).

Submerged Cover

Spotted Bass used habitat with submerged cover during 87% of observations while Shorthead Redhorse was associated with cover during 46% of observations (Figures 1-9 and 1-10). Spotted Bass most frequently used complex cover including woody debris complexes or areas with two or more types of submerged structure. They also used simple woody debris such as single logs without a rootwad. Occasionally, Spotted Bass were observed using habitat near training structures, karst bluffs, boulders, or emergent vegetation which, collectively, accounted for 22% of all used locations. Shorthead Redhorse used open water without observable cover more often than not. However, during 46% of total observations in which Shorthead Redhorse associated with submerged cover, they typically used complex woody structures, simple woody debris, and training structure habitat.

Discussion

Our study found that both Spotted Bass and Shorthead Redhorse exhibited habitat selection during all seasons and flow regimes. Although considered a habitat generalist and occupying both rivers and reservoirs (Kansas Fishes Committee 2014), Spotted Bass, exhibited consistent habitat preference on the Osage River. Specifically, Spotted Bass used moderate depth and submerged cover in all seasons and slower velocities during spring and summer, which is in contrast to Spotted Bass in the Upper Flint River in

Georgia that use habitat proportionally to availability (Goclowski et al. 2013). Shorthead Redhorse, a fluvial specialist, exhibited distinctive seasonal selection of current velocity (Figure A-1), yet also selected habitats with cover (during seasons except summer), distance to bank, and depth (during seasons except fall). Our findings were consistent with our hypotheses for spring habitat use by Spotted Bass, however, Shorthead Redhorse used deeper and more diverse habitat than expected. During colder seasons, Spotted Bass and Shorthead Redhorse used shallower habitat, despite that we expected them to use deeper habitat. Additionally, we did not expect to see clear habitat selection during fluctuating flows, however, Spotted Bass and Shorthead Redhorse used habitats with similar characteristics among flows.

Depth & Velocity

Modeled though a seasonal lens, our results indicated that Spotted Bass used a similar suite of habitat characteristics throughout the year, including depth and velocity. Spotted Bass used slow velocities during spring and summer, similar to Spotted Bass on the New River in Virginia and West Virginia, whose locations were negatively correlated to velocity (Lobb and Orth 1991) and that used bank habitat away from high current velocity (Scott and Angermeier 1998). Spotted Bass used moderate depths among all seasons and flows, similar to those reported in the Upper Flint River in Georgia, a similarly sized system (Goclowski et al. 2013). A previous study on Otter Creek in Kansas found that Spotted Bass used deeper pools during winter (Horton and Guy 2002), however, we found that they were more likely to be in shallow to moderately deep pool and run habitats (Lobb and Lueckenhoff 2013). The difference in relative depth occupied in our study compared to Otter Creek was likely a function of river size since the Osage River drainage area is two orders of magnitude larger than Otter Creek drainage area.

During spring, Shorthead Redhorse selected habitats with deeper and faster flowing water than described for spawning habitats in other studies (depth 0.2 – 0.9 m; velocity 0.3 – 0.9 m/s; Curry and Spacie 1984; Harbicht 1990). This suggests that fish in the Osage River may have spawned in deeper and faster water than in other systems, or that they were not spawning during our telemetry observations. Previous studies have described large concentrations of Shorthead Redhorse (approx. 3,000 fish) in riffles during spawning, prior to dispersal (Burr and Morris 1977; Sule and Skelly 1985; Reid 2006), however, we did not observe assembly of the tagged Shorthead Redhorse during spring or any season. Shorthead Redhorse exhibited selection for a range of moderate velocities and depths during summer which may corresponded to a diversity of feeding resources used by Shorthead Redhorse. On the Kanakakee River in Illinois, Shorthead Redhorse most frequently occupied riffle margins with cobble substrate and emergent vegetation, but also congregated in deeper pools feeding on invertebrates and detritus during summer and fall (Sule and Skelly 1985). Shorthead Redhorse selected shallower to moderate depths during winter, unlike previous studies which suggested that they moved to deeper waters once water temperature had dropped in late fall (Sule and Skelly 1985; Harbicht 1990). The Osage River is located at a lower latitude than the other studies, and therefore, warmer water temperatures due to geography and hypolimnetic release from the dam, may have enabled use of shallower low-velocity habitat during winter.

Distance to Shore & Substrate

Substrate selection by Spotted Bass was not detected in any season, however, Spotted Bass may use fine substrates (Scott and Angermeier 1998; Stewig and DeVries 2004) and some gravels and coarse rocky substrates for nest sites (Stewig and DeVries 2004; Kansas Fishes Committee 2014). Differences is substrate selection by Spotted Bass may relate to the different substrate compositions on these rivers. However, we observed Spotted Bass using a variety of substrates in the river (fines = 40%, gravel = 32%, cobble = 25%) despite gravel accounting for over 80% of substrate in the focus reach. Much of the fine and cobble substrates occurred on the channel margins, which, often contained shallower depths and submerged cover which Spotted Bass selected consistently. Habitats within 20 m of the bank were commonly selected by Spotted Bass among seasons, similar to observations on the New River in Virginia, where Spotted Bass were often located in near bank habitat with slow velocities (Scott and Angermeier 1998). Near-bank habitat may have provided shade and overhanging cover from avian predators, particularly during summer due to tree foliage.

Shorthead Redhorse used gravel 66% of the time (including 71% of detections during spring) which aligns with previous observations that Shorthead Redhorse spawn and feed in gravel and cobble riffles (Sule and Skelly 1985) and are most abundant in streams with rocky substrate (Pflieger 1997; Quist and Spiegel 2012). However, Shorthead Redhorse had high growth rates in a system with fine sediments where they fed on abundant dipteran prey (Quist and Spiegel 2012). Shorthead Redhorse selected habitats closer to the bank during summer but used a wider range of locations between the bank and mid-channel throughout the rest of the year. There is limited known about the lateral habitat association of Shorthead Redhorse, but our work suggests they may inhabit a diversity of areas within the river (nearshore and mid-channel), particularly in summer to forage on macroinvertebrates, whose composition may vary throughout the habitats used by these fish.

Submerged Cover

Woody structures may be important for Spotted Bass across small and large river systems (Scott and Angermeier 1998; Tillma et al. 1998; Lobb and Orth 1991; Goclowski et al. 2013), and our results suggest cover is important in the Osage River among all seasons, also. Spotted Bass most often selected complex cover and woody debris in all seasons, however, Spotted Bass also used boulders 15% of time during fall and winter (>320% increase from spring and summer use), similar to as documented in Smallmouth Bass (Todd and Rabeni 1989). Submerged structure may provide useful protection for ambushing prey that also benefit from cover (Harris et al. 2018). Spotted Bass were less associated with open water than in the flow-altered Coosa River in Alabama (Stewig and DeVries 2004).

Shorthead Redhorse were approximately 3 times as likely to use cover as to use open water, when cover was available, despite that they often used mid-channel run habitat where cover was sparse. Shorthead Redhorse most commonly used simple and complex woody debris and training structures, similar to the Robust Redhorse that used coarse woody debris during non-spawning seasons on the Pee Dee River in North Carolina (Fisk II et al. 2015). During hydropeaking events, training structures create fast, channelized flow with boulders and coarse rocky substrate that may be hospitable to

Shorthead Redhorse, providing drift feeding opportunities. Despite both species selecting for habitats with submerged structure, Spotted Bass used cover more consistently than Shorthead Redhorse.

Habitat Selection in Context of Flow

Spotted Bass selected moderate depth, slower velocity, and presence of submerged cover during both steady and fluctuating flow (Figure A-2), similar to habitat selected by Spotted Bass in the free-flowing Upper Flint River in Georgia. Similar habitats were selected regardless of steady or changing flows, which aligns with Stewig and DeVries (2004) that found that flow reversals had minimal effect on habitat selection of black bass on the flow-regulated Coosa River in Alabama, suggesting that black bass exhibited notable resilience to habitat modification. Spotted Bass showed stronger selection for slow velocity during steady flow, which may indicate a greater opportunity for fish to seek out and occupy slower velocity compared to fluctuating conditions, where current actively changes across the channel as discharge increases or decreases (Capra et al. 2017). However, Spotted Bass may use submerged cover in higher current velocity to forage on sheltered prey during fluctuating discharge. Spotted Bass selected for habitat closer to the bank during fluctuating flow but not during steady flow, which may correspond to use of near-bank refugia, as sought by Smallmouth Bass during floods (Todd and Rabeni 1989). Our results suggested that similar habitats were generally selected regardless of stable or dynamic flows, however, Spotted Bass used a wider range of velocity, and selected for near-bank habitat, during fluctuating flow.

Shorthead Redhorse used fast velocity during steady flows (including 32 to 821 m^3/s; Table 1-4) but used the range of available velocities during fluctuating flow (Figure 1-5). During steady flow in spring, Shorthead Redhorse used fast velocity, submerged cover, near to the bank, with moderate depth. However, during fluctuating flow, Shorthead Redhorse only selected for depth, which coincided with increased movement during fluctuating flow at this time of year (Chapter 2). Foraging opportunities on drifting dislodged macroinvertebrates may have been high during fluctuating flows (Imbert and Perry 2000) and may have created opportunity for opportunistic feeding in various habitats. Shorthead Redhorse used glide, run, and pool habitat during both flow conditions, yet used riffle habitat more frequently during steady than fluctuating flow, based on habitat classified by Lobb and Lueckenhoff (2013).

We hypothesized that fish would not be able to select for consistent habitat characteristics during fluctuating flow due to the changing distribution of physical habitat attributes, however, this study showed that Spotted Bass and Shorthead Redhorse were able to use similar habitat characteristics during both steady and fluctuating flow. Their ability to access suitable locations is derived from their ability to move among available habitat, perhaps, also suggesting reliable navigation and orientation within changing environments. The hydropeaking flows on the Osage River can have predictable shapes on the hydrograph, pertaining to magnitude, rate of change, and duration, to which these fishes may be adaptable. Underwater landmarks, such as rock ledges or submerged cover, may change or disappear as water level rises and falls. Some fish can learn the topographical landscape which can be recalled later when escaping a treat or changing currents (Aronson 1971; Braithwaite and Burt de Perera 2006).

Context for Flow Metrics and Spatial Scale

The timescales at which fish respond to environmental cues, especially pulsed flows, remain largely unknown (Young et al. 2011; Jones and Petreman 2015). Our results, however, suggest that downstream of a hydropeaking dam, habitats selected by native fish may be related to daily flow. Short term trends (2 – 3 days) in environmental conditions have been linked to fish migrations and reproductive condition (Nesler et al. 1988; Catalano and Bozek 2015) and may influence the type of habitat necessary for fish to successfully carry out particular life history events. In addition to delivering cues for spawning and migration, changes in streamflow can also deter fish from using habitat that was unavailable in the recent past. Below a hydropeaking dam on the Rhône River, fish avoided habitat that had been dewatered in the last 15 days (Capra et al. 2017), which may suggest that habitat that is recently wetted may not be perceived as “available” to a fish based on preceding flow conditions. By combining habitat selection and movement information with discharge on the Osage River, we may be able to estimate the rate of colonization in recently dry habitats, which could be pivotal for providing suitable habitat for adult, native fishes.

We evaluated microhabitat selection of fish within a large river where used and available habitat points were collected within 100 m from the fish location. All points in a single choice set were sometimes all collected within the same macrohabitat (such as run, riffle, slackwater, etc.), yet represented the range of microhabitats available within a relatively small area. Selected microhabitats, therefore, may have been nested in a selection for habitat at a larger scale first. Thus, habitat scale must be considered when applying these results within the Osage River and other systems. Although we did not differentiate habitat selection by fish size or sex, our results are representative of adult Spotted Bass and Shorthead Redhorse habitat selection as a whole. Unmeasured differences among our study fish, which may have contributed to individuals' behaviors, were accounted for by using individual fish as a random effect. The resultant alphas from the discrete choice models indicated similar habitat selection behavior among individual fish within each species. In addition, the habitat selection relationships identified for Spotted Bass may be more representative and, thus, transferable to similar habitats within the Osage River than the relationships for Shorthead Redhorse, as suggested by habitat model cross-validation values.

Mortality and Tag Loss

We estimated 42% tag loss for Spotted Bass and 29% for Shorthead Redhorse including mortality, expelled tags, and angler harvest during the 15 month study. The rate of tag loss and mortality for Spotted Bass was consistent with Harris et al. (2018) that estimated 37% of tagged Largemouth Bass were confirmed dead, harvested, or had expelled the tag during a 14 month study. Additionally, our rates aligned with total annual mortality of adult black bass that was estimated at 30 – 53% (Novinger 1987; Paukert and Willis 2004). During our fifteen-month study, transmitters from eight Spotted Bass were located in Great Blue Heron rookeries or Bald Eagle nests near the banks of the Osage River, indicating predation from birds. Two of these tags were recovered and re-implanted in study fish during fall 2016. There were two reports of angler harvest of tagged Spotted Bass. Mortality and tag loss for Shorthead Redhorse

(29%) was slightly higher than the 21% annual mortality in the Grand River, Ontario (Reid 2009), yet considerably lower than the estimated 41 – 62% annual mortality of fish in non-wadable streams in Iowa (Quist and Spiegel 2012). Our estimate also included transmitter expulsion, thus, our rate of fish loss was expected to be higher than from annual mortality alone; however, our estimate is comparable to other systems.

Management Implications

Our results inform flow regulations and habitat management in regulated rivers, particularly with the fluctuating flows of hydropeaking dams. Hydropeaking dams are common on our landscape and the impact to the downstream system may be irreversible (if the dam remains in place) (Poff and Hart 2002), however, with appropriate science-based management, flow regulated systems offer an opportunity to provide important wetted habitat for fish and other riverine taxa during all times of the year and within organisms' annual life-cycles that may enhance their abilities to persist. Shorthead Redhorse and Spotted Bass habitat selection illustrates that even native fish with mechanisms for resilience and aptitude to persist in a highly regulated river, have habitat requirements that may be better met through integrating ecological relationships into river management.

The habitats selected during steady and fluctuating flows were generally similar (in depth, velocity, presence of cover, and distance from bank) and therefore, it may be more important to provide or maintain the preferred habitat by fishes regardless of the magnitude of discharge. Spotted Bass and Shorthead Redhorse exhibited distinct seasonal preferences, including an overall use of submerged structure. Thus, maintaining complex structure (i.e., complex woody debris or multiple structure sources) may serve many fish species by providing velocity breaks, resting areas for fish, and habitat for invertebrates (Angermeier and Karr 1984; Crook and Robertson 1999). A diversity of depth and velocity should be present to supply slow velocity habitats with shallow to moderate depth for Spotted Bass while providing the range of velocities and depths selected by Shorthead Redhorse which differed among season.

Our results can be can be applied to two-dimensional (2D) models created of the focus reach on the Osage River at discrete flow conditions mapped by the Missouri Department of Conservation during 2015 to 2018. The 2D models contain interpolated depth and velocity information at 6 m resolution. Using a scenario development framework, we can model the quantity of suitable habitat for Spotted Bass and Shorthead Redhorse that exists under various discharges and evaluate connectivity of habitats and under which flows key habitats become limiting or abundant. Similar methods have been applied to the Osage River in Missouri to identify persistence of freshwater mussel habitat (Missouri Department of Conservation 2004), and used in the context of fish habitat in the Biobío River, Chile and the Lijiang River, China (Garcia et al. 2011; Li et al. 2015).

Spotted Bass and Shorthead Redhorse life histories are quite different but represent species commonly found in many regulated rivers in the United States and Canada. These species may be more tolerant to hydropeaking than other fishes due to the common presence of submerged cover, moderate depths, and adequate foraging opportunities for these species in medium to large rivers downstream of dams. In addition, adult Spotted Bass and Shorthead Redhorse are large-bodied and able to swim to suitable habitat when conditions in a location become unhospitable (Chapter 2). Centrarchids such as Spotted Bass have similar life histories and habitat needs with differences lying in the details (Pflieger 1997). All centrarchids spawn on nests that are guarded by males and have generally sedentary lives associated with submerged or overhanging cover. Likewise, while the Shorthead Redhorse may be the most adaptable in habitat requirements of the redhorse in Missouri (Pflieger 1997), several catostomid species are abundant throughout rivers in the Midwestern and Eastern United States and Canada and require similar habitats and food sources (Cooke et al. 2005; Grabowski and Isely 2007). Therefore, maintaining suitable habitat for Spotted Bass and Shorthead Redhorse is likely to benefit a much larger class of riverine fishes with similar resource needs.

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Tables & Figures

Table 1-1. Habitat variables measured at Spotted Bass and Shorthead Redhorse locations and available habitat locations and the associated instruments used for data collection on the Osage River, Missouri. The mean and standard deviation of observed values throughout the study are listed.

Habitat Variable	Instrument/Method	Mean Observed
Depth	acoustic Doppler current profiler	2.6 ± 1.6 m
Velocity	acoustic Doppler current profiler	0.59 ± 0.47 m/s
Submerged cover	visual observation; side-scan sonar	NA
Distance to land	range finder	32 ± 26 m
Substrate	visual observation; side-scan sonar; prodding	NA
Temperature	multiparameter datasonde	14.3 ± 6.1 ˚C
Dissolved oxygen	multiparameter datasonde	9.54 ± 2.74 mg/L

Table 1-2. Categories of substrate identified on the Osage River, Missouri using side-scan sonar, visual observation, and physical prodding of the bed material.

Substrate Classification	Description
Fines	Clay, silt, sand (< 2 mm).
Gravel	Fine to coarse gravel dominant (2 – 64 mm).
Rocky-coarse	Dominated by cobble; typically contained two or more substrate sizes including fines, gravel, or boulders. Includes riprap training structures.
Bedrock	Large solid rock surface.

