Distribution, Relative Abundance, and Habitat Association of Warrior Bass *Micropterus warriorensis* in the Black Warrior Watershed, Alabama

Submitted by:

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ABSTRACT

Single season occupancy and zero inflated poisson models were used to identify relationships between Warrior Bass *Micropterus warriorensis* occurrence, relative abundance, and multiscale habitat factors. Warrior Bass distribution and relative abundance were assessed by conducting canoe and backpack electrofishing surveys. Habitat data were quantified over multiple spatial scales using existing geospatial data and stream surveys. Warrior Bass were detected in 31% stream sites and detection probability increased with sampling effort. Warrior Bass occurrence probability increased with the amount of run and rock habitat within a reach, was higher in catchments containing limestone, and lower in catchments with a higher disturbance index. Warrior Bass occurrence was higher in 2021 compared to 2020 likely due to my sampling scheme. Warrior Bass density (per m^2) decreased with increasing drainage area and was higher in catchments comprising higher percentages of limestone. Overall, Warrior Bass distribution and abundance were limited throughout the Black Warrior watershed.

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DEDICATION

I dedicate this thesis to the memory of my grandmother Mozelle Young who I promised at a young age that I would pursue a college education and follow my dreams. It is due to her unwavering love and endless support that encouraged me to pursue my master's degree and never give up on my dream of becoming a fisheries biologist.

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LIST OF ABBREVIATIONS OR SYMBOLS

ADCNR	Alabama Department of Conservation and Natural Resources
ALB	Alabama Bass
BP	Backpack Electrofishing unit
CI	Confidence interval
GADNR	Georgia Department of Natural Resources
IUCN	International Union for Conservation of Nature
LBWR	Lower Black Warrior River
LDI	Landscape Disturbance Index
LFR	Locust Fork River
LMB	Largemouth Bass
LWD	Large Woody Debris
MFR	Mulberry Fork River
MSW	Mean Stream Width
NASS	National Agricultural Statistics Service
NBBI	Native Black Bass Initiative
NHD Plus HR	National Hydrography Dataset Plus High Resolution
gSSURGO	Gridded Soil Survey Geographic Database
QQ	Quantile plot
SD	Standard Deviation
SE	Standard Error
SFR	Sipsey Fork River
SMB	Smallmouth Bass
SSA	Species Status Assessment
UBWR	Upper Black Warrior River
USA	United State of America
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
WB	Warrior Bass
WBH	Warrior Bass X Alabama Bass Hybrid
ZIP	Zero Inflated Poisson Model

INTRODUCTION

The southeast United States possesses the richest diversity of freshwater fishes compared to areas of comparable size in North America (Warren et al. 2000; Jelks et al. 2008). Unfortunately, a high proportion of these fishes are imperiled due to human disturbances associated with introduction of non-native species (e.g., predation, competition, and hybridization) and habitat degradation (Lenat and Crawford 1994; Noss and Peters 1995; Noss et al. 1995; McKinney and Lockwood 1999). This is especially true for obligate lotic species as these systems are some of the most threatened in the world (Noss and Peters 1995; Noss et al. 1995; Jelks et al. 2008). Channelization, impoundment, sedimentation, and flow alteration are all common stream modifications that have led to the decline of many freshwater fishes in the southeast (Warren et al. 2000). These modifications have increased the decline of species with limited ranges and made them more vulnerable to extirpation (Warren et al. 2000). Although many of these fishes are vulnerable to extirpation, there is little information about their distribution, abundance, and resource requirements.

Black bass *Micropterus spp.* reflect the diversity trends of the southeastern United States where 10 of the 13 described species and subspecies are endemic to this area: Alabama Bass *M. henshalli*, Cahaba Bass *M. cahabae*, Chattahoochee Bass *M. chattahoochae*, Guadalupe Bass *M. treculi*, Redeye Bass *M. coosae*, Shoal Bass *M. cataractae*, Neosho Bass M. velox, Suwannee Bass *M. notius,* Tallapoosa Bass *M. tallapoosae*, Warrior Bass *M. warriorensis* (Hubbs and Bailey 1940; Baker et al. 2013; Freeman et al. 2015; Taylor et al. 2019). Several of these black bass species are newly described, have small ranges, and have never been studied. Basic information such as distributional patterns, status, and threats are lacking for many of these species. Southeastern endemic black basses face many of the same challenges as other narrowrange endemic freshwater fishes (Birdsong et al. 2015; Curtis et al. 2015; Leitner and Earley 2015; Nagid et al. 2015; Sammons et al. 2015; Tringali et al. 2015;). The notion that black bass need conservation action is relatively new, as these species have historically been viewed as ubiquitous and tolerant to environmental perturbations (Shaw 2015).

The Native Black Bass Initiative (NBBI) was formed to address conservation needs of endemic black basses and to support long-term species persistence (Birdsong et al. 2015). The initial plan was adopted by the National Fish and Wildlife Foundation as a keystone initiative to address conservation needs of Guadalupe Bass in the Edwards Plateau ecoregion in Texas, Redeye Bass in the Savannah River basin in Georgia and South Carolina, and Shoal Bass populations in the Apalachicola River watershed of Alabama, Florida, and Georgia. These species were chosen for the initial focus due to their limited ranges, loss of habitat, and the introduction of non-native species (Koppelaman and Garrett 2002; Tringali et al. 2015). However, this plan will likely be expanded to include other species as they are discovered or described (Baker et al. 2013; Taylor et al. 2019).

Described by Hubbs and Bailey (1948), Redeye Bass is one of the least studied species within Micropterus. Redeye Bass is a diminutive species compared to other *Micropterus* spp. and are typically associated with low order rocky streams (Leitner and Earley 2015). In general, this species is considered intolerant of impoundments; however, populations in the Savannah River basin, known as Bartrams Bass *Micropterus sp. cf. cataractae*, have persisted in reservoirs following impoundment but are currently threatened by extirpation through hybridization with the non-native Alabama Bass (Barwick et al. 2006; Bangs et al. 2018; Judson 2018). Historical distribution of Redeye Bass ranged from the upper Savannah River and Altamaha River basin, in Georgia-South Carolina to the upper Mobile basin in Alabama (Hubbs and Bailey 1940).