Table 1-3. Variables included in discrete choice models describing habitat selection by Spotted Bass and Shorthead Redhorse on the Osage River, Missouri from April 2016 to June 2017.

Variable	Description	Range
D	Depth (m)	0.3 – 10
V	Velocity (m/s)	0 – 1.74
C	Submerged cover (present/absent)	0, 1
B	Distance to bank or nearest land (m)	1 – 177
α	Individual fish as a random effect	

Table 1-4. The number of Spotted Bass and Shorthead Redhorse measured within each season and flow category and summary of the 24-hr discharge (including mean 24-hr discharge and average range of the 24-hr discharge) during fish locations on the Osage River, Missouri. The discharge (from USGS gage nearest each fish location) represents the conditions when habitat selection measurements were collected and is not necessarily representative of average discharge conditions during each season or flow category as a whole.

Model Categories	Steady Flow				Fluctuating Flow			
	spring	summer	fall	winter	spring	summer	fall	winter
					Spotted Bass			
Number of samples	44	5	14	10	42	17	13	31
Mean, 24-hr discharge (m^3/s)	887	32	73	28	365	747	236	145
Range, 24-hr discharge (m^3/s)	127	4	31	4	456	692	249	295
					Shorthead Redhorse			
Number of samples	13	4	12	10	30	7	8	19
Mean, 24-hr discharge (m^3/s)	821	32	182	32	418	739	152	154
Range, 24-hr discharge (m^3/s)	124	4	95	2	475	671	168	280

Table 1-5. K-fold cross-validation results reporting percentage of correctly classified used locations by the seasonal and flow habitat selection models for Spotted Bass and Shorthead Redhorse on the Osage River, Missouri.

Species	Model Category	Cross-validation
Spotted Bass	Season	67%
	Flow	64%
	Spring flow	72%
Shorthead Redhorse	Season	48%
	Flow	45%
	Spring flow	38%

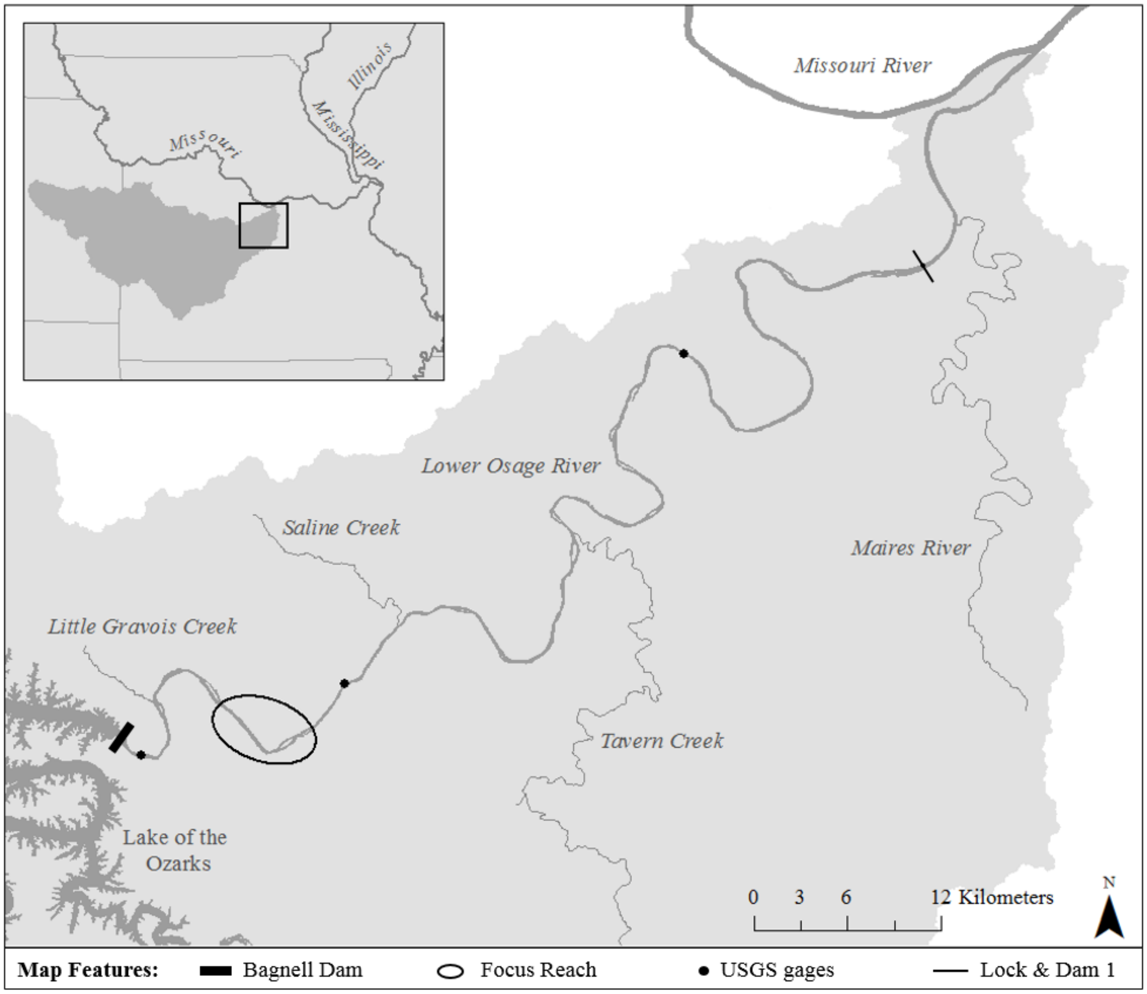


Figure 1-1. Lower Osage River, Missouri flows from Bagnell Dam (rkm-131) to the Missouri River and contains three USGS gaging stations. The focus reach for our study was located between rkm-110 and km-118 (oval). The Osage River Basin drains parts of eastern Kansas and Missouri.

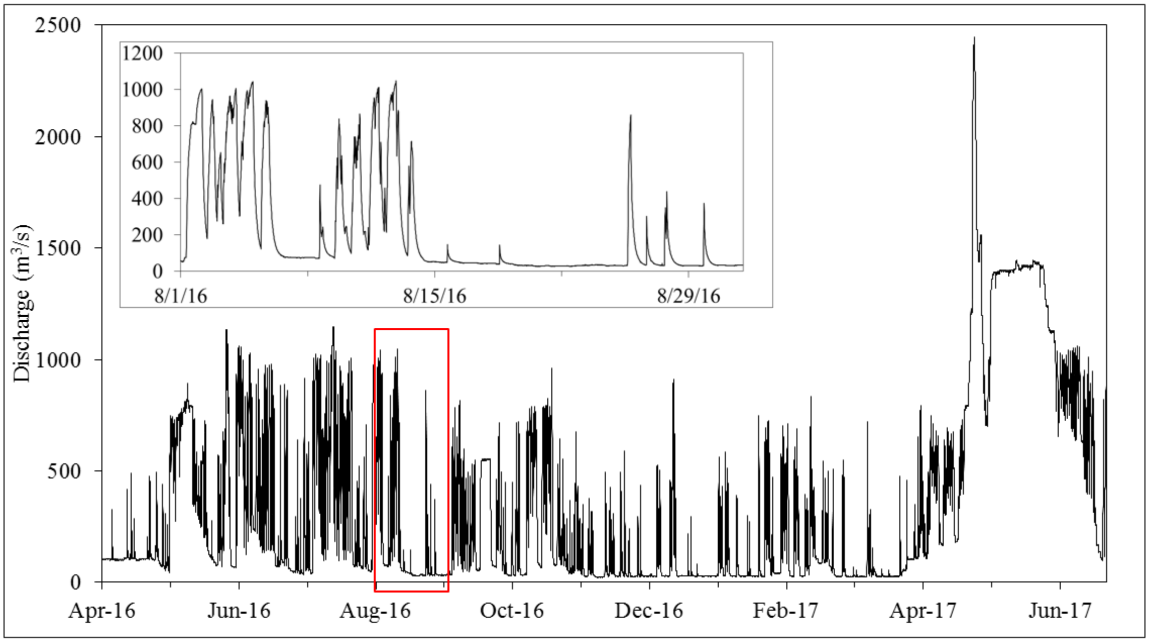
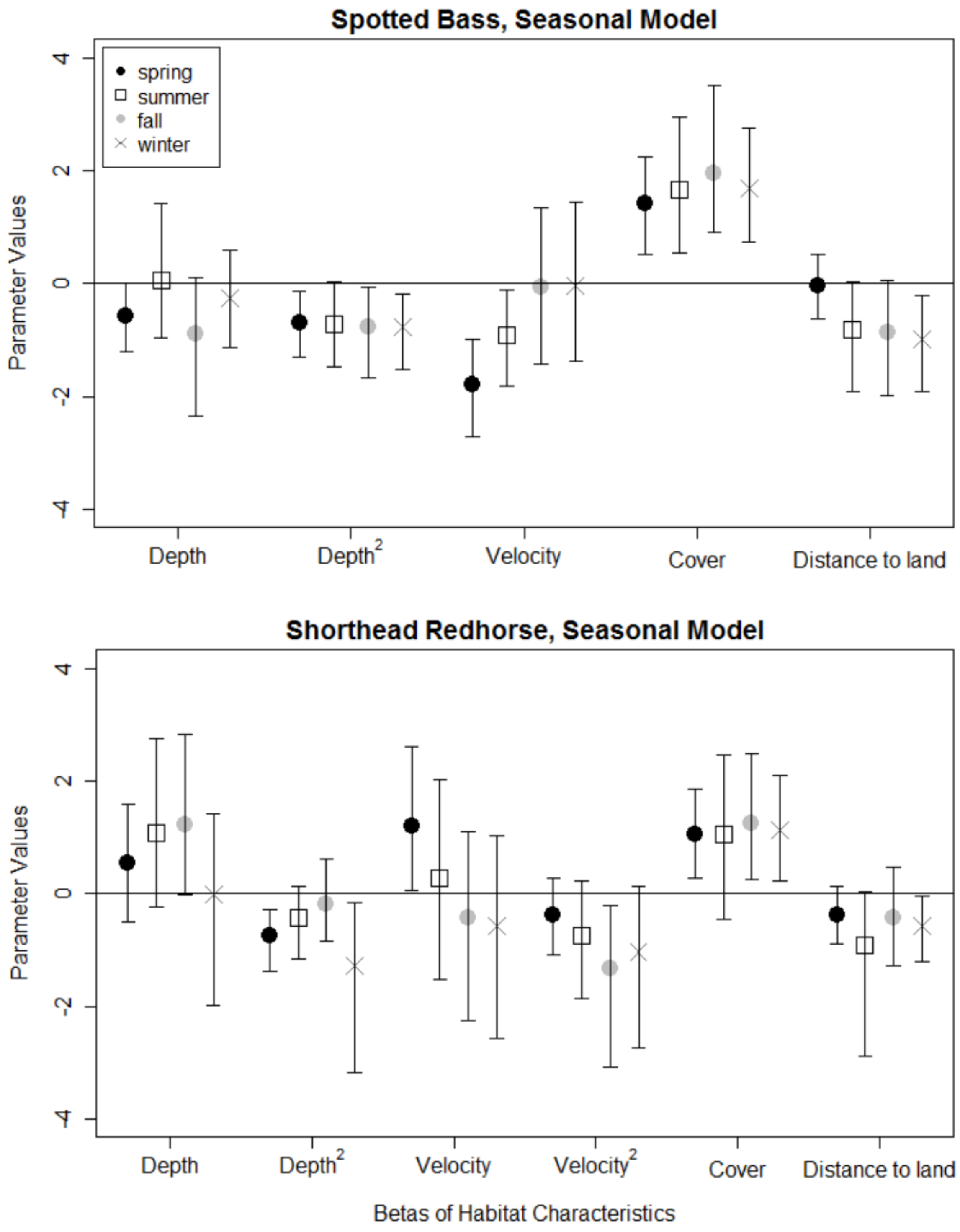


Figure 1-2. Discharge (m^3/s) of the Osage River near Bagnell, Missouri (USGS 06926000) at rkm-129 from April 1, 2016 through June 30, 2017. The insert from August 1, 2016 to September 1, 2016 shows daily patterns in flow including hydropeaking and steady base flow.


Spotted Bass, Seasonal Model

Shorthead Redhorse, Seasonal Model

Figure 1-3. Habitat selection by Spotted Bass and Shorthead Redhorse on the Osage River, MO modeled seasonally and showing beta means and 95% credible intervals. Spotted Bass model corresponds to equation 1-2 and Shorthead Redhorse model corresponds to equation 1-1.

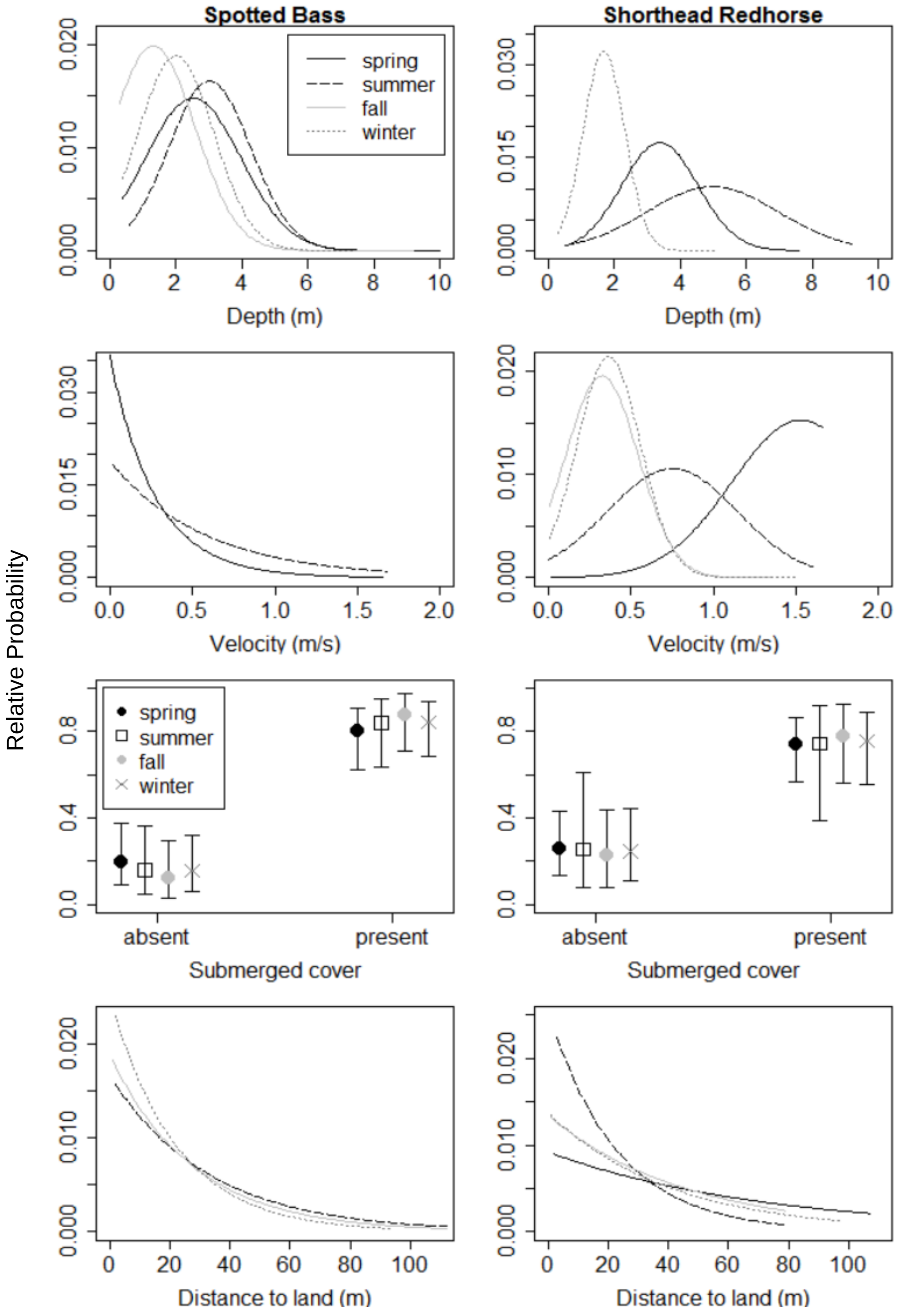


Figure 1-4. Relative probability of seasonal habitat selection by Spotted Bass and Shorthead Redhorse including water depth, velocity, submerged cover, and distance to land. The models correspond to equation 1-2 (Spotted Bass) and equation 1-1 (Shorthead Redhorse).

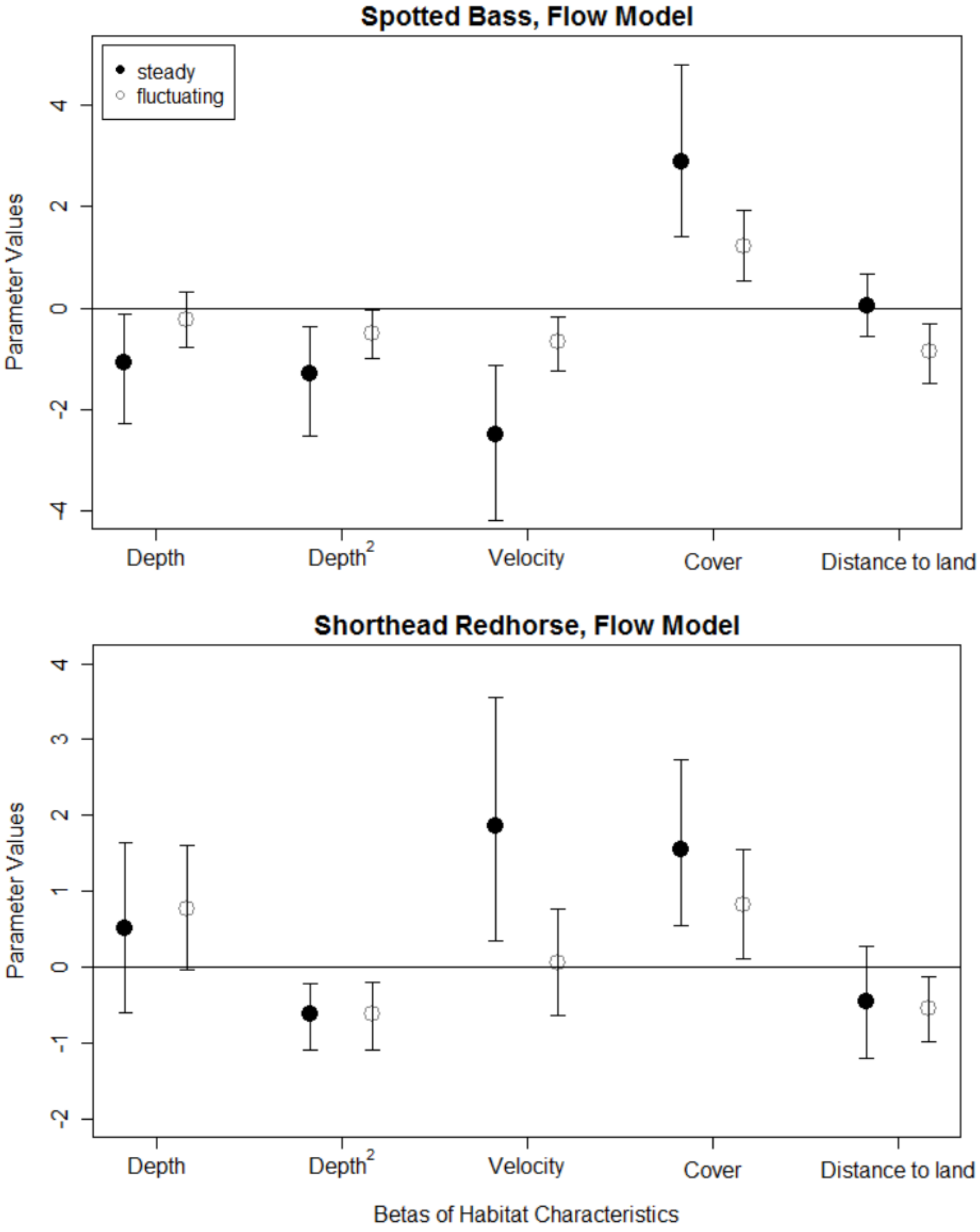


Figure 1-5. Habitat selection by Spotted Bass and Shorthead Redhorse on the Osage River, MO modeled by flow regime (24-hour) and showing beta means and 95% credible intervals. Spotted Bass and Shorthead Redhorse models correspond to equation 1-2.

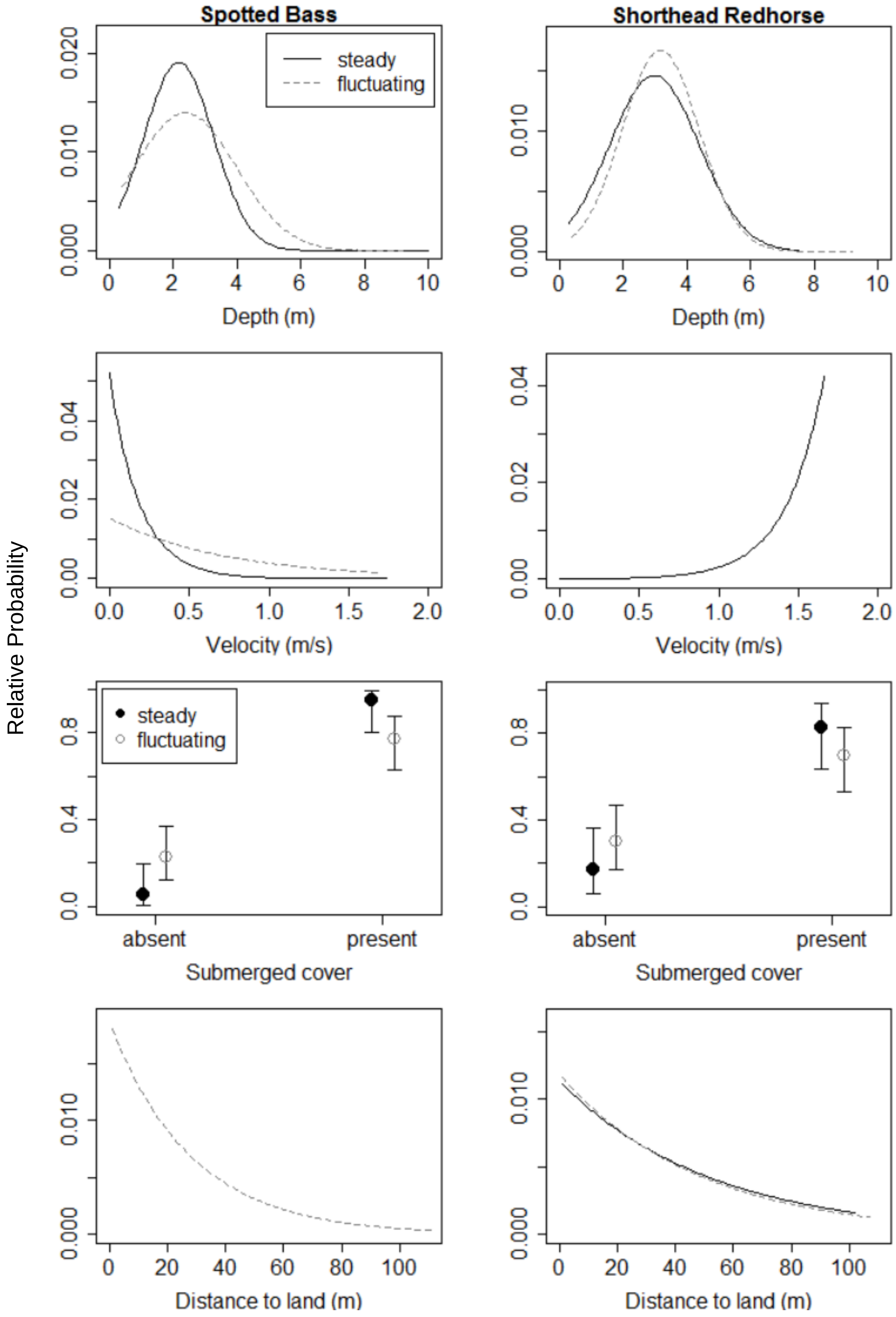


Figure 1-6. Relative probability of habitat selection among steady and fluctuating flow regimes by Spotted Bass and Shorthead Redhorse, including water depth, velocity, submerged cover, and distance to land. The models correspond to equation 1-2.

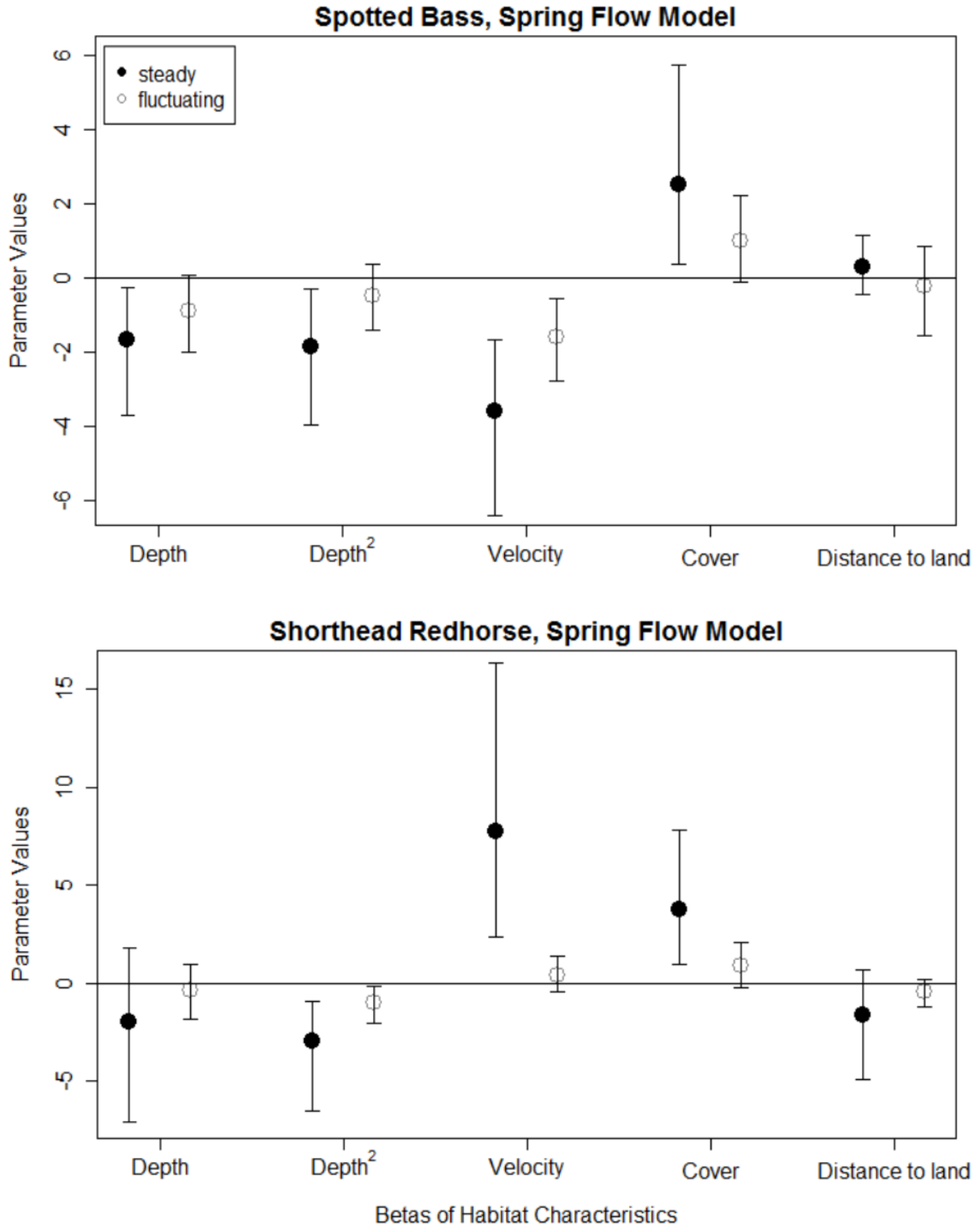


Figure 1-7. Spring habitat selection by Spotted Bass and Shorthead Redhorse on the Osage River, MO modeled by flow regime (24-hour) and showing beta means and 95% credible intervals. The models correspond to equation 1-2.

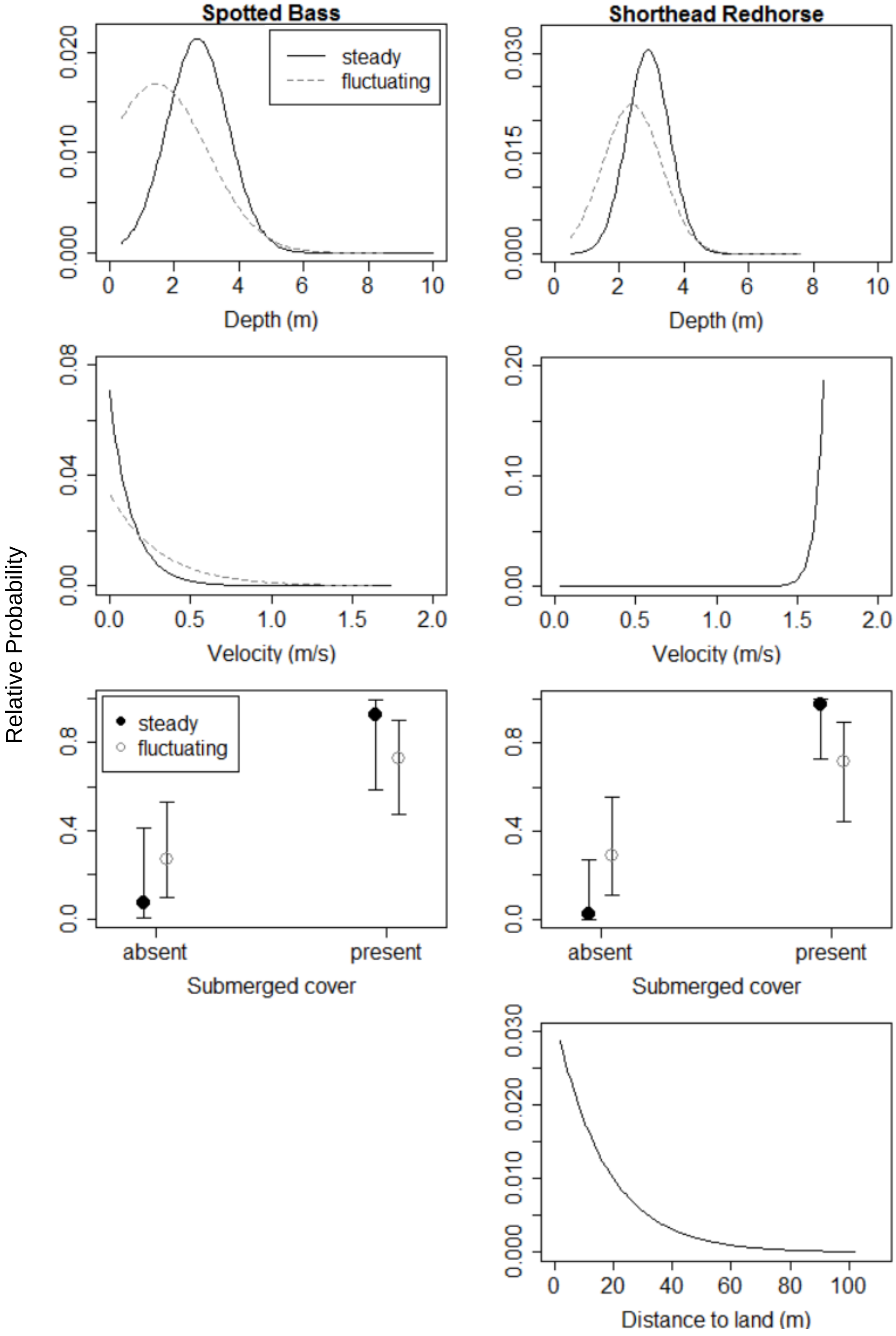


Figure 1-8. Relative probability of spring habitat selection among steady and fluctuating flow regimes by Spotted Bass and Shorthead Redhorse, including water depth, velocity, submerged cover, and distance to land. The models correspond to equation 1-2.

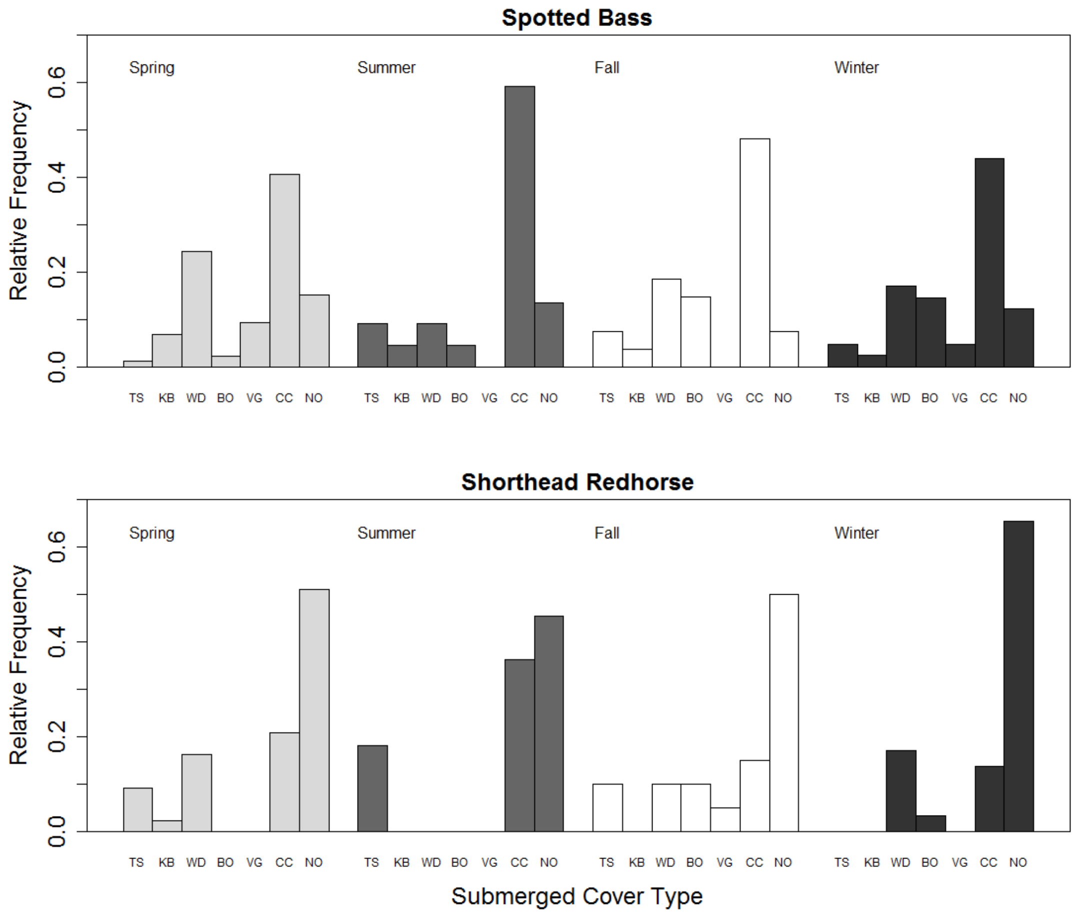


Figure 1-9. Relative frequency that submerged cover was used by Spotted Bass and Shorthead Redhorse during in each season (denoted by shade) in the Osage River, Missouri, where TS = training structure, KB = karst bluff or ledge, WD = simple woody debris, BO = boulder, VG = emergent vegetation, CC = complex woody debris structure or combination of two or more cover types, NO = open water without cover.