However, in 2013 Redeye Bass from the Chattahoochee and Mobile River basins were elevated to five new species (i.e., Cahaba Bass, Redeye Bass, Chattahoochee Bass, Tallapoosa Bass, and Warrior Bass) with each species occurring in a single catchment (Baker et al. 2013). The relatively small ranges occupied within each basin raised concerns regarding higher risks of imperilment (Taylor et al. 2019). To properly address conservation needs of these recently described Redeye Bass species, basic distribution and the associated environmental factors related to both occurrence and abundance of these fish need to be determined.

Warrior Bass is found above the fall line within the Black Warrior watershed, Alabama (Figure 1.1). Their appearance is very similar to the other species within the Redeye Bass group and are popular among the angler community due to the unique fishing opportunities they provide. However, little is known about their distribution, status, and life history. Thus, before any management actions can be reasonably directed, resource managers need a better understanding of Warrior Bass distribution and relative abundance and how these factors are shaped by both habitat and human disturbances. Understanding these relationships will allow resource managers to identify areas within the watershed that could be prioritized for conservation and management of the fisheries. The objectives of my study are to: 1) determine the multiscale factors related to the distribution of Warrior Bass, and 2) assess the relationships between Warrior Bass relative abundance and hierarchical landscape factors. Identifying the multiscale habitat factors related to the distribution and relative abundance of Warrior Bass will help managers identify their range and understand the physicochemical factors important to the success of Warrior Bass.

STUDY AREA

The Black Warrior watershed drains 16,555 km^2 in central and western Alabama and is the largest watershed contained within Alabama (Black Warrior River Clean Water Partnership 2003; Figure 1.1). The Black Warrior River flows south through Alabama from the confluence of the Locust and Mulberry Fork rivers. Downstream, the Black Warrior River merges with the Tombigbee River near Demopolis, Alabama and then flows ≈343 km before terminating in the Gulf of Mexico. The Black Warrior River has four lock and dam structures (i.e., John Hollis Bankhead, Holt, William Bacon Oliver, and Warrior) and many of the tributaries of the Black Warrior River are impounded. Average annual precipitation in the Black Warrior watershed is approximately 1.37 m and average air temperature ranges from 15-17 °C (Black Warrior River Clean Water Partnership 2003). Land use in the Black Warrior watershed comprises 75% forested, 16% agriculture, and 9% urban (CropNASS dataset). Major catchments of the Black Warrior watershed include the Sipsey Fork River (SFR), Mulberry Fork River (MFR), Locust Fork River (LFR), Upper Black Warrior River (UBWR) and Upper Black Warrior River (LBWR; Figure 1.2). Four catchments of the Black Warrior River (i.e., SFR, MFR, LFR, and UBWR) are contained within the Cumberland Plateau physiographic region (Boschung and Mayden 2004). Terrain in this region is mountainous with steep sided valleys and gorges (Carter-North 2005). Below the Cumberland Plateau physiographic region is the Coastal Plain physiographic region, separated by the fall line, which is the transition between the upland physiographic regions to the costal plain. The LBWR catchment is entirely contained in the Coastal Plains physiographic region. Streams in this region are characterized by sandy substrates with gravel riffles separating pools (Boschung and Mayden 2004; Carter-North 2005).