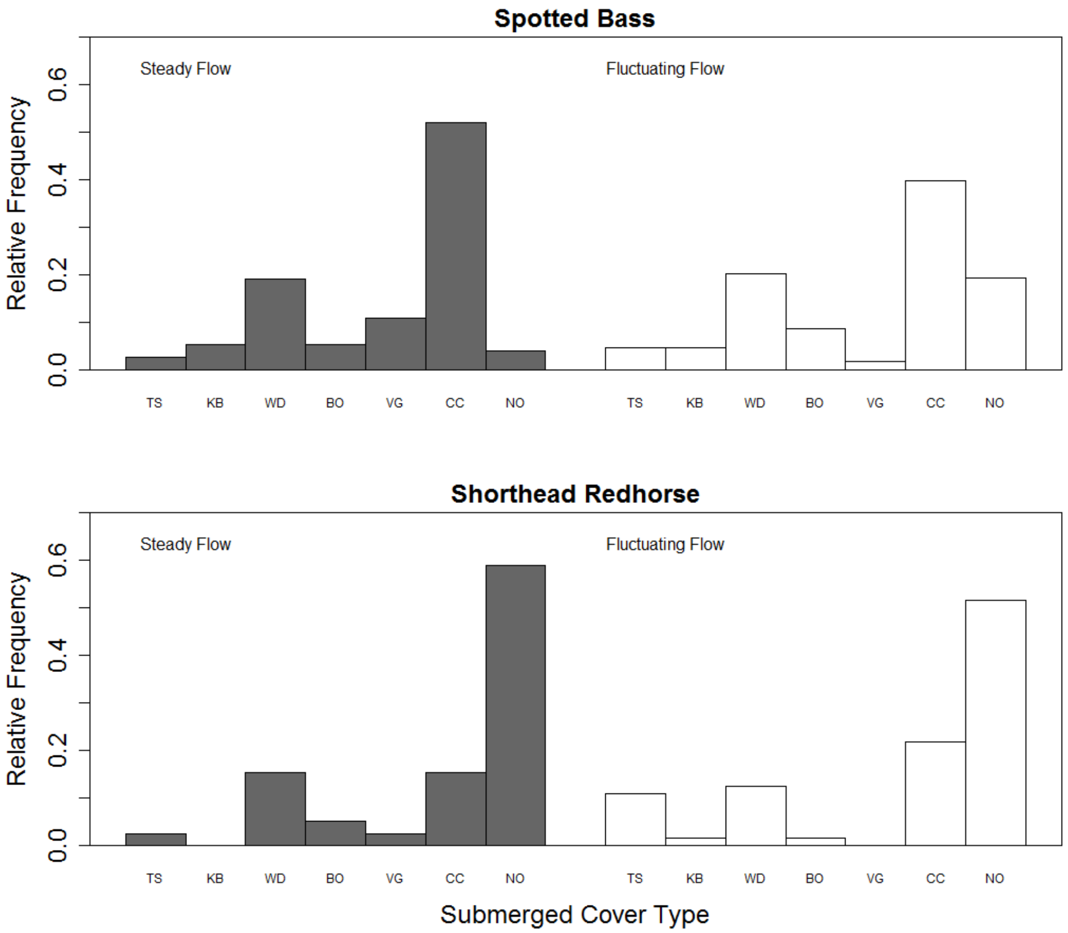


Figure 1-10. Relative frequency that submerged cover was used by Spotted Bass and Shorthead Redhorse during steady and fluctuating flows (denoted by shade) in the Osage River, Missouri, where TS = training structure, KB = karst bluff or ledge, WD = simple woody debris, BO = boulder, VG = emergent vegetation, CC = complex woody debris structure or combination of two or more cover types, NO = open water without cover.

CHAPTER TWO

Daily and Seasonal Movements of Spotted Bass and Shorthead Redhorse on a Highly Flow Regulated River

Elisa N. Baebler and Craig P. Paukert

Abstract

Movements by fish are indicative of the resources and habitats that are necessary for their survival and growth and may be synced to environmental gradients. However, flow alterations due to hydropeaking dams may change patterns of streamflow, temperature, and physical habitat and, thus, impact the behavior of fish. Understanding the relationship between highly regulated flow and fish response is an important step toward conservation of freshwater fish. Therefore, we used radio telemetry from April 2016 to June 2017 to determine movement rate of two native fish from different guilds, Spotted Bass (*Micropterus punctulatus*) and Shorthead Redhorse (*Moxostoma macrolepidotum*), on the Osage River, Missouri, downstream of a hydropeaking dam, where water level can fluctuate up to 5 m/day. We used linear regression in a Bayesian framework to determine predictors of movement rate. Streamflow affected movement of Spotted Bass and Shorthead Redhorse over short time periods (10 hours to 3 days), wherein movement rate (meters/hour) was lower during stable flow for Spotted Bass and Shorthead Redhorse, increasing with greater fluctuation in discharge. Spotted Bass movement rate peaked when 3-day average discharge was 500 m^3/s, which occurred during consecutive days of hydropeaking or flood management at the dam. Small adult Spotted Bass had greater movement rates than large bass, whereas Shorthead Redhorse movement was related to barometric pressure and Julian day. Both Spotted Bass and

Shorthead Redhorse movement rates were greatest during spring (10 – 23˚C) and differed among seasons. Mean dispersal by Spotted Bass and Shorthead Redhorse was 20 and 30 river km, respectively, suggesting the importance of suitable habitat across long segments of river.

Introduction

Hydropower operations are prevalent on rivers, contributing 17% of electricity globally and continue to be developed to meet increasing energy demand throughout the world (Zarfl et al. 2015; Winemiller et al. 2016; Couto and Olden 2018). Hydropeaking dams alter flow regimes by manipulating magnitude, frequency, timing, duration, and rate of change of discharge to meet energy needs (Poff et al. 1997). Therefore, downstream of hydropeaking dams, the flow regime is often synced with human electricity demand, resulting in daily patterns of large fluctuation in flow. Highly regulated flow influences the ecology of downstream rivers through changes in river channel morphology, nutrient inputs, available habitat, and the ability for native invertebrates and fish to persist (Bunn and Arthington 2002; Poff and Zimmerman 2010; Nestler et al. 2012; Wohl et al. 2015). Therefore, understanding the implications of flow alterations on aquatic ecology is relevant to fish conservation globally.

Riverine fish often move among habitats to access suitable resources for spawning, rearing, and other life history requirements. These movements may be linked to environmental cues, including streamflow (Albanese et al. 2004; Gillette et al. 2006). Therefore, hydropeaking dams may influence the movement of fish by changing the timing and patterns of environmental variables that affect fish. Rapid flow rises and subsequent dewatering associated with hydropeaking can change the quantity or location of suitable habitat available for feeding or refuge, thus, causing fish to seek out alternative habitat or explore newly submerged resources (Lyon et al. 2010; Capra et al. 2017). Similarly, the survival of displaced small fish is at risk if adequate velocity refuge cannot be found (Thompson et al. 2011). Alternatively, fish could become stranded as water level drops (Berland et al. 2004; Cocherell et al. 2012). Catostomid, cyprinid, ictalurid, and salmonid fishes increase their movement activities in association with high flow events (Harbicht 1990; Albanese et al. 2004; Berland et al. 2004). Thus, high flow releases due to hydropeaking or flood control could cue migrations for spawning at inappropriate times of year (Lallaman 2012) or preclude migrations until flows lessen (Jones and Petreman 2015). Other environmental variables, such as water temperature and dissolved oxygen, are often linked to discharge and may lead to fish movement to avoid low oxygen conditions (Gent et al. 1995; Knights et al. 1995) or to seek thermal refuge (Bunn and Arthington 2002; Westhoff et al. 2016). Highly altered flows downstream of hydropeaking dams may impact movements of fish that rely on environmental cues for survival.

A growing body of research is investigating fish movements as they may be impacted by streamflow (Murchie et al. 2008; Taylor and Cooke 2012); however, the spatial and temporal scales at which flow influences individual fish behavior are not clearly understood. Many studies used daily or seasonal discharge metrics, but hydropeaking dams produce sub-daily flow fluctuations that are not captured in daily metrics and whose impact on fish behavior is unknown (Bevelhimer et al. 2015). Results relating flow alteration to fish movements have been mixed (Murchie et al. 2008; Taylor and Cooke 2012), and a need remains to study fish movement in the context of regulated flow. Few studies have monitored movements of two or more fishes from different habitat guilds during the same period, yet those studies have indicated unique responses to environmental variables among life history strategies and morphologies (Murchie and Smokorowski 2004; Jeffres et al. 2006; Chun et al. 2011).

This study used radio telemetry to determine movements of two fishes of different guilds that are abundant in rivers of the southern and Midwestern United States and eastern Canada. The first species, Spotted Bass (*Micropterus punctulatus*), is a habitat generalist and often a top predator in streams, feeding on fish and crayfish (Scalet 1977; Churchill and Bettoli 2015). Spotted Bass build spawning nests that are guarded by males for several weeks after spawning when temperatures are 14 – 23 ˚C (Warren 2009). While considered relatively sedentary, Spotted Bass may make upstream migrations to spawn and then return downstream to overwinter in lower gradient habitat (Warren 2009). Movement rates of Spotted Bass in streams are 7 to 76 m/hr, with more movement occurring in larger stream systems (Horton and Guy 2002; Goclowski et al. 2013). Faster movement rates occurred between 15 and 25 ˚C in some studies although others have found no difference related to season or temperature (Horton and Guy 2002; Hunter and Maceina 2008; Goclowski et al. 2013). The second species, Shorthead Redhorse (*Moxostoma macrolepidotum*), is fluvial dependent and generally found in swift velocity riffles where they feed on benthic insects. Shorthead Redhorse migrate (up to 32 km) upstream to spawning sites coinciding with increased discharge when water temperature reaches 10 – 16 ˚C and then migrate downstream post spawn (Burr and Morris 1977; Harbicht 1990). Moxostoma species may have extensive migrations, although they occupy localized core areas during most of the year (Sule and Skelly 1985; Grabowski and Isely 2006). Examining the ways that fishes of these different habitat guilds interact with their environment through the study of movement, will help to inform river management that supports native fishes downstream of hydropeaking dams.

We anticipated that movement rates would be linked to environmental conditions, including stream flow, water temperature, and season. We hypothesized movement for both Spotted Bass and Shorthead Redhorse to be greatest during spring and fall, reflecting moderate water temperatures and typical migratory seasons for redhorse species (Horton and Guy 2002; Grabowski and Isely 2006; Reid 2006). Additionally, we expected flow would be an important factor in predicting movements of both fishes, although, perhaps, less so for Spotted Bass since they are habitat generalists. Shorthead Redhorse are fluvial dependent and often occupy higher flow habitat, thus, we hypothesized greater movements would be associated with high flow pulses (Harbicht 1990).

Methods

Study Site

We studied the movements of Spotted Bass and Shorthead Redhorse on the Osage River, Missouri to test our hypotheses. The lower Osage River extends from Bagnell Dam to the Missouri River, across 131 river kilometers (rkm). Bagnell Dam is a hydropeaking facility fed by hypolimnetic releases from Lake of the Ozarks upstream. Discharge from Bagnell Dam fluctuates substantially annually and daily and it is presumed that frequent flow variation on the Osage River results in unstable habitat for the aquatic community.

The focus reach of this study was from rkm-110 to 118, approximately 13 rkm downstream of Bagnell Dam. We selected this reach because it corresponds with two-dimensional bathymetric and velocity models created by the Missouri Department of Conservation, and because the reach includes diverse habitat, including pool, glide, run, riffle complex, side channel, backchannel, and training structure habitats at low flows (25 – 31 m^3/s; Lobb and Lueckenhoff 2013). In this river section, streamflow magnitude, rate of change, and timing closely mirrored outflows from the dam due to close proximity and the lack of tributaries present upstream of this reach. Additionally, both study species are abundant within the focus reach (Farless et al. 2018).

Fish Tagging

We collected and implanted with radio tags, 37 adult Spotted Bass (24 in spring, 13 in fall) and 38 adult Shorthead Redhorse (25 in spring, 13 in fall) within the focus reach of the Osage River during March 16 to 31 and November 16 to December 1, 2016. Spotted Bass total length ranged from 218 to 399 mm (mean=295 mm) and weighed 110 to 970 g (mean=365 g). Shorthead Redhorse total length ranged from 265 to 451 mm (mean=389 mm) and weighed between 183 and 1,160 g (mean=614 g). Details about the implantation of radio transmitters are described in Chapter 1 on Habitat Selection.

Fish Tracking

We tracked the tagged fish from a boat, using a SRX 600 radio receiver (LOTEK Wireless Inc., Ontario, Canada) and five-element Yagi antenna during 1 to 5 days per month from April 2016 to June 2017. Each day, a subset of fish (average of 10 fish total including both species, range=2 – 18) were located approximately every 2 hours (Ettinger-Dietzel et al. 2016; Harris et al. 2018) during daylight. Fish located within the first 2 hours of searching became the subset tracked during that day. We attempted to locate fish during steady and fluctuating flows in each season. Locations of tagged fish were recorded using an Archer Field PC (Juniper Systems Inc., Logan, Utah). Search efforts primarily took place within the focus reach from April 2016 to June 2017. However, we searched a larger area for tagged fish upstream 13 rkm to Bagnell Dam (rkm-131) during April, July, and September 2016 and downstream up to 90 rkm toward Lock and Dam 1 (rkm-19) during May, June, and August 2016 (Figure 1-1).

We searched for fish beginning at the upstream end of a reach and traveling downstream in the middle of the channel or in a zig-zag pattern between the banks. We searched the main channel, connected backchannels, side channels, and tributaries. The accuracy of our homing technique was tested by navigating to tags deployed at a fixed location and measuring the distance between the estimated tag location and the true tag location using a global positioning system (GPS). Based on these results we estimated our accuracy to be within 3 m.

Movement Summary

We used ArcGIS (version 10.3.1; Environmental Systems Research Institute, Redlands, California) to calculate movement rate by measuring the shortest wetted distance between consecutive locations of each individual fish over a single day of tracking. We divided the distance by the time elapsed between locations (2±0.6 hours) to calculate a movement rate expressed as minimum displacement per hour (MDPH) in meters per hour.

Distance of river occupied by Spotted Bass and Shorthead Redhorse was calculated in ArcGIS by measuring the greatest longitudinal displacement by an individual in kilometers. We measured distance between the most upstream location and the most downstream location of each fish, including locations collected for the habitat selection objective (Chapter 1 on Habitat Selection). Longitudinal displacement was determined for fish that were located during a minimum of three seasons and ten days throughout the entire study.

We summarized the movement rates and length of river channel used for Spotted Bass and Shorthead Redhorse by season. Seasonal determinations were based on water temperature: winter, < 10˚C; spring, rising from 10˚ to 23˚C; summer, > 23˚C; and fall, falling from 23˚ to 10˚C (Todd and Rabeni 1989; Goclowski et al. 2013).

Modeling and Analysis

We developed a linear regression to predict MDPH based on variables we expected to be predictors of movement rate for Spotted Bass and Shorthead Redhorse (Table 2-1). We included fish length which may affect individuals' swimming speed or ability to compete for resources (Albanese et al. 2004; Lupandin 2005; Monnot et al. 2008). We also included several environmental variables that have been linked to movement and life history migrations including water temperature which influences metabolism, growth, reproduction, and movement (Westhoff et al. 2016) and Julian day which relates incorporates season and day length (Albanese et al. 2004). Barometric pressure was included, although relationships between air pressure and movement have been mixed (Guy et al. 1992; Jones and Rogers 1998; Heupel et al. 2003). We incorporated two discharge metrics, including average discharge magnitude over 3 days and change in discharge during a given tracking day (10 hours). Change in discharge represents the difference between the greatest and least discharge magnitude from hourly readings during the 10 hours prior to the last location of a fish on a given day, and thus, represents flow fluctuation from rising and falling patterns of the hydrograph. Discharge metrics were calculated based on records from the nearest USGS gaging station to the fish location (rkm-129 near Bagnell, MO, USGS 06926000; rkm-108 near Tuscumbia, MO, USGS 06926080; and rkm-55 near St. Thomas, MO, USGS 06926510; Figure 1-1).

Movement rates (MDPH) of both species were natural log transformed to meet assumptions for regression models. We used Markov chain Monte Carlo simulation (iterations=20,000; burn in=5,000; thin=10) to approximate the posterior distribution of our parameters using Bayesian hierarchical models in the *JAGS* package in R (package version 4.3.0; Plummer 2003). We included individual fish as a random effect to account for unique preferences and tendencies among individuals. Covariates included in the model were standardized by mean and standard deviation. We assumed vague priors with normal distribution of μ (mean=0; variance=1000) and uniform prior distribution of σ (min=0; max=100) for alpha, where $\alpha_i \sim \text{Normal}(\mu_\alpha, \sigma_\alpha^2)$. Variables (Table 2-1) were represented in the regression model where *k* is an index representing observation, *i* represents individual fish, and α is a random intercept associated with each individual fish:

$$(2\text{-}1)\quad \log(MDPH_{ik}) = \alpha_i + \beta_1 L_i + \beta_2 S_{ik} + \beta_3 S_{ik}^3 + \beta_4(P_{\Delta B})_{ik} + \beta_5(T_{3d})_{ik} + \beta_6(T_{3d})_{ik}^2 + \beta_7(Q_{\Delta 10hr})_{ik} + \beta_8(Q_{3d})_{ik} + \beta_9(Q_{3d})_{ik}^2 + \varepsilon_{ik}$$

We also modeled a subset of the movement data in July, August, and September 2016 to evaluate the effect of dissolved oxygen on movement rates of Spotted Bass and Shorthead Redhorse during the period when dissolved oxygen sometimes falls below the state minimum standard (5 mg/L; Farless et al. 2018). Due to collinearity between 10-hour discharge and both water temperature and dissolved oxygen predictors within this 3-month dataset, we created models incorporating dissolved oxygen and temperature only. Variables (Table 2-1) were incorporated into the following model:

$$(2\text{-}2)\quad \log(MDPH_{ik}) = \alpha_i + \beta_1(T_{10hr})_{ik} + \beta_2(O_{min})_{ik} + \beta_3(O_{min})_{ik}^2 + \varepsilon_{ik}$$

Results

Sample Size and Tag Loss

Between April 2016 and June 2017, we tracked 32 Spotted Bass, generating a total of 220 observations and 25 Shorthead Redhorse, totaling 134 observations. We observed fish movement rates at 2-hour intervals during all seasons and various flows. Our estimated mortality and transmitter expulsion rates were 46% for Spotted Bass and 29% for Shorthead Redhorse, which was based on the number of recovered transmitters and unrecovered submerged transmitters that were confirmed to have been expelled. We determined if tags had been expelled from a fish following a thorough search, often over several visits. One Spotted Bass and two Shorthead Redhorse were never located after they were initially implanted with a transmitter.

Seasonal Movements

Movement rates of both Spotted Bass and Shorthead Redhorse differed among seasons (Figure 2-1). Spotted Bass movement rate was greater during spring (64 m/hr; range=3 – 329 m/hr) and summer (37 m/hr; range=1 – 152 m/hr) compared to fall (20 m/hr; range=3 – 90 m/hr) and winter (18 m/hr; range=2 – 54 m/hr; Figure 2-2). The movement rates of Shorthead Redhorse were greatest during spring (94 m/hr; range=13 – 342 m/hr) compared to summer (39 m/hr; range=2 – 119 m/hr), fall (13 m/hr; range=1 – 41 m/hr), and winter (34 m/hr; range=5 – 64 m/hr; Figure 2-2). Shorthead Redhorse moved less during fall compared to both spring and summer (Figure 2-2). The greatest average movement rate of Spotted Bass and Shorthead Redhorse occurred during spring.

Spotted Bass made localized movements, often occupying habitat within 20 m of the banks near woody debris (See Chapter 1 on Habitat Selection). Ten Spotted Bass used small tributaries of the Osage River during spring of 2016 or 2017. Four fish were found using tributaries during summer and one fish was located in a tributary during fall. On average, the total longitudinal displacement of Spotted Bass was 18 km but varied from less than 1 to 73 km. Eleven Spotted Bass made long movements downstream including five fish during spring (9 – 53 km), two during summer (30 – 73 km), and four during winter (6 – 25 km). Twelve fish made long upstream movements including seven during spring (7 – 70 km), four during winter (6 – 15 km), and one during summer (16 km) which traveled up to Bagnell Dam. Of the ten fish that settled within the focus reach (occupying 0.5 – 3 rkm) for the duration of the tracking, four made movements up to 13 km and returned to the same core area within a few days.

Alternatively, Shorthead Redhorse used both mid-channel and margins of the Osage River (See Chapter 1 on Habitat Selection). Mean longitudinal displacement of Shorthead Redhorse was 20 km, but varied from less than 1 km to 96 km in the main channel of the Osage River. Fish were never located within tributaries, but three Shorthead Redhorse used island backchannels during April and May 2017, when flow was characterized by hydropeaking on top of elevated base discharge (135 – 340 m^3/s) for one week or more. Fourteen Shorthead Redhorse made long downstream movements, including five during late spring (11 – 96 km), two during summer (28 – 64 km), four during fall (8 – 86 km), and three during winter (22 – 75 km). Upstream movements were made by seven Shorthead Redhorse during spring (4 – 85 km) and by one fish during summer (4 km) and fall (5 km). Four Shorthead Redhorse occupied smaller river reaches (3 rkm) and traveled distances less than 1 rkm between seasonally occupied habitats.

Environmental Drivers of Movement Rate

Spotted Bass movement rates were most related to fish length, difference in discharge over a 10 hour period, and the average 3-day discharge as both a linear and quadratic term. Conversely, Shorthead Redhorse movement rates were most related to Julian day as linear and cubic terms, change in barometric pressure, and change in discharge over a 10 hour period. Shorthead Redhorse movement was also related to water temperature but not as strongly as the other variables.

Spotted Bass movement rate was correlated to fish size and discharge (Figure 2-3). Larger adult fish moved less than smaller fish (Figure 2-4). However, 29 of 32 fish included in the movement analysis were adults (>250 mm total length; Pflieger 1997). High variability among the movement rates of small fish was partially attributed to small sample size of fish <250 mm (3 fish). Spotted Bass moved more during highly fluctuating flows (during 10 hour period) and peaked when the average 3-day discharge was between 450 and 700 m^3/s. When sustained discharge was greater than 700 m^3/s, movement rates decreased.

Shorthead Redhorse movements were related to a suite of environmental variables, including change in discharge, barometric pressure, Julian day, and water temperature (Figure 2-5). Like Spotted Bass, Shorthead Redhorse movement rates were greater as the range of discharge increased within a 10 hour period (Figure 2-5). Shorthead Redhorse movements were lower during falling barometric pressure (often related to cloudy and rainy weather). The modeled movement rates of Shorthead Redhorse peaked between mid-March and late April (Julian Day 70 – 120) when water temperature was 8 to 15 ˚C. Movement slowed throughout summer and fall until early December when rates began to rise again (Figure 2-5). Overall, movement increased as water temperature increased, but variability was high. Four large movements rates (400 – 1200 m/hr) were observed between mid-April and mid-August when temperature was 12 – 20 ˚C (Figure 2-3).

Summer Movements Related to Dissolved Oxygen and Temperature

Movement rates for Spotted Bass and Shorthead Redhorse were modeled using average water temperature and minimum dissolved oxygen over 10 hours during July, August, and September 2016. Neither variable predicted Shorthead Redhorse movement, however, both were related to movement rates of Spotted Bass as linear variables (Figure 2-6). Movement of Spotted Bass decreased as water temperature increased from about 25 to 28 ˚C (Figure 2-7). Similarly, Spotted Bass movement rate decreased as the minimum dissolved oxygen concentration increased, although temperature and minimum dissolved oxygen were not correlated (r=0.2; Figure 2-7). We observed low variability in movement rate when dissolved oxygen concentration approached 6 mg/L, but high variability among fish (30 – 250 m/hr) when dissolved oxygen dropped close to 2 mg/L due to the limited number of observations less than 4 mg/L.

Discussion

Movement Rate Predictors

Our results have shown that the best predictors of movement rate of Spotted Bass and Shorthead Redhorse differed with the exception of discharge fluctuation (over 10 hours), which was important for both species. Spotted Bass and Shorthead Redhorse movement rates were influenced by season with some of the greatest movements during spring. We observed large variation in movement among individuals of the same species, as commonly reported in other telemetry and mark-recapture studies (Meyer 1962; Taylor and Cooke 2012; Ettinger-Dietzel et al. 2016). However, movement predictors for each species may corresponded to the unique life history strategies of these two fishes.

Spotted Bass movement increased with decreased fish length and may suggest that larger fish are more competitive in selecting and maintaining suitable habitat than smaller fish, which may be outcompeted for resources (Mittelbach 1981). Additionally, large fish may have the swimming capacity to hold their position through changes in flows in this dynamic system, whereas a smaller fish may need to move in search of refuge (Chun et al. 2011). Spotted Bass that remained within a small area between consecutive locations were often near large submerged cover, which has been suggested to provide area for resting or ambushing prey in Largemouth Bass (Savino and Stein 1982; Harris et al. 2018). Long upstream and downstream movements (>6 rkm) were made by Spotted Bass, with body length ranging from 239 to 399 mm and by Shorthead Redhorse of lengths 313 to 433 mm, showing that the distance of river occupied by a fish was not related to body size (r=-0.3 and -0.1, respectively), at least for these adult fish. Additionally, we did not detect a relationship between fish size and rate of movement by Shorthead Redhorse. Shorthead Redhorse use predominantly gravel substrates (Sule and Skelly 1985; Quist and Spiegel 2012), which are abundant on the Osage River (See Chapter 1 on Habitat Selection), and adult fish are opportunistic foragers using seasonally available foods (Sule and Skelly 1985; Harbicht 1990). Thus, there may be less competition for resources between Shorthead Redhorse compared to Spotted Bass, which may be reflected in the unimportance of Shorthead Redhorse body size on movement rate in this system.

Spotted Bass movement rates were greater in spring than in fall or winter, although Julian day was not related to movement rate. Our results differed from Spotted Bass in smaller streams in Kansas that moved more during spring and fall compared to summer and winter (7 – 18 m/hr; Horton and Guy 2002), and from Goclowski et al. (2013) that found no differences in seasonal movements rate (76 m/hr) in a mid-size river in the Piedmont region of Georgia. Spring movement likely coincided with spawning since water temperature was within the spawning range for Spotted Bass (14 – 23 ˚C; Churchill and Bettoli 2015) and Spotted Bass may move greater distances during spring to arrive at suitable spawning sites (Goclowski et al. 2013). We observed Spotted Bass guarding nests at the mouth of a tributary, Little Bear Creek (Figure 1-1), in May 2016, although these fish were not tagged for our study. In the summer, movement rate was greater when temperature was around 25 ˚C and decreased as water warmed toward 28 ˚C, which may correspond with feeding activity of black bass, which peaks between 22 and 26 ˚C and declines at higher temperatures (Zweifel et al. 1999). This is similar to Hunter and Maceina (2008) that noted that Spotted Bass movement was greatest between 15 and 25 ˚C and slowed in mid-summer around 30 ˚C.

Seasonal differences in movement rate may also be related to flow. Movement rates of Spotted Bass peaked at a 3-day mean discharge of approximately 500 m^3/s. On the Osage River, 3-day average discharge at or above 500 m^3/s typically corresponded to flood management during May 2016 and late April through June 2017, or consecutive days of hydropeaking for energy production during the week days in June to October 2016. These conditions occurred during 23% and 62% of spring 2016 and 2017, respectively, 24% of summer, 8% of fall, and did not occur during winter. During these flows, velocity within the main channel may have been unsuitable, causing Spotted Bass to seek velocity refuge, such as emergent vegetation near islands, tributaries, and near bank habitat. This behavior is similar to what is described by Matheney and Rabeni

(1995), who found that Northern Hogsucker (*Hypentelium nigricans*) remained in their home areas, even during peak discharge of a flood by moving into inundated riparian areas where velocity was lower. Flow refuge in lower velocity margins, including island backchannels, were also used by Shorthead Redhorse during sustained high flow conditions in spring.

We observed higher variability in movement rates among Spotted Bass and Shorthead Redhorse during highly fluctuating flows (up to 800 m^3/s difference over 10 hours) compared to steady flow conditions, suggesting that there may be more factors influencing fish movement during changing flows. This was the only physical variable that affected movement rates of both species. Our results are similar to Salmon par that move more during variable flows (Berland et al. 2004). Fish have complex reasons for moving (i.e., reproduction, seeking refuge, exploit newly available food resources, dispersal), which is exhibited through multiple movement strategies employed during high flow events including settling within the home area, moving to settle elsewhere, or moving temporarily and returning to the home area (David and Closs 2002).

Shorthead Redhorse movement rate was greatest from mid-March through late April and the lowest rates occurring from mid-August until early December. Spring movement likely coincided with spawning since water temperature on the Osage River corresponded to spawning temperature of Shorthead Redhorse (10 – 15 ˚C; Reid 2006) and migratory movements to spawning sites are common in Shorthead Redhorse (Harbicht 1990). Julian day corresponds to seasonality and day light hours and may be an indicator of spawning for catostomids (Catalano and Bozek 2015). Migration and spawning activities of Moxostoma species typically occur in predictable order related to timing and water temperature (Grabowski and Isely 2006; Reid 2006; Catalano and Bozek 2015). Seasonal movement rates of Shorthead Redhorse were not previously documented, however, movement of other redhorse species indicated both sedentary and migratory individuals (Fisk II et al. 2015), and our results showed similar patterns. For example, eight Shorthead Redhorse moved more than 50 rkm, whereas four fish were only located within a 3 km segment of river. Shorthead Redhorse movement rate was lower during fall compared to spring and summer, unlike studies with other Moxostoma species that found the greatest movements occurred during both spring and fall (0.5 to 1.0 km/day; Bowman 1970; Grabowski and Isely 2006).

Shorthead Redhorse movement rates increased with rising barometric pressure, which is typically related to clear skies. Although not directly tested, Robust Redhorse spawning increased in association with increased cloud cover during the day and clear skies with moon illumination at night on the Savannah River in Georgia (Straight et al. 2015), which is likely correlated to both barometric pressure and light level. Thus, atmospheric conditions may influence the behaviors of redhorse species who may use visual cues. Studies have tested the relationship between barometric pressure and fish movement (Warden and Lorio 1975; Markham et al. 1991; Jones and Rogers 1998), however, few studies have found a relationship. Guy et al. (1992) found that higher barometric pressure correlated with greater movement of adult Black Crappie, while also indicating that light intensity was the most influential variable influencing movement rate.

Summer Movement Related to Dissolved Oxygen and Temperature

Temperature and dissolved oxygen were predictors of movement rate for Spotted Bass during summer, but not for Shorthead Redhorse. Spotted Bass movement rate increased as minimum 10-hour dissolved oxygen decreased below 5 mg/L. Our findings contrasted Dahlberg et al. (1968) that found Largemouth Bass swimming speed decreased below 5 mg/L at 25 ˚C in a test chamber. Thus, ideal metabolic swimming conditions may occur when dissolved oxygen is above 5 mg/L, however, in flow-regulated rivers, other environmental variables may require movement to alternative habitat despite low dissolved oxygen concentrations. On the Osage River, increased discharge from the hydropeaking dam was associated with decreased dissolved oxygen concentrations (r=-0.7; Farless et al. 2018) and may be a more dominant variable influencing movement. The functional relationship between movement and dissolved oxygen was not examined in this study, but movement could be associated with habitat avoidance, metabolic lethargy, or behavior modifications that increase oxygen uptake such as swimming activity or positioning in faster current velocity (Randall 1982; Kramer 1987). Centrarchids, including Largemouth Bass (Hasler et al. 2009), Bluegill and Black Crappie (Knights et al. 1995), avoided habitat with concentrations at or below 2 mg/L and exhibited changes in behavior at such concentrations (i.e. yawning, vertical movement, and temperature and velocity selection), but we never recorded dissolved oxygen lower than 2 mg/L in the Osage River during summer 2016. Although tolerances vary among species, the minimum oxygen levels observed during this study were above the lethal limits for centrarchids and catostomids (Doudoroff and Shumway 1970). Likewise, summer temperature in the main channel thalweg of the Osage River was within the thermal tolerance for Spotted Bass (34.2˚C), and within an assumed limit for

Shorthead Redhorse based on thermal tolerances of catostomid species (30.8 – 34.9˚C; Beitinger et al. 2000).

Migration/Long Movements

We observed long movements upstream and downstream by Spotted Bass throughout the 15 month study. On the Osage River, Spotted Bass made long movements (up to 73 km) during winter, spring and summer, in contrast to the Upper Flint River in Georgia, where Spotted Bass were observed making migrations (5 km) during spring only (Goclowski et al. 2013). The seasons during which long movements occurred may be related to discharge. The Osage River experienced flow pulses (>550 m^3/s) during all seasons due to hydropeaking operations, whereas high flows occurred only during spring on the Upper Flint River, followed by drought conditions during summer and fall, which reduced heterogeneity of available habitat (Goclowski et al. 2013). Thus, hydropeaking flows in the Osage River may have encouraged long movements throughout more of the year than systems that experience flow pulses driven primarily by precipitation.

Similarly, long movements (up to 91 km) were also made by Shorthead Redhorse in the Osage River during all seasons. Shorthead Redhorse may have extensive dispersal (based on low recapture rates; Sule and Skelly 1985) but the extent of dispersals has not been well documented. We observed longer migrations than have been reported in other studies (Burr and Morris 1977; Harbicht 1990), which may be related to the larger size of the Osage River compared to other study systems or our use of telemetry techniques, which enabled tracking fish over large distances.

There was a negative correlation (Spotted Bass, r=-0.5; Shorthead Redhorse, r=-0.7) between the total river distance occupied and the number of times a fish was located, suggesting that sedentary fish were located more frequently than their peers who occupied broader extents of the river. However, this also suggested that we did not over-estimate distance based on contact bias. Although locating fish every 2 hours is a common method in daily movement studies, this approach may underestimate the activity compared to more frequent locations (Horton et al. 2004). Estimates of the total river distance used by fish and daily movement rates represent conservative estimates of movement since fish may be moving non-linearly between telemetry locations.

Management implications

Movements of Spotted Bass and Shorthead Redhorse, two species with different life history requirements, were related to change in flow, which was a highly-variable and highly-regulated characteristic of discharge downstream of a hydropeaking dam. Management of dam releases impacts the movement and, therefore, energetic expenditure and habitat accessibility for native fishes (Weyers et al. 2003). Both Spotted Bass, of the family centarchidae, and Shorthead Redhorse, of the family catostomidae, are common throughout the eastern United States and Canada. These families represent a considerable portion of biomass in freshwater streams.