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FIGURES

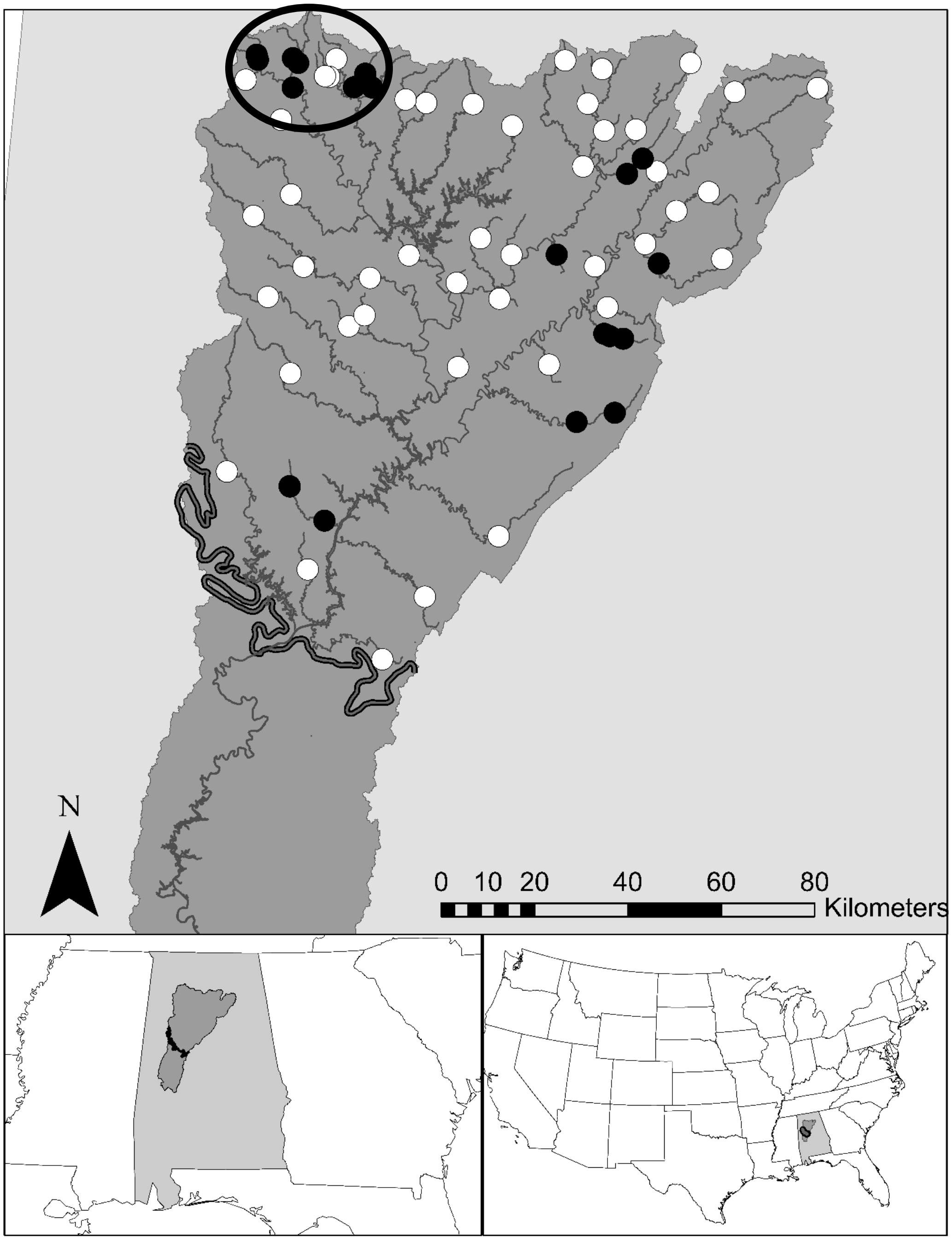

Figure 1.1. My study area within the Black Warrior watershed of Alabama. Black circles are sites where Warrior Bass was detected and white circles are sites where Warrior Bass was not detected. The fall line is represented by the dark gray, thicker line. Large black circle in top left corner of map is Bankhead National Forest.

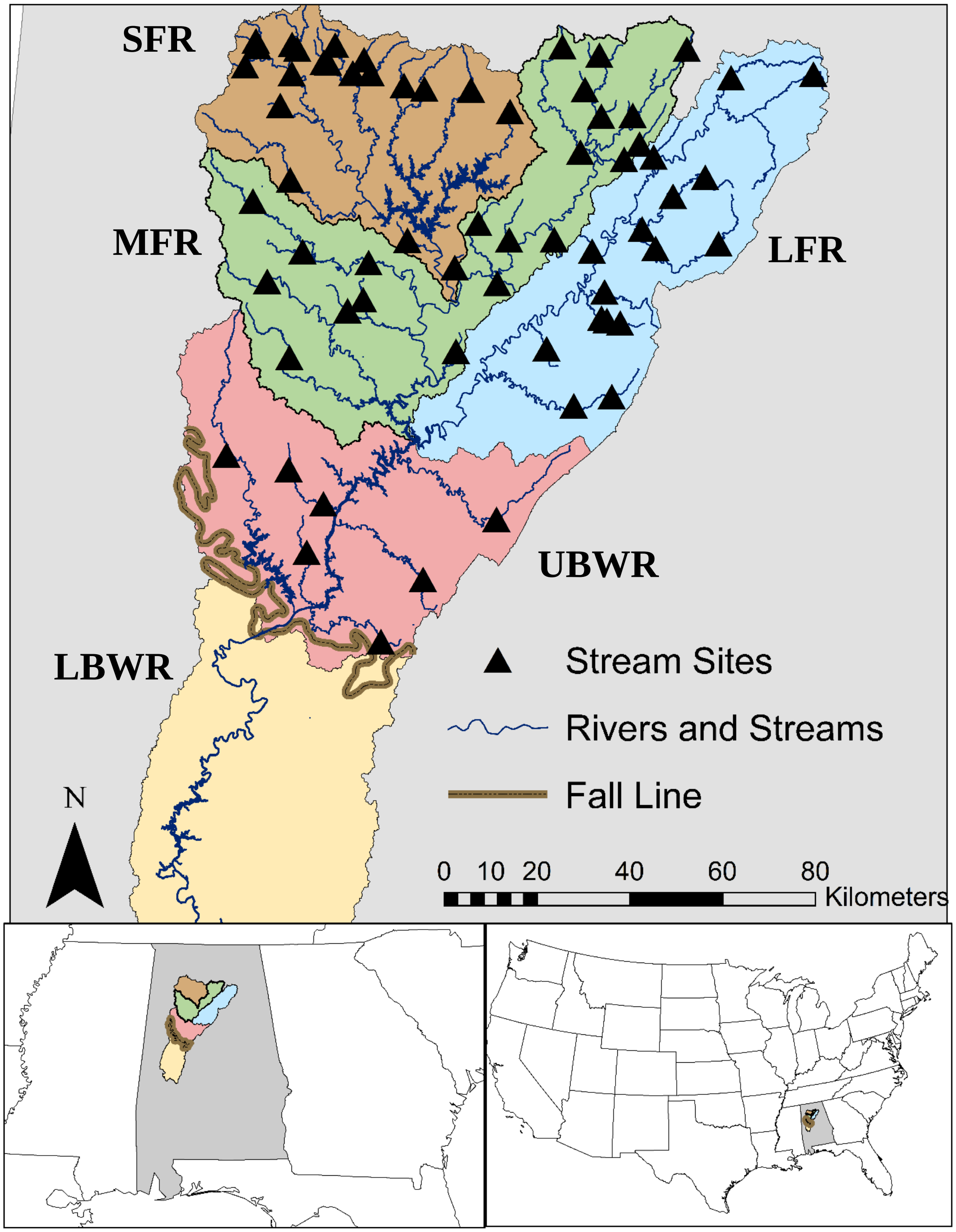

Figure 1.2. Sites (i.e., stream reaches) sampled in 2020 and 2021 from catchments in the Black Warrior River watershed, Alabama. Catchments include the Sipsey Fork River (SFR), Mulberry Fork River (MFR), Locust Fork River (LFR), Upper Black Warrior River (UBWR), and the Lower Black Warrior River (LBWR).

CHAPTER II

THE DISTRIBUTION AND MULTISCALE HABITAT ASSOCIATIONS OF WARRIOR BASS

INTRODUCTION

Information on the distribution and associated habitat of a species can be used to identify areas for conservation or management (Dauwalter and Rahel 2008). Distribution data are valuable for identifying habitat refuge, conservation status of a species, and areas for habitat restoration and reintroductions (Bearlin et al. 2002; Wall et al. 2004; Kelly 2021). Filipe et al. (2004) used distribution and landscape data paired with a conservation derived value for native freshwater fish to select reserves in the Guadiana River Basin, Spain. Wall et al. (2004) used distribution, status, and habitat associations of Topeka Shiners *Notropis topeka* to suggest areas for restoration and reintroduction in South Dakota. More recently, a hierarchical framework has been used in distributional studies and has been proven to be beneficial to how we manage and conserve stream reaches. For example, Brewer et al. 2007 used multiscale habitat factors to provide fishery managers with information on Smallmouth Bass fishery potential for every stream reach in Missouri. Overall, distributional studies are valuable for identifying environmental factors associated with a species and can result in more informed management and conservation decisions.

Riverine freshwater fishes are influenced by a variety of environmental factors operating at multiple spatial and temporal scales. These environmental factors occur in a hierarchal framework that shapes local stream habitat (Hynes 1975; Frissell et al. 1986; Ward 1989). Coarse-scale factors such as climate and geology constrain patterns at finer spatial scales (i.e., segment, reach, channel-units) and influence the structure, chemistry, temperature, and productivity of streams (Hynes 1975; Ward 1989). Including multiscale habitat factors in studies can account for the hierarchal structure (i.e., nestedness) of streams and provide more insight into environmental factors that are important for fish distribution (Durance et al. 2006). If multiscale habitat factors are not included, then key relationships between fish and their habitat may be missed resulting in incomplete or misleading information that could hinder the effectiveness of management and conservation of those fish species. For example, stream reach restoration efforts may not be effective if larger scale habitat factors such as land use are influencing local stream habitat. Therefore, multiscale habitat factors should be included in distributional surveys in order for managers to make effective management and conservation decisions.

Human disturbances can shape freshwater fish distributions. Because of the hierarchical nature of streams, these disturbances can initiate a complex cascade of changes that can alter steam habitat across multiple spatial and temporal scales (Hynes 1975; Frissell et al. 1986; Ward 1989; Harding et al.1998; Foster et al. 2003). For example, deforestation in watersheds from agriculture and urban land use can result in stream reaches with decreased base flows and increased sediment loads (Allan et al. 2003;Allan 2004). With a growing economy, increased amounts of urban and agricultural land use commonly threaten many freshwater fish. Watersheds with urban and agricultural land uses are typically characterized by increased sedimentation and nutrient loads, and have altered flow and temperature regimes (Allan 2004). Stream fish assemblage in watersheds dominated by agriculture and urban land use typically have lower fish diversity and abundance compared to less disturbed streams (Allan et al. 1997; Wang et al. 1997; Argent and Carline 2004). However, the amount of agriculture and urbanization within a catchment prior to degradation of the fish assemblage is variable (Wang et al 1997; Argent and Carline 2004; Moerke and Lamberti 2006; Utz et al. 2010). Furthermore, urbanization appears to degrade aquatic habitats and associated fish assemblages at relatively low amounts of the catchment compared to agriculture (Paul and Meyer 2001; Brewer and Rabeni 2011). For instance, Brewer and Rabeni (2011) found that catchments in Missouri with an average of 22% urban land use had lower densities of Smallmouth Bass *Micropterus dolomieu* compared to streams from catchments with intense agriculture (i.e., 82%). Similarly, Wang et al. (1997) reported Wisconsin watersheds with only 20% urban land use had lower biotic integrity compared to streams in watersheds with 80% agriculture. Thus, quantifying disturbances caused by land uses in catchments is important when investigating the current distribution of fish.

Redeye Bass was described by Hubbs and Bailey (1948) and is one of the least studied species within the black bass genus. In 2013, Redeye Bass from the Chattahoochee and Mobile River basins were split into five species, (i.e., Cahaba Bass, Chattahoochee Bass, Tallapoosa Bass, Redeye Bass, and Warrior Bass) with each species now occurring in a single watershed (Baker et al. 2013). This resulted in each putative species occupying relatively small ranges within each basin including the Warrior Bass, found above the fall line within the Black Warrior watershed, Alabama (Boschung and Mayden 2004). However, developing meaningful conservation plans are hindered by the lack of information relative to how and why Warrior Bass are currently distributed. Therefore, my study objective was to determine the multiscale factors related to the current distribution of Warrior Bass throughout the Black Warrior watershed. Results of this study will provide resource managers with the tools needed to identify areas within the Black Warrior watershed that would benefit from protection or conservation actions for the restoration of Warrior Bass populations.

METHODS

Site Selection

Warrior Bass were sampled from stream reaches located above the fall line in the Black Warrior watershed to estimate the current distribution of Warrior Bass (Table A1; Figure 2.1). Because Redeye Bass are generally not found in Coastal Plain streams (Boschung and Mauden 2004, Leitner and Earley 2015; Thompson 2021), these streams were not included in the study to increase geographical coverage within their expected range. Streams were haphazardly chosen and stratified across the major catchments to ensure complete coverage across Warrior Bass range (Figure 2.2). Specific streams were chosen using historical collection data (Boschung and Mayden 2004; Baker et al. 2013) and angler reports; and overall, selected stream reaches included a range of geomorphology, stream sizes, and disturbances that were hypothesized to be important to Warrior Bass distribution and habitat use. Some stream reaches could not be sampled due to lack of access or sampling gear restrictions (i.e., Sipsey Wilderness Area). Further, larger rivers such as the Locust Fork, Mulberry Fork, and Black Warrior River were not sampled due to gear and access limitations.