Additionally, discharge patterns at sub-daily and multi-day time periods were indicators of movement behavior, and movement was generally greater with fluctuating flows and lower during stable flows. The effect of altered flow regimes on fish behavior encompasses the extent of resource availability among different temporal scales. Therefore, temporal resolution, including sub-daily variability, should be a consideration when evaluating the effect of flow schedules on river ecology (Spurgeon et al. 2016). In addition to flow, other environmental gradients including barometric pressure, day of year, and water temperature, may also influence the decisions of fish to settle or move among habitats in search of resources and may differ between seasons.

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Tables & Figures

Table 2-1. List of variables included in models describing daytime movement rates of Spotted Bass and Shorthead Redhorse on the Osage River, Missouri from April 2016 to June 2017.

Variable	Description	Range
L	Total length of fish (mm)	226 – 399 (Spotted Bass)
		280 – 451 (Shorthead Redhorse)
S	Julian day	20 – 357
T_{3d}	Water temperature, 3-day average (˚C)	6.2 – 26.8
T_{10hr}	Water temperature, 10-hour average (˚C)	6.5 – 27.8
$P_{\Delta B}$	Barometric pressure, 24-hour change (cm H_20)	± 0.1 – 12.3
$Q_{\Delta 10hr}$	Discharge, 10-hour change (m^3/s)	3 – 820
Q_{3d}	Discharge, 3-day average (m^3/s)	24 – 880
O_{min}	Dissolved oxygen, 10-hour minimum (mg/L)	2.3 – 6.9
α	Individual fish as random intercept	

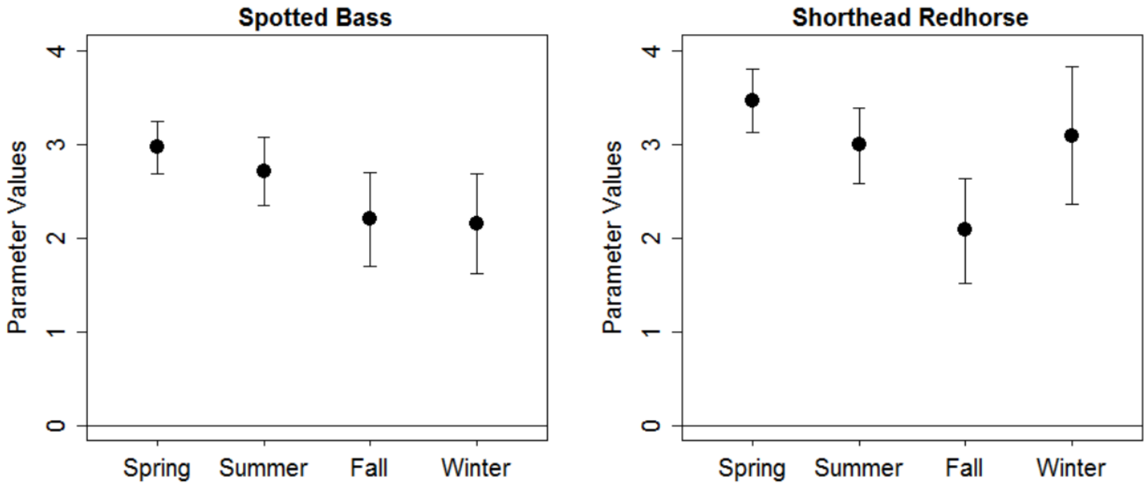

Figure 2-1. Spotted Bass and Shorthead Redhorse movement rate ($MDPH_{log}$) modeled as a function of season. Beta means and 95% credible intervals of posterior distribution are shown.

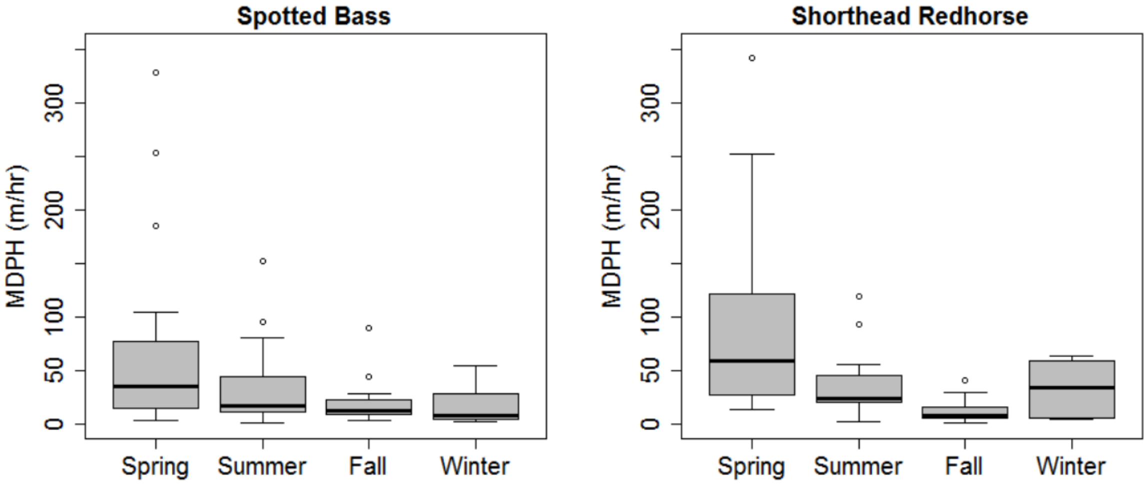

Figure 2-2. Seasonal movement rates measured in minimum displacement per hour (MDPH) of Spotted Bass and Shorthead Redhorse in the Osage River, Missouri. Interquartile range, median (black bar), and outliers shown.

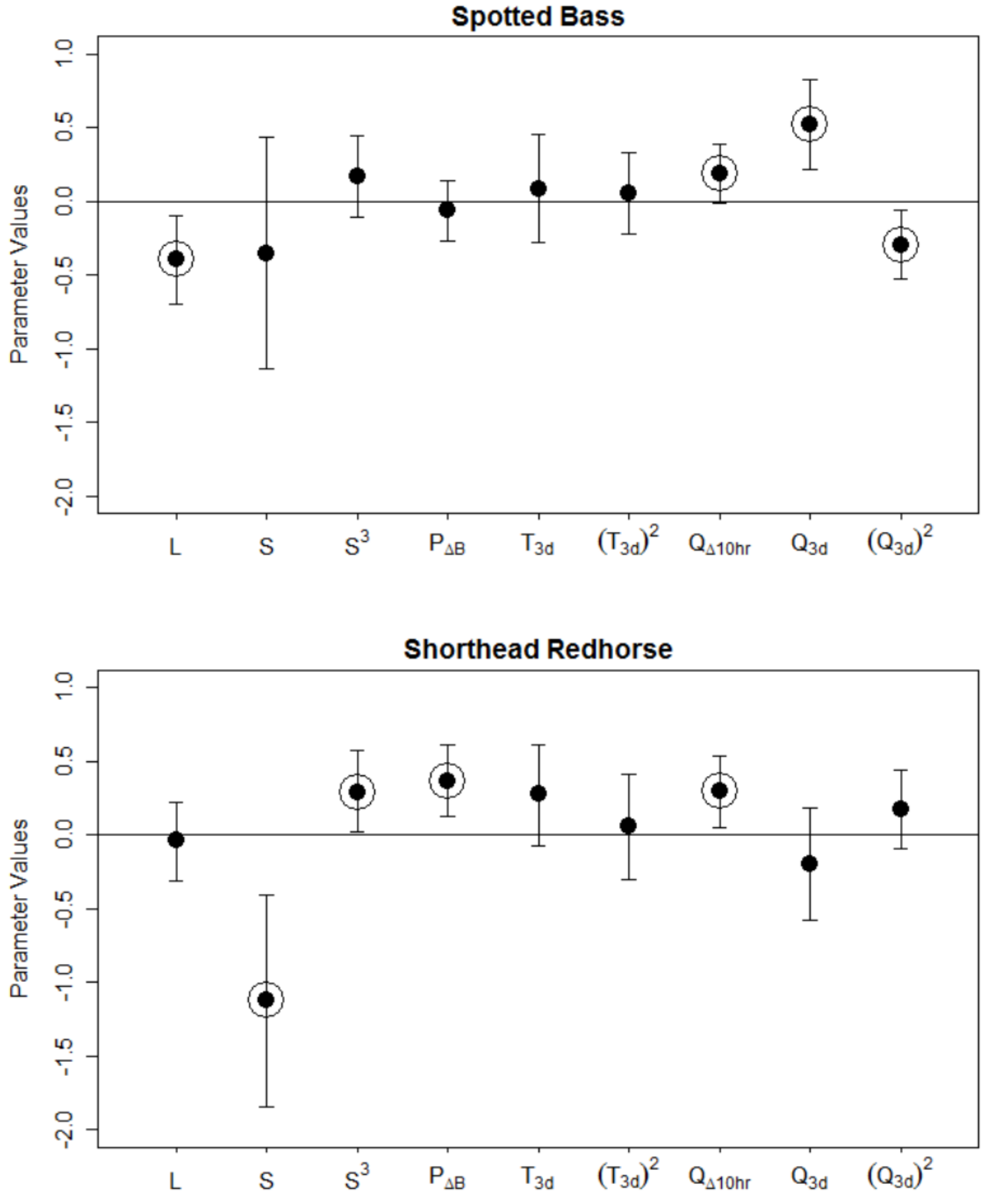

Figure 2-3. Spotted Bass and Shorthead Redhorse movement rate ($MDPH_{log}$) models showing mean beta and 95% credible interval of posterior distribution for variables described in Table 2-1. Variables whose 95% credible interval does not include zero are circled.

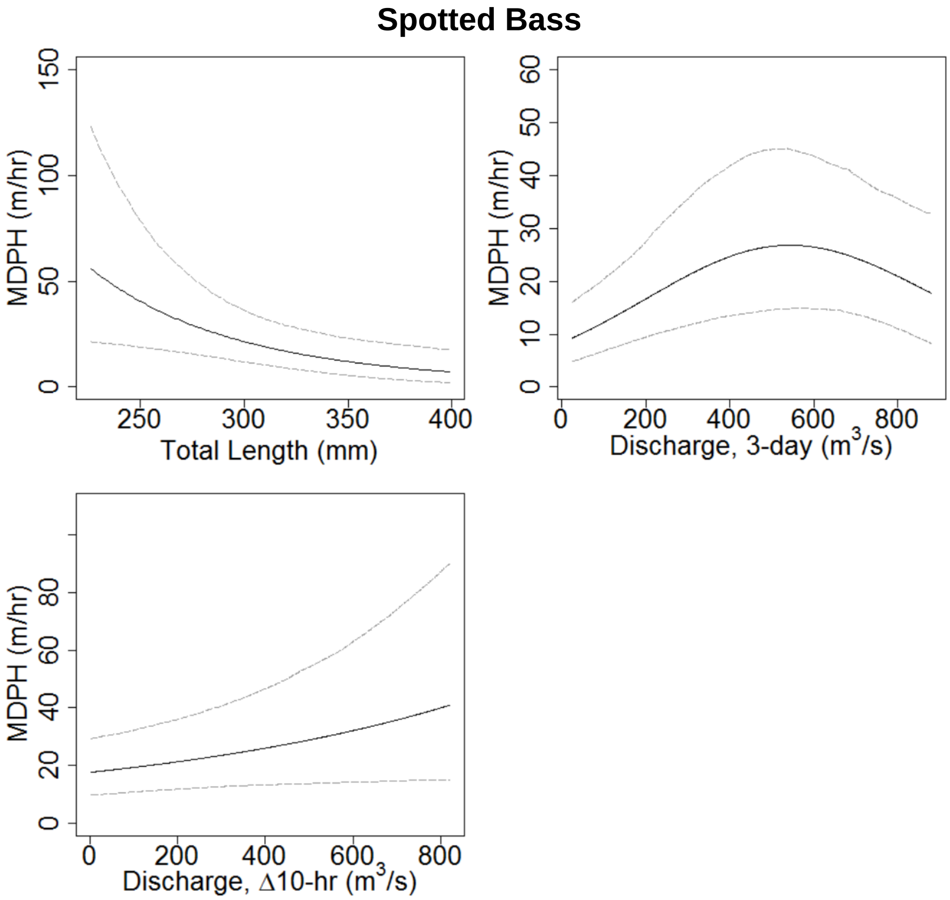

Figure 2-4. Predicted movement rate (MDPH; solid line) and 95% credible interval (dashed line) of Spotted Bass on the Osage River, Missouri based on equation 2-1.

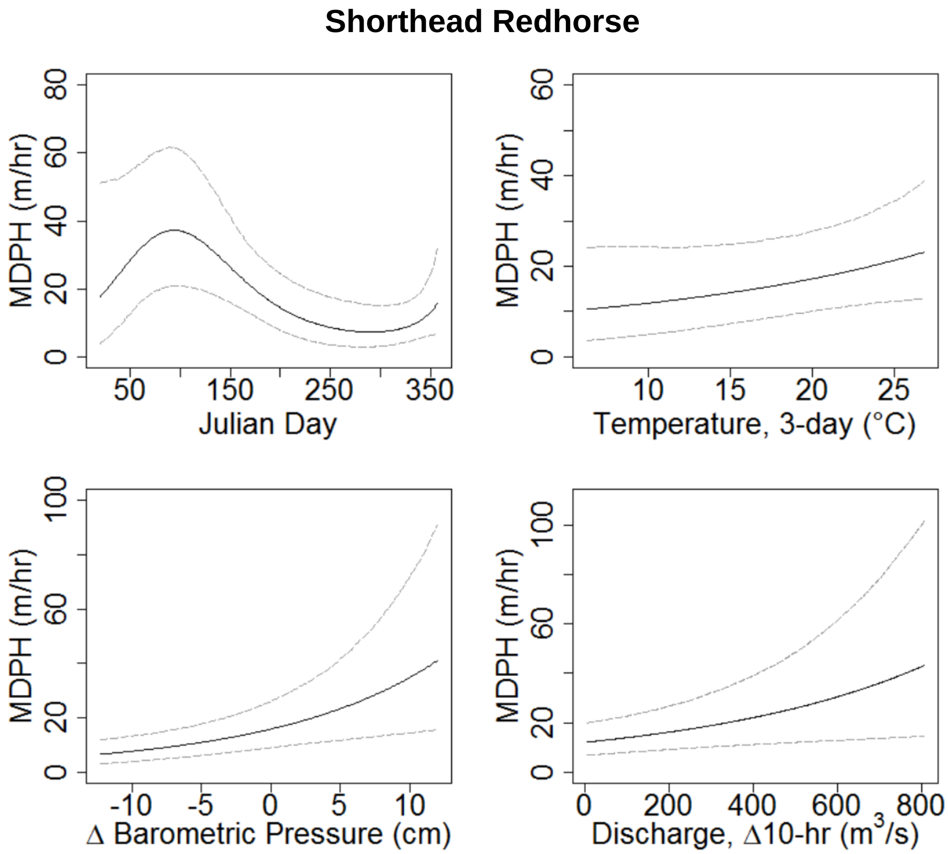

Figure 2-5. Predicted movement rate (MDPH; solid line) and 95% credible interval (dashed line) of Shorthead Redhorse on the Osage River, Missouri based on equation 2-1.

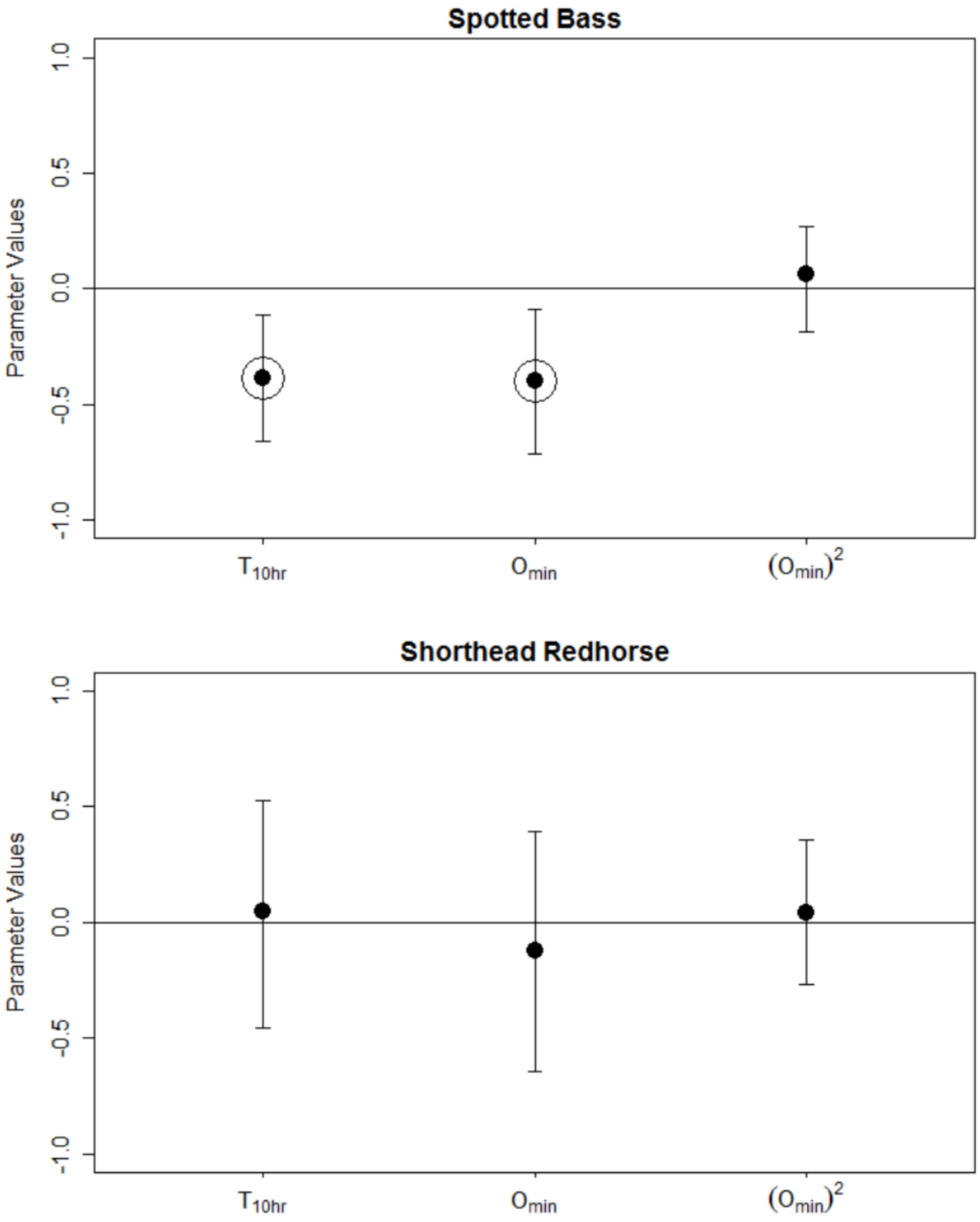

Figure 2-6. Spotted Bass and Shorthead Redhorse movement rate ($MDPH_{log}$) models showing mean beta and 95% credible interval of posterior distribution for variables described in Table 2-1. Variables whose 95% credible interval does not include zero, are circled.

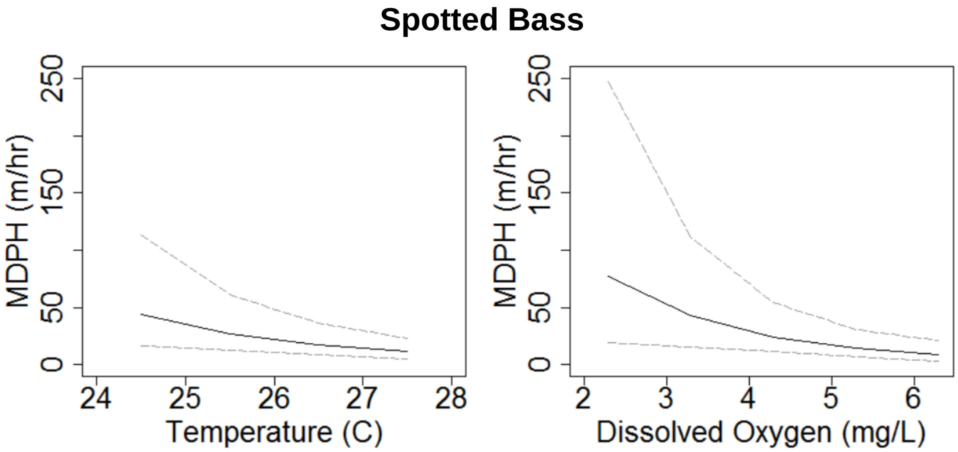

Figure 2-7. Predicted movement rate (MDPH; solid line) and 95% credible interval (dashed line) of Spotted Bass on the Osage River, Missouri based on equation 2-2.

CONCLUSIONS

This study explored the habitat selection and movement rates by Spotted Bass and Shorthead Redhorse within a highly flow-regulated, large river in Missouri. We addressed responses of fish to season and streamflow on an ecological timescale (i.e., hours to years) because fish behavior impacts the health and viability of populations persisting within the system. This time scale is also relevant to flow management at hydropeaking dams, as operators respond to electricity demand and flood management on the order of hours to weeks. Our research may help to inform river management through better understanding the effects of discharge schedules and environmental conditions on fish and riverine ecology.

Flow-ecology relationships, particularly related to abundance, of Spotted Bass and other micropterus were considered highly transferable. Catostomid species were considered to have generally low transferability across space (Chen and Olden 2018), although Shorthead Redhorse were not specifically evaluated. Transferability tends to be similar for species within the same family, which suggests a phylogenetic (Chen and Olden 2018) or guild-based (Macnaughton et al. 2016) component to explain ecological relationships to flow and temperature. Spotted Bass and Shorthead Redhorse have persisted within the Osage River, which has experienced extensive hydrologic alteration for nearly 90 years. The resilience of these fishes may be related to their ability to move and relocate to suitable habitat with cover and foraging resources amidst flow disturbances. Our results, including relationships of movement and habitat selection to altered streamflow, may be relatable to other species within the respective guilds, in a broader geographic and temporal context.

Management Implications of Key Findings

Our study indicated that short-term (10- and 24- hour) flow fluctuations, related to hydropeaking operation, caused greater movement rates among both Spotted Bass and Shorthead Redhorse compared to steady flow, while habitat selection remained fairly similar among flow regimes. Movement during rising or falling flow may be attributed to opportunistic exploration of newly submerged resources or continual relocation to suitable habitat while depth and velocity change (Capra et al. 2017). Spotted Bass selected moderate depth (1.5 – 4 m) and submerged cover in all seasons and flow categories, and selected habitat closer to the bank during fluctuating flows and all seasons except spring. Spotted Bass used slow velocity during steady flows, particularly during spring and summer, and also used slower velocity, relative to available habitats, during fluctuating flow. Velocity was a year-round indicator of habitat used by Shorthead Redhorse, although preferred velocities differed between season and flows, with the fastest velocity selected during spring, moderate velocity during summer, and slower velocity during fall and winter. Shorthead Redhorse selected for faster velocity during steady flow but used the range of available velocities in fluctuating flow conditions. Although submerged cover was not used as frequently by Shorthead Redhorse as by Spotted Bass, Shorthead Redhorse selected cover during all seasons except summer, in nearshore habitat with shallower depth during winter than spring or summer. Selected habitat characteristics were similar among flow regimes indicating that during highly fluctuating flows, fish may be moving more to relocate within suitable habitat as depth and velocity distribution actively change. Additionally, some habitat characteristics were important to Spotted Bass or Shorthead Redhorse among all seasons while others differed throughout the year. Therefore, flow management intended to provide suitable habitat of fishes, may need to incorporated seasonal considerations.

The greatest movement rates of Spotted Bass and Shorthead Redhorse occurred in spring when water temperature was between 10 and 23 ˚C. Hydrologic connectivity of suitable habitats for spawning (e.g., moderate depth, low velocity and submerged cover for Spotted Bass; Churchill and Bettoli 2015, and gravel riffles for Shorthead Redhorse; Sule and Skelly 1985) may be particularly important during spring and may be facilitated by increasing the wetted channel area via increased baseflow. Although Shorthead Redhorse exhibited selection for depth and velocity during summer, the range of used habitat was more diverse than during other seasons which may correspond to diverse food sources available in different habitats. Thus, maintaining habitat diversity may be beneficial to Shorthead Redhorse during summer. Benefits of channel connectivity and habitat diversity across seasons may reach several levels of the ecosystem beyond our study fish. For example, six of the tagged Spotted Bass used habitat near the mussel bed during mid-April to early June, corresponding to the time of year and water temperature (Gascho Landis et al. 2012) that Pink Mucket, a federally endangered and reintroduced native mussel, release glochidia to make contact with a suitable fish host, such as Spotted Bass.

Spotted Bass movement rates peaked when 3-day average discharge was approximately 500 m^3/s during consecutive days of hydropeaking or during flood control management of the dam, which occurred most frequently during spring, followed by summer, and then fall. Spotted Bass used tributaries during spring and summer when high flow connected these off-channel habitats to the main channel and provided velocity refuge. Connectivity of off-channel habitat was important for Spotted Bass, particularly during spring, perhaps due to protected, slower velocity habitat that may be suitable for nest building. Utility of these habitats is related to the frequency and extent to which they are inundated and hydrologically connected to the main channel which is controlled primarily by flow on the Osage River, since these tributaries are small.

Six Spotted Bass (21%) and two Shorthead Redhorse (8%) were located in Sloan Eddy backchannels during mid-April to early June 2016 and 2017 during hydropeaking or continuous flood release. One Shorthead Redhorse used Cotton Island backchannel during flood conditions in May 2017. Neither species was ever located in Lick Creek backchannel. Sloan Eddy and Cotton Island backchannels are 40 – 60% wider than Lick Creek backchannel, and had a greater proportion of gravel substrate than fines, unlike Lick Creek backchannel. These physical habitat characteristics may influence the utility of the resources for fishes within these three island backchannels, to which flow is restricted at discharge less than approximately 120 m^3/s (Lobb and Lueckenhoff 2013). It is possible that if connected at lower flow, backchannel habitat may provide beneficial habitat for spawning and rearing during spring and possibly during other seasons. Although the main channel of the Osage River was primarily used by Spotted Bass and Shorthead Redhorse, island backchannels should be considered for potential habitat restoration, including increasing hydrologic connectivity.

Spotted Bass and Shorthead Redhorse, collectively, dispersed across 105 rkm of the main channel of the Osage River, although nearly 40% of Spotted Bass and 12% of Shorthead Redhorse remained within the 8 rkm focus reach. On average, Shorthead

Redhorse used a longer extent of river (29±31 rkm) than Spotted Bass (18±20 rkm). However, within each species, individuals used similar habitats, regardless of their location along the river length. Maintaining longitudinal connectivity, as well as, patches of suitable habitat for both Spotted Bass and Shorthead Redhorse, may be important across 20 to 30 rkm or more. It may be useful to determine if there are segments of river, outside of the focus reach, where suitable habitats are limited or abundant, and how that may be effected by seasonal and flow-related variability in habitat selection.

Flow Metrics

We selected flow metrics that we believed were ecologically relevant. We used flow categories (i.e., steady and fluctuating) to test the relationship between used and available habitat in the context of flow (Chapter 1). We considered using these flow categories for our movement analysis (Chapter 2), however, we decided to incorporate metrics that we believe to be more biologically meaningful (i.e., 3-day mean discharge and 10-hour change in discharge). We were able to test the effect of both streamflow and season on habitat selection during spring, but not during other seasons due to limited sample size during other seasons and flow classifications. Assessing the flow influences on fish, within each season, could bring greater resolution to the generalized habitat selection patterns identified under steady and fluctuating flow. The mechanisms driving movement and habitat differences in different flow regimes is unknown, but our results indicated that flow influenced fish behavior at a sub-daily to multi-day scale. Our findings may be combined with ecology-flow relationships over broader time scales to understand the implications of altered flow and loss of natural flow variability on fish communities.

Future Research Questions

Our focus reach corresponds with the site of two-dimensional bathymetric and velocity models that are being created by the Missouri Department of Conservation, which may be integrated with our telemetry data. Pairing observed fish locations from 2016 and 2017 with models of available habitat (i.e., depth, velocity, and substrate) under a range of discharges may bridge the gap between movement and habitat selection to explore additional questions, and may include the following:

- What proportion of the focus reach is suitable habitat for Spotted Bass or Shorthead Redhorse during a given flow? Are suitable habitats connected?
- Were fish using habitat that was continuously wetted or subject to transition between dry and wetted between hydropeaking events?
- During movement rate observations, did fish move between similar or different habitat characteristics?

Additional questions to guide ecologically sustainable river management on the Osage River include:

- What functional benefits were gained in the habitats used by Spotted Bass and Shorthead Redhorse? What mechanisms directed fish behavior?
- Expand study to include additional common species on the Osage River. How relatable are habitats used by Spotted Bass and Shorthead Redhorse to other

native fishes? Identify additional feeding guilds and spawning guilds, and their associated habitat needs to incorporate in habitat suitability assessments.

- What characteristics of Spotted Bass, Shorthead Redhorse, and other fishes that have persisted within a highly flow-altered river enable them to adapt to the environment?
- How long does it take for fish to use recently submerged/connected habitat? How long does it take for recently wetted habitat to be considered available for fish to exploit?
- How do increased movement rates that are associated with highly fluctuating flows influence the bioenergetics of fish in flow-regulated rivers?

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APPENDICES

Appendix A: Habitat Selection

Flow Category Criteria

Flow categories were separated into *steady* and *fluctuating* flows based on discharge during a 24-hr period prior to each fish location. Flow was considered "steady" if the maximum and minimum discharge during the one day period of interest were within 30% of the mean flow. Conversely, we considered flows "fluctuating" when the maximum, or minimum, flow during the time period exceeded 30% of the mean discharge. In addition to 24-hr time increments with 30% discharge deviations from the mean, we also considered 10% discharge deviations and 3-day and 5-day time increments. These categories, however, resulted in the number of observations in either steady or fluctuating flow accounting for 10% or fewer observations in each category in at least one season for both species. Therefore, due to low reproducibility of flow categories during some seasons, coupled with a preliminary WAIC model comparison that ranked 24-hr discharge and 30% deviation as the best ranking model for both species (by 3 – 14 points), these alternative categories were not further considered.

Habitat Selection Distinctions

We compared the habitat (i.e., depth, velocity, submerged cover, and distance to bank) selected by Spotted Bass and Shorthead Redhorse among seasons and flow pattern. The relative probability showed how likely a specific habitat characteristic was to be used, relative to the other available options within the given season or flow. We considered the 95% credible intervals of the relative probability distribution to determine if the habitat characteristics selected by Spotted Bass or Shorthead Redhorse differed among seasonal or flow categories. In this section, we included relative probability and 95% credible intervals for select results to illustrate the differences between selected habitat traits among different seasons or flows.

We highlight the following relationships:

- Shorthead Redhorse selected different velocities among seasons (Figure A-1). Probability distribution for velocity during spring was negatively skewed with increasing likelihood of selection as velocity increased toward 1.5 m/s. During summer, probability distribution was flatter with likelihood peaking around 0.7 m/s. Distributions during fall and winter were shifted toward slower velocities with little chance of selection for velocity > 0.8 m/s.
- Shorthead Redhorse selected different depths among seasons (Figure A-2). The relative probability distribution during spring was symmetrical with the greatest likelihood of selecting depth 3.5 m. Compared to spring, the relative probability distribution of habitat selected during summer was flatter with less likelihood of selecting a specific depth. During fall, there was no selection for depth. The winter probability distribution was shifted toward shallower habitat and more narrow than the other seasons, peaking between 1.5 and 2 m.
- Spotted Bass selected different velocity and distance to the bank between steady and fluctuating flow. Both curves were skewed right, but the slope of the curve during steady flow was steeper as velocity decreased from 0.5 to 0 m/s. There was no difference in selection for depth or submerged cover (Figure A-3).

- Shorthead Redhorse selected faster velocity during steady flow and exhibited no selection for velocity during fluctuating flow. There was no difference in selection for depth, distance to bank, or submerged cover (Figure A-4).

Shorthead Redhorse

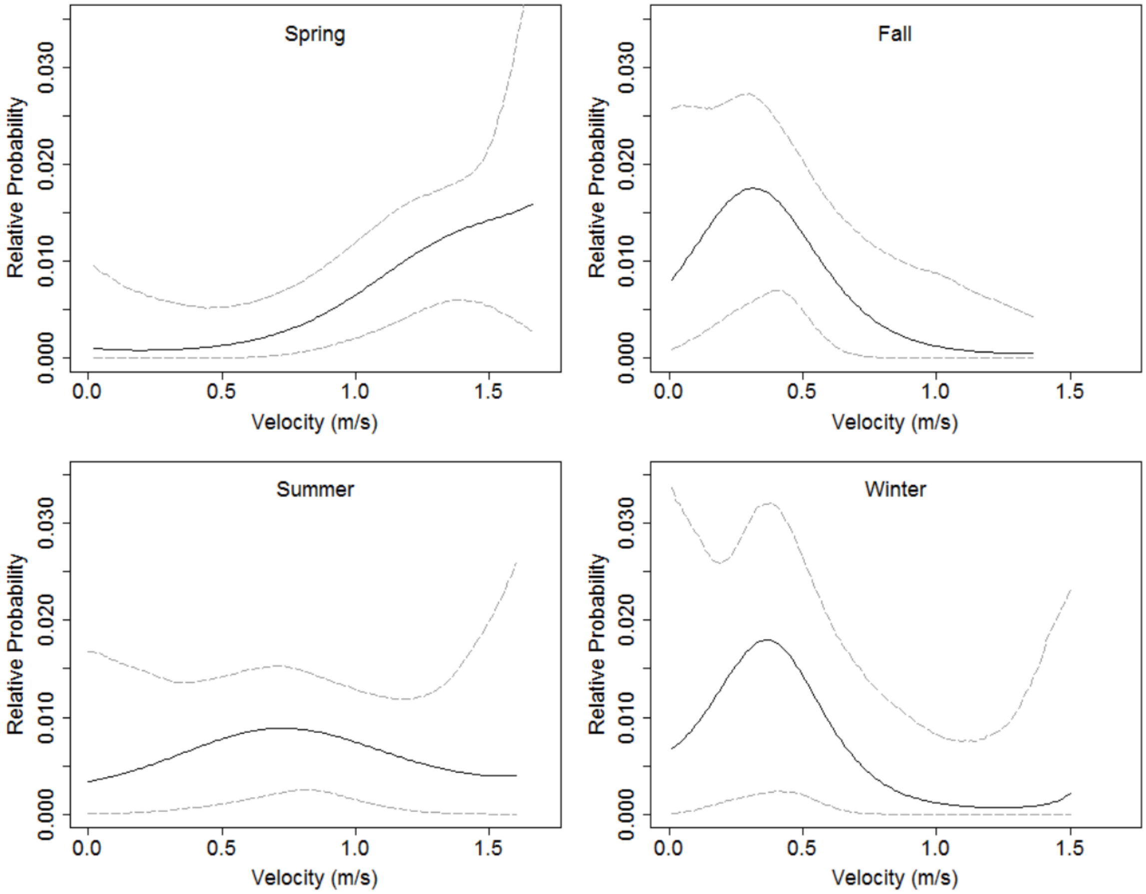

Figure A-1. Relative probability of velocity selected by Shorthead Redhorse (solid line) and 95% credible interval (dashed line) seasonally on the Osage River, Missouri.