Study Design and Fish Sampling

Streams reaches (i.e., the length of stream between the start of the first transect and end of the last transect) were sampled using canoe and backpack electrofishing. Mean stream width (MSW) was determined at the start of each stream site by measuring the wetted width of the stream five to seven times within the first 50 m of the site using a range finder (Leupold, Beaverton, Oregon). At each site, 2-5 spatially replicated transects (hereafter surveys) were sampled using canoe or backpack electrofishing gear. The beginning of each channel unit was used to mark the start and end of each survey. All surveys were separated longitudinally by at least 10 MSW to maintain independence. Because it was not feasible to accurately measure long surveys in non-wadeable streams, I attempted to standardize surveys lengths via shocking time. Timed length for canoe surveys were determined by multiplying MSW by 90 sec and dividing by 60 to obtain length in minutes (Thompson 2021). Canoe sampling was conducted using a DC electrofishing unit and a hand-held anode, powered by a 2000-Watt Honda generator (Katechis 2015) and were sampled while moving downstream, alternating from left to right bank to target available habitat. Shallow sections of streams that required wading during the canoe survey were sampled by using the canoe as a barge. Wadeable streams that were too shallow for canoe shocking were sampled with one (≤ 6 m MSW), two (7 – 11 m MSW), or three (≥ 12 m MSW) Smith Root LR-24 backpack units (Vancouver, Washington). Backpack electrofishing reaches were sampled over a standard distance of 40 MSW which was expected to adequately sample available habitat (Lyons 1992; Simonson and Lyons 1995; Temple and Pearsons 2007). All black basses collected in each survey were identified, weighed (g), measured for total length (mm), fin clipped for genetic analyses, and released downstream. Species identifications were updated later from genetic results to omit hybrid Warrior Bass from my analyses.

Physicochemical Conditions

Channel units (i.e., pool, riffle, run, shoal) were defined following the general classification of Rabeni and Jacobson (1993). Pools were classified as relatively deep-water depositional areas, lower gradients, typically slower velocities, and finer substrates. Riffles were classified as shallower areas with faster velocities, higher gradients, and coarser substrates compared to surrounding channel units. Transitional areas with intermediate velocities, depths, and coarser substrates were classified as runs. Shoal, not defined by Rabeni and Jacobson (1993), were a complex mosaic of relatively shallow sections of stream with small cascades and deep to moderate micro-pools, with large sheets of bedrock (Cottrell 2018).

Covariates that were hypothesized to relate to Warrior Bass detections were measured at each stream survey (Table 2.1). I measured conductivity µS and water temperature ºC using a Hanna Combo pH and EC meter. Conductivity was measured to account for the variability in capture efficiency with electrofishing gear (Hill and Willis 1994; Reynolds and Kolz 2012). Also, water temperature was collected because fish are more active in warmer water which could increase their ability to escape the gear make them harder to detect (Reynolds and Kolz 2012). Because water clarity is related to fish detection, I also measured turbidity using a SPER Turbidity meter (Scottsdale, AZ; Price and Peterson 2010; Reynolds and Kolz 2012). Water samples for the turbidity meter were collected upstream of any previously disturbed stream section. Large woody debris (LWD) was visually assessed because increased amounts of LWD could reduce detection probability (Thurow et al. 2006). Scoring criteria for LWD was derived based on similar metrics found in the Georgia Stream Team Protocol (Table A2; Thompson 2021). Briefly, lower LWD scores represented little to no wood in the survey and higher scores represented stream surveys with multiple complexes of LWD in the stream. A SpeedTech Depthmate Portable Sounder (Great Falls, VA) was used to estimate maximum pool depth. Capture efficiency using electrofishing gear can be reduced when water is deep (Reynolds and Kolz 2012). Effort (seconds) was recorded in each survey because detection probability can increase with the amount of sampling time (Kelly et al. 2021).

Site- and survey- occupancy covariates were collected to determine multiscale habitat factors associated with Warrior Bass occurrence (Table 2.1). Bank stability and bank vegetative cover were visually assessed and scored in each survey based on the Georgia Stream Team Protocol (Table A3 and A4; GADNR Stream Team 2005). Briefly, stream banks with little erosion and large quantities of diverse vegetative cover received higher scores (5-10) while banks with increased erosion (>50%) and little vegetative cover received lower scores (1-4). Rock and LWD composition were also scored for each survey and scores were derived from similar metrics found within the Georgia Stream Team Protocol (Table A5). Rock and LWD habitat are commonly associated with black bass presence and abundance in streams (Early and Sammons 2015; Thompson 2021). Additionally, bank stability and vegetative cover were measured because sediment loads in streams are related to unstable banks (Rosgen 2001). All scores were then averaged across surveys to get an overall score for each reach. Percent of each channel unit type was visually estimated in each survey and averaged to represent the general channel unit distribution for the stream reach. Lastly, pH was measured but not used in this study because it was a point-in-time measurement and was uninformative.

I used the National Hydrography Dataset Plus High Resolution (NHD Plus HR) to calculate several reach- and stream segment (i.e., stream section between two second order tributary confluences) occupancy covariates (Moore et al. 2019). Sinuosity, stream order, and gradient, were measured at the segment scale to obtain reliable measurements (Strahler 1957; Gordon et al. 1994) but were applied to each sample reach. Sinuosity was measured because sinuous streams create more heterogeneous habitat (Rabeni and Jacobson 1993). Stream order was used as an indicator of stream size. Stream gradient was obtained to estimate relative steepness (Gordon 1994). Drainage area (km^2) was calculated upstream of each site. Drainage area is correlated with the two year flood return interval within streams (Gordon 1994) and is also an indicator of network position. Downstream link magnitude (D-link) was also calculated to reflect stream network (Osborne and Wiley 1992). For instance, streams with similar drainage areas can have lower or higher D-link values depending on their location in the drainage network.

I calculated the proportion of lithology and hydrological soil groups within each drainage area using the United States Department of Agricultural National Resources Conservation Service Gridded Soil Survey Geographic Database (USDA NRCS gSSURGO) and Preliminary Integrated Geologic Map Databases for the United States (Dicken et al. 2005; USDA NRCS 2012). I measured lithology and hydrological soil groups because they can influence water chemistry, nutrients, and groundwater infiltration (Hynes 1975). Land-use proportions were calculated (i.e., forested/natural, agriculture/cropland, or developed/urban) for the floodplain and drainage area of each reach using the USDA Crop National Agricultural Statistics Service dataset (USDA 2017).

Following simplified methods of Brown and Vivas (2005), I calculated a disturbance index from land-use proportions. The disturbance index was calculated by simplifying the Brown and Vivas (2005) landscape development intensity index (LDI) into three main land-use categories: forested/natural (1.00), agriculture/cropland (3.91), and developed/urban (7.86; Table A6). For example, when multiple categories for a land-use type existed such as: woodland pasture (2.02), improved pasture (without livestock; 2.77), improved pasture-low intensity (with livestock; 3.41), improved pasture-high intensity (with livestock; 3.74), row crops (4.54), and agriculture (high intensity; 7), these categories were averaged to get a single value for each land use category. Coefficients for the disturbance index ranged from 1 to 10 with higher values indicating increased disturbance.

Lastly, I calculated dam metrics using the Southeast Aquatic Barrier Inventory (SARP 2021) because of their hypothesized influence on stream fishes and habitat. Dams disrupt the natural flow regime and degrade channel morphology (Poff and Zimmerman 2010; Angus Webb et al. 2013), so I hypothesized that dams could have cumulative effects on Warrior Bass distribution. Therefore, I calculated the number of dams ≥ 10ft in the drainage area by using the spatial join tool and manually measured the distance to the nearest downstream dam (i.e., ≥10ft) for each reach using the measuring tool.

Data Analysis:

I used spatial replicates to develop a single-species, single-season, occupancy model to determine the environmental factors influencing Warrior Bass occurrence while accounting for incomplete detection (MacKenzie et al. 2002). Temporally or spatially replicated surveys are needed to differentiate detection based on gear inefficiencies and true occupancy of the species (MacKenzie et al. 2002, MacKenzie et al. 2006). Spatially replicated surveys are often used in large scale occupancy studies when logistical challenges and financial costs are involved and serve as acceptable surrogates for temporal replication (Srivathsa et al. 2017; Charbonnel et al. 2017; Kelly et al. 2021; Reid et al. 2021). However, spatial replicates are to be used with caution because they can bias occurrence and detection probabilities estimates (Mackenzie and Royle 2005; Kendall and White 2009). Spatial replicates can create dependency among surveys and introduce a positive or negative bias in the detection estimates if dependency is not tested and accounted for using a trap response (Kendall and White 2009; MacKenzie et al. 2006; Mollenhauer et al. 2018). Spatial replicates were used in this study because the goal of the study was to maximize geographical coverage of the expected Warrior Bass range, most of which was characterized by rugged terrain with difficult access.

I designed the study to ensure I met the assumptions of occupancy modeling: 1) occupancy status at a site does not change over the study season (i.e., summer); 2) occurrence probability is constant across sites or covariates are used to explain differences in occupancy probability; 3) detection probability is constant across all sites or differences in detection probability are explained using covariates; and 4) detection histories are independent. The first assumption was met by conducting the study from May to August to make sure that Warrior Bass occupancy status did not change at each site (e.g., springs floods and changing water temperatures). The second and third assumptions were met by including covariates to explain differences in occurrence and detection probabilities. The fourth assumption was satisfied by including a trap response in my model set (Kendall and White 2009; Mollenhauer et al. 2018).

Prior to developing the detection model, I transformed my data, examined correlations, and standardized detection covariates. All detection covariates were $\log_{10}$-transformed to reduce skewness. I checked for multicollinearity among my continuous covariates using Pearson's correlation coefficients and none of the variables were correlated $|r| \geq 0.50$ so all were retained for modeling (Table 2.1). Continuous covariates were standardized to a mean of zero and standard deviation of one to help with model convergence and to improve model interpretation (Gelman and Hill 2007).

Next, I built a detection model while holding occupancy constant (i.e., at one). I did this using the "unmarked" package in statistical software R (Fiske and Chandler 2011). I used only 1 covariate in the detection model because of small sample size and needing more degrees of freedom to be available for explaining occurrence. The final detection model included effort. The detection model could be expressed as:

$$logit(p_{ij}) = \beta_0 + \beta_{Effort[ij]}$$

$$for\ i = 1, 2 \ldots N\ for\ j = 1,2 \ldots J$$

Where p_{ij} is the probability of detecting Warrior Bass at site i in survey j. β_0 is the grand intercept representing the detection probability of Warrior Bass at mean levels of effort and $\beta_{Effort[ij]}$ is the slope for effort.

I transformed my data, examined preliminary plots, checked for correlations, and standardized my continuous occurrence covariates before fitting my occurrence model. In order to reduce skewness, I $\log_{10}$ transformed shoal%, riffle%, segment slope, drainage area, and large woody debris (Gelman and Hill 2007). After transformations, LDI, limestone proportions, and hydrological soil group D were still highly skewed. Therefore, these covariates were converted to categorical variables based on natural breaks in the data: LDI was a two-level categorical variable with low LDI ≤ 2 and high LDI > 2 in the drainage area, limestone proportions (≤ 0.1 = low, > 0.1 = high), and hydrological soil group D (≤ 0.4 = low, > 0.4 = high). Segment sinuosity, percent shoal, downstream dam distance, and floodplain disturbance index were not used in the analysis because of low variation among streams (Table 2.4). Covariates were examined for multicollinearity and independence as described above for the detection model (Table 2.3). Continuous covariates were then standardized to a mean of zero and standard deviation of one (Gelman and Hill 2007). Covariates retained after Pearson's correlation test included riffle, run, rock, drainage area, drainage area disturbance index, limestone, soil group D, and year (Table 2.3).

I used all subsets analysis to select the top occurrence model while holding my final detection model constant. Prior to running an all subset analysis, I tested for a quadratic term for rock and an interaction between rock and drainage area in the global model. Neither the quadratic term nor interaction were significant and therefore were not included in the all subsets analysis. I then ran an all subsets analysis of the global occurrence model using the MuMIn package in statistical software program R. The global model occurrence could be written as:

$$logit(\psi_{ij}) = \beta_0 + \beta_{run[ij]} + \beta_{riffle[ij]} + \beta_{rock[ij]} + \beta_{Area[ij]} + \alpha_{D[ij]} + \alpha_{DI[ij]} + \alpha_{Lime[ij]} + \alpha_{year[ij]}$$

$$for\ i = 1, 2 \ldots N\ for\ j = 1,2 \ldots J$$

Where ψ_{ij} is the occurrence probability of Warrior Bass at site i in survey j. β_0 is the grand intercept. β_{run}, β_{riffle}, β_{rock}, β_{Area} are the slopes for run%, riffle%, rock score, and drainage area. $\alpha_D + \alpha_{LDI} + \alpha_{Lime} + \alpha_{year}$ are the factors for soil group D, drainage area, LDI limestone proportions in the drainage area, and year. I ranked the models using AICc. Any model within 2 AICc values of the top model was considered to have equal support.

After the top model was selected, I tested for a trap response, and checked my model fit and over dispersion. Two types of trap responses were assessed to determine if there was dependency between reaches. The first trap response tested if fish were being pushed into subsequent reaches by sampling gear. The second trap response tested if Warrior Bass was detected in a prior reach, then would the species be detected in subsequent reaches due to increased sampling. Model fit was assessed using the MacKenzie and Bailey (2004) chi-squared goodness of fit test to calculate a ĉ; values ranging from 1.00 to 1.02 are considered acceptable values. Values of ĉ higher or lower than 1.02 and 1.00 suggest the model is over or under dispersed and has a lack of fit (MacKenzie and Bailey 2004).

RESULTS

I sampled 70 stream sites and 57 streams above the fall line in the Black Warrior watershed (Table A7). Forty-eight stream sites were sampled in 2020 and 22 stream sites were sampled in 2021. Stream surveys ranged approximately 60 - 672 m and stream reaches ranged 400 – 14,700 m (Table 2.4); MSW ranged from 3 to 25.5 m. Of the 70 stream sites sampled, 29 were sampled with canoe electrofishing gear and 41 were sampled with backpack electrofishing gear; 31% of sites sampled were in the Sipsey Fork catchment, 31% were in the Mulberry Fork catchment, 24% were in the Locust Fork catchment, and 14% were in upper Black Warrior catchment. Warrior Bass were detected at 22 of 70 stream sites sampled in the Black Warrior watershed. Catchments with the highest Warrior Bass detections were the Sipsey Fork (9 of 22 sites) and Locust Fork (7 of 22 sites), but Warrior Bass were detected at 3 of 22 sites in both the Upper Black Warrior River and Mulberry Fork catchment. Warrior Bass detections in the Sipsey Fork catchment all occurred in Bankhead National Forest streams.

Physicochemical conditions of reaches and sites varied among streams in the Black Warrior watershed (Table 2.4). Stream order ranged 2-5 and drainage areas ranged 1.62-405.75 km^2 across stream sites. Streams sampled in the Locust Fork catchment were characterized by rockier habitat (average rock score of 7.8) than the streams in the Mulberry Fork catchment (average rock score of 6.07). Channel-unit distribution within stream sites was generally similar among catchments, but those in the Locust Fork and Upper Black Warrior River catchments had more shoal habitat (Table A8). Average soil group D was highest in drainage areas of streams in the Sipsey Fork catchment and lowest in drainage areas of streams in the Locust Fork catchment (Table A8). The Locust Fork catchment generally had higher limestone proportions than the other three catchments (Table A8). Stream sites in the Locust Fork and Mulberry Fork catchments had the highest average LDI and the Sipsey Fork and Upper Black Warrior catchments had the lowest average LDI (Table A8).

Warrior Bass detection and occurrence was related to a variety of environmental coefficients at multiple spatial scales. The top model included effort in the detection model and percent run, rock score, limestone proportions, LDI, and year in the occurrence model. As expected, Warrior Bass detection probability increased with sampling effort (Table 2.5; Figure 2.3). Occurrence probability of Warrior Bass increased with the amount of run habitat within each stream reach and rock within each reach (Table 2.6; Figure 2.4, 2.5). Warrior Bass occurrence probability was higher in 2021 (Figure 2.6). Watershed scale covariates were also related to Warrior Bass occurrence probability. For instance, Warrior Bass were positively associated with drainage areas containing more than 10% limestone (Table 2.6; Figure 2.7) and were negatively associated with drainage areas with higher levels of disturbance (i.e., LDI > 2; Table 2.6; Figure 2.8). Neither trap response was significant ($P = 0.36$; $P = 0.15$) when added to the model and was therefore, not included in the final model. The top occupancy model had appropriate model fit. The top occurrence model had a $\hat{c}$ of 1.01 from the Goodness-of-Fit test indicating adequate model fit and no over or under dispersion.

DISCUSSION

Warrior Bass have a limited distribution throughout the Black Warrior watershed. The Sipsey Fork catchment had the highest detections of Warrior Bass and all of those detections occurred in Bankhead National Forest. The Locust Fork catchment had the second highest detections of Warrior Bass. Warrior Bass were not detected in the lower portions of the Mulberry Fork catchment or in the upper portions of Upper Black Warrior catchment.

Detection is related to many environmental factors such as stream habitat, fish species, gear type, fish size, and sampling effort (Thompson 1998; Anderson 2001; MacKenzie 2002). Warrior Bass detection was related to the amount of sampling time in each stream reach. Detection probability of Warrior Bass increased from 0.8 to 0.9 when effort increased from 500 to 2,000 seconds. However, Reid and Haxton (2017) found that detection probability of Largemouth Bass and Smallmouth Bass increased 50 – 80% when effort was increased from 250 to 1000 seconds using backpack electrofishing gear. Therefore, it is recommended that future studies use a minimum of 500-1000 seconds in stream reaches sampled with canoe or backpack electrofishing gear to provide confident detections of Warrior Bass in tributary streams. Future studies would also benefit from accounting for incomplete detection and/or capture efficiency when determining habitat relationships. Additionally, these results are limited to smaller streams, and larger streams such as the Locust Fork River and Mulberry Fork River will likely require different sampling gear and designs, but accounting for incomplete detection would likely be an important consideration (Anderson 2001).

Warrior Bass occurrence differed among years; however, this was likely an artifact of study design and geographical distribution of the species. All sites for this study were selected prior to sampling in 2020 and a schedule was made based on the location of sites in the watershed, gear, and the number of personnel that were needed to sample the streams. Sites in Bankhead National Forest were not sampled until the second year of the study due to time, personnel, and logistic constraints. Because Warrior Bass were rarely found outside of Bankhead National Forest, occurrence was higher in 2021.

Warrior Bass occurrence was higher in streams that contained greater amounts of limestone in the drainage area. Streams with increased amounts of limestone are typically more productive and could be providing more food resources for Warrior Bass. For instance, increased amounts of limestone in streams can result in high alkalinity which stabilizes pH and improves nutrient availability for lower trophic levels (Hamid et al. 2020). Alkalinity is associated with stream fertility (Allan et al. 2021) and has been linked to the productivity of fish populations. For example, Kwak and Waters (1997) found that alkalinity was related to the annual production of salmonids in streams in southeastern Minnesota.

Warrior Bass were not detected in the lower portions of the Mulberry Fork and the Upper Black Warrior catchments. These areas are located in the center of the Warrior Coal Field which has been heavily mined for its coal since the 1800's (McCalley 1886). Therefore, waste from coal mines in this area could have introduced heavy metals into the streams (Goldhaber and Hatch 2001). For instance, copper and zinc are typically more abundant in coal and are known to be toxic to fish at low concentrations (Powell 1988). Also, data from coal mines in Illinois, Missouri, and Iowa showed lower pH and increased concentrations of iron and sulfate downstream from the mined areas (Powell 1988). Limestone is known to neutralize acidity from mine effluent (Powell 1988; Hamid 2020) and could be the reason Warrior Bass are associated with streams with increased amounts of limestone. Currently, data are not available to adequately assess relationships with coal mines and Warrior Bass distribution. Future studies would benefit from collecting long-term water-quality measurements from streams in the Upper Black Warrior and lower Mulberry Fork catchments to assess any biological influences from current or historic coals mines (Bott et al. 2012).

Warrior Bass occurrence was associated with stream reaches that contained increased amounts of rock. Redeye Bass species are known to be associated with streams containing higher amounts of rocky substrates (Leitner and Early 2015). For example, Thompson (2021) and Knight (2011) found that Tallapoosa Bass were associated with increased amounts of boulders and bedrock in streams. Higher amounts of boulder and bedrock in streams could be providing refuge to Warrior Bass by creating interstitial spaces that act as a shelter from increased flow and predators (Cech and Moyle 2005). Conversely, Warrior Bass could also be using interstitial spaces for cover to ambush prey (Carter et al. 2010; Klecka and Boukal 2014). In general, complex substrate is related to increased concentrations of invertebrates which may be providing more food resources for Warrior Bass (Voshell 2002).

Landscape disturbance was negatively associated with Warrior Bass occurrence. Landscape disturbances initiate a complex cascade of changes that can alter steam habitat at multiple spatial and temporal scales. Urban and agricultural landscapes increase impervious surfaces and alter flow regimes, water chemistry, groundwater, sediment, and nutrients (Allan 2004). Water temperatures can also increase in smaller streams from deforestation of riparian areas (Allan 2004). Factors related to the decline of Warrior Bass occurrence are unknown, but several studies have reported declines in aquatic fauna in streams with more than 2-12% of their watersheds comprising impervious surfaces from urban land use (Klein 1979; Wang et al. 2000;

Wenger 2007). Also Brewer (2013) found that Smallmouth Bass occurrence was more likely in watersheds dominated by forest land use than those dominated by urban or agricultural land use.

Warrior Bass occurrence increased in stream reaches with higher percentages of run habitat. Adult Tallapoosa Bass were found to be associated with moderate current in the Tallapoosa river, Alabama (Earley and Sammons 2015), which may be the reason why run habitat was an important factor for the occurrence of Warrior Bass. However, it is likely that Warrior Bass occurrence is associated with other channel units within stream reaches because different life stages of fish are related to a variety of channel units in streams (Moyle and Cech 2005). For instance, adult Smallmouth Bass are known to occupy run and pool habitat whereas age-0 fish are associated with riffle and pool (Brewer 2013; Brewer and Orth 2015). Therefore, future studies should consider habitat use of Warrior Bass at various life stages and at smaller spatial scales.

I used spatially replicated surveys to differentiate detection based on gear inefficiencies and true occupancy of the species. Spatial replicates can bias occurrence and detection probability estimates because detection histories may not be independent. I used two types of trap responses to assess independence but neither trap response was statistically significant in the detection model, suggesting my surveys were independent of one another.

Overall, Warrior Bass distribution is sparse throughout the Black Warrior watershed. Streams in Bankhead National Forest had the highest detections of pure Warrior Bass and should be protected if the species is to persist into the future. Future research should focus on identifying reach scale habitat factors such as sedimentation, temperature, etc. that are driving the negative relationship between Warrior Bass distribution and landscape disturbances. Once these physical factors have been identified, then restoration efforts will be more effective for the conservation and management of Warrior Bass. Stream reaches with abundant rocky habitat, increased limestone proportions in the drainage area, and a lower landscape disturbance index should be prioritized for the conservation and management of Warrior Bass. The Locust Fork catchment generally had streams with the highest average rock and proportion of limestone in the drainage areas; however, these streams also had some of the highest disturbance indices. Therefore, it may be beneficial for managers to focus restoration efforts on streams in the Locust Fork catchment since these streams already possess habitat features found to be associated with Warrior Bass occurrence. Many of the streams in the Locust Fork catchment also had hybrid Alabama X Warrior Bass, but factors behind the hybridization between the two native species are unknown. Therefore, future research should consider investigating the environmental factors that are driving the hybridization of Warrior Bass and Alabama Bass in the Black Warrior watershed. Overall, results of this study demonstrated that Warrior Bass distribution