Shorthead Redhorse

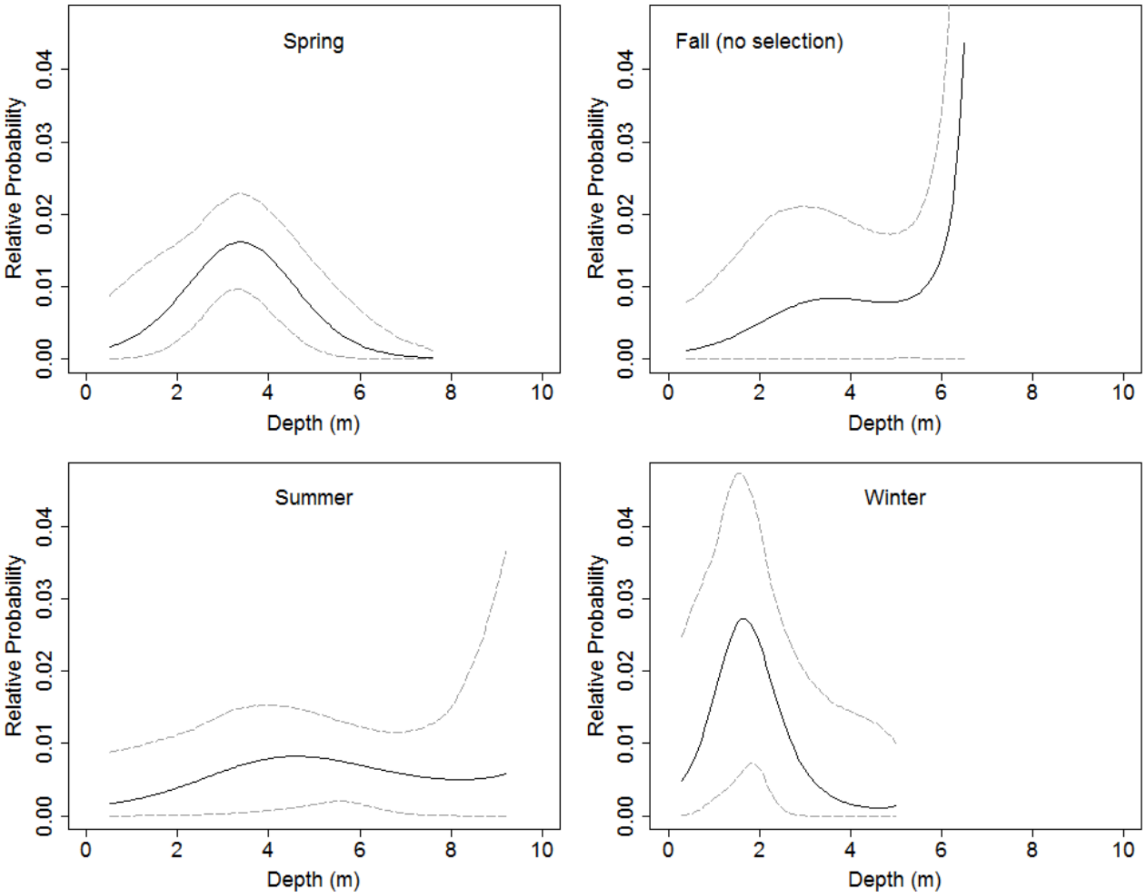

Figure A-2. Relative probability of depth selected by Shorthead Redhorse (solid line) and 95% credible interval (dashed line) seasonally on the Osage River, Missouri.

Spotted Bass

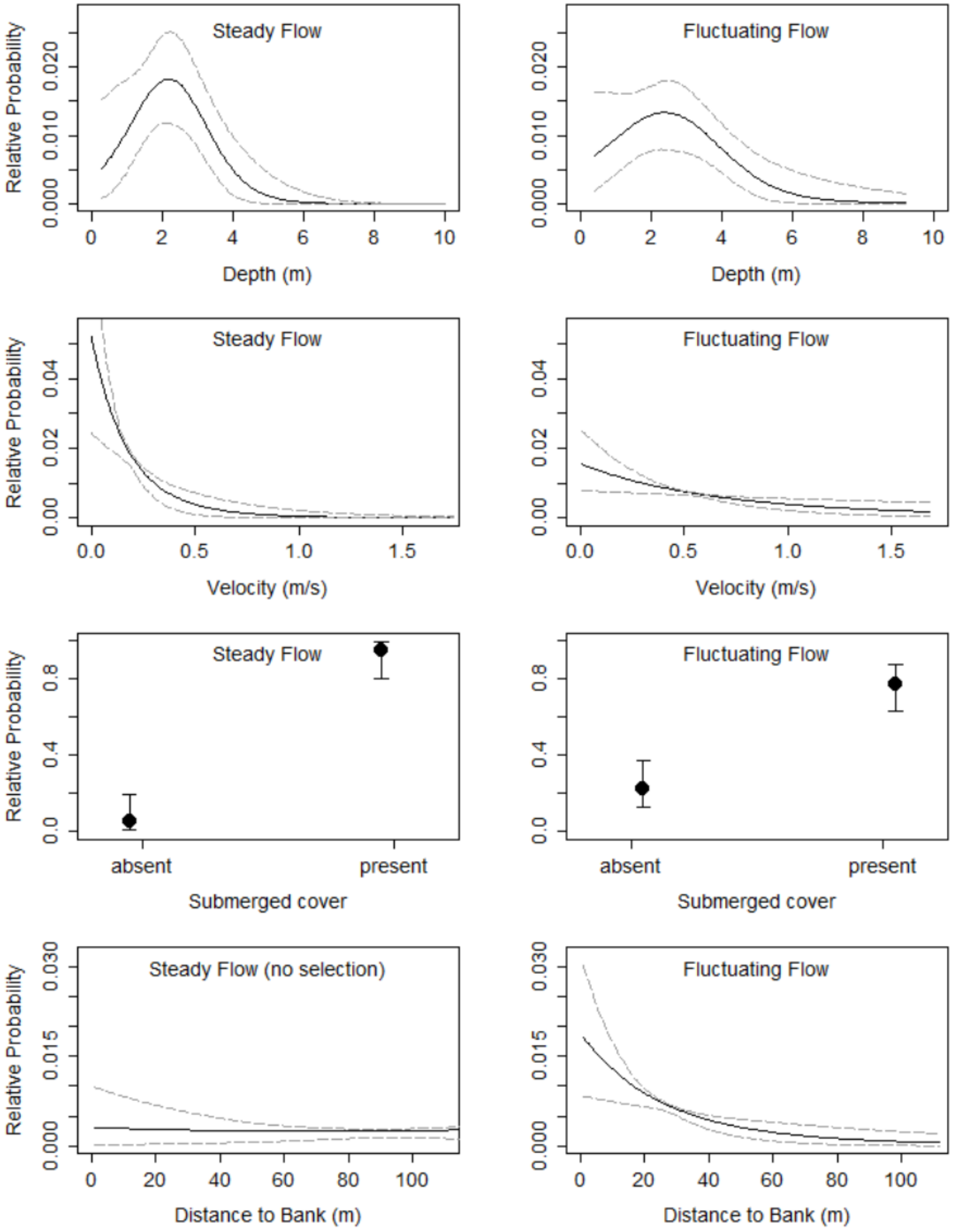

Figure A-3. Relative probability of selected velocity, depth, submerged cover, and distance to bank by Spotted Bass (solid line or black dot) and 95% credible interval (dashed line or whisker) among steady and fluctuating flow on the Osage River, Missouri.

Shorthead Redhorse

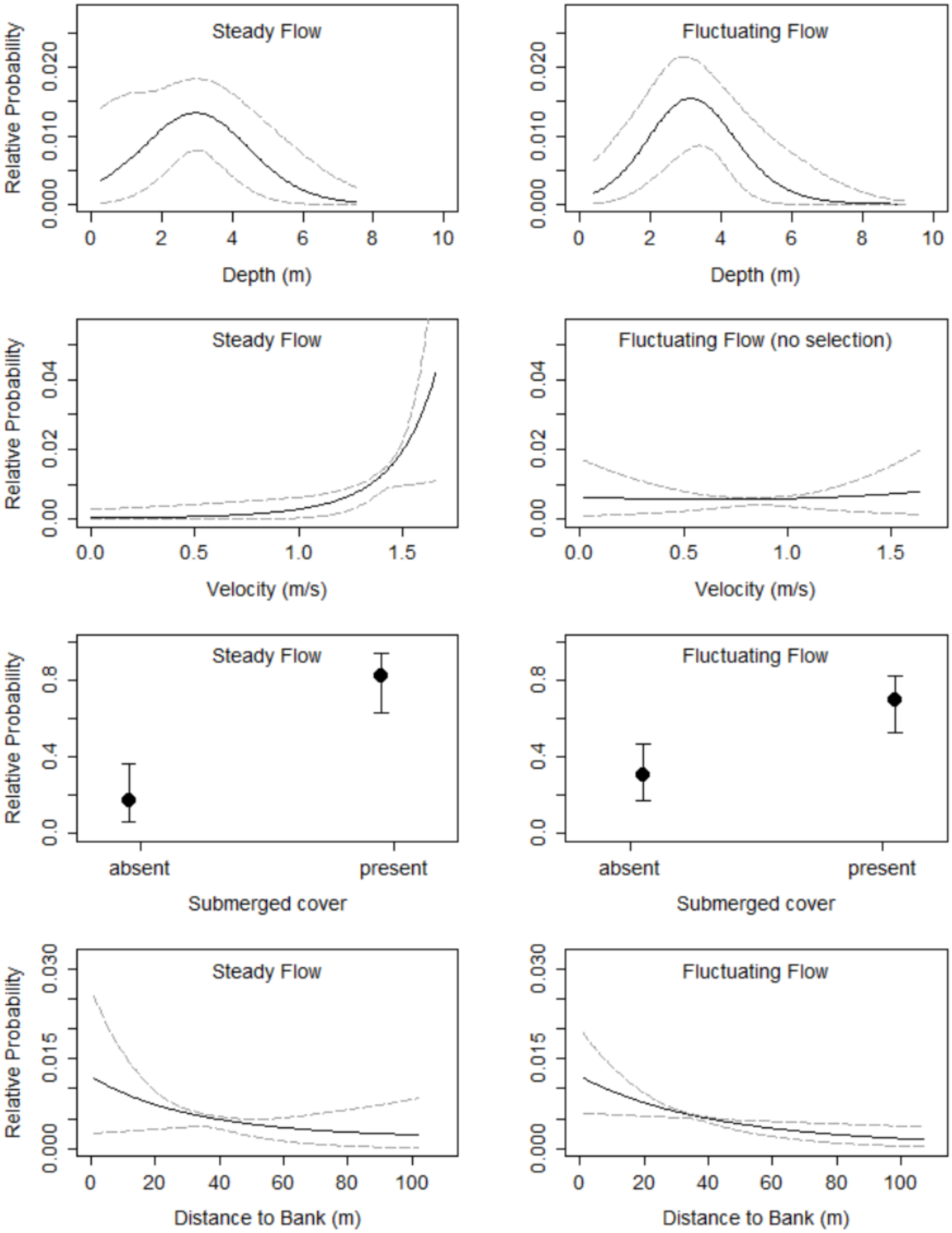

Figure A-4. Relative probability of selected velocity, depth, submerged cover, and distance to bank by Shorthead Redhorse (solid line or black dot) and 95% credible interval (dashed line or whisker) among steady and fluctuating flow on the Osage River, Missouri.

Appendix B: Movement

Although we used $Q_{\Delta 10hr}$ and Q_{3d} (Table 2-1) as flow metrics in our analysis (Chapter 2), we originally summarized flow as a categorical variable (modified from Chapter 1) to test a relationship between movement rate of Spotted Bass and Shorthead Redhorse and streamflow. We partitioned 24-hour discharge into four categories including high-steady, low steady, high-fluctuating, and low-fluctuating flow (Table B-1). Steady and fluctuating flow were determined by a 30% deviation from the mean 24-hour flow, as described in Chapter 2. Discharge greater than 283 m^3/s (10,000 ft^3/s) was considered "high" and discharge less than 283 m^3/s was considered "low", which was a natural divide based on daily flow patterns during April 2016 to June 2017. Greater movement rates by Spotted Bass and Shorthead Redhorse occurred during both high-fluctuating and high-steady flow (Figure B-1), which reiterates the importance of incorporating both flow magnitude and rate of change into movement-flow relationships. Spotted Bass had the lowest movement rates during low-steady flow.

Table B-1. Number of movement observations and unique individuals (in parentheses) of Spotted Bass and Shorthead Redhorse during each season and 24-hour flow regime on the Osage River, Missouri. Flow categories include HS=high-steady, LS=low steady, HF=high-fluctuating, and LF=low-fluctuating.

Season	Spring				Summer				Fall				Winter			
Flow	HS	LS	HF	LF	HS	LS	HF	LF	HS	LS	HF	LF	HS	LS	HF	LF
Spotted	20	0	55	26	6	11	40	2	5	5	5	17	0	5	5	18
Bass	(14)		(17)	(19)	(6)	(8)	(13)	(2)	(5)	(5)	(5)	(11)		(5)	(5)	(13)
Shorthead	10	0	30	17	3	11	28	1	4	5	4	9	0	3	2	7
Redhorse	(9)		(15)	(12)	(3)	(7)	(9)	(1)	(4)	(5)	(4)	(8)		(3)	(2)	(5)

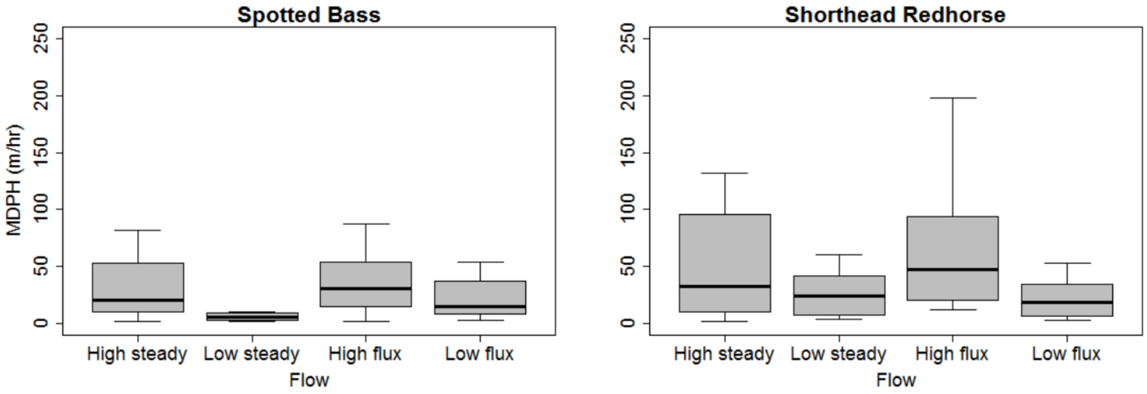

Figure B-1. Movement rates (minimum displacement per hour; m/hr) of Spotted Bass and Shorthead Redhorse during flow regimes summarized over 24-hrs in the Osage River, Missouri.

Appendix C: Conclusions

We created a visual representation of the habitat characteristics (i.e. depth, velocity, submerged cover, and distance to bank) selected by Spotted Bass and Shorthead Redhorse during spring, summer, fall, and winter on the Osage River, Missouri based on the results from habitat selection analysis (Figure C-1; Chapter 1).

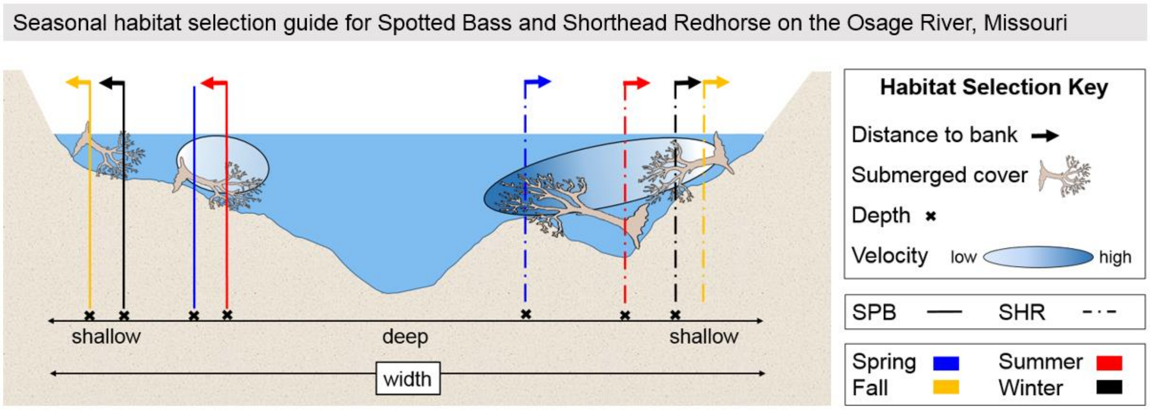
Seasonal habitat selection guide for Spotted Bass and Shorthead Redhorse on the Osage River, Missouri

Figure C-1. This diagram presents a cross-sectional view of a river illustrating the characteristics of habitat with the highest relative probability of selection by Spotted Bass (solid line) and Shorthead Redhorse (dashed line). Vertical lines only align with symbols representing habitat features selected in the given season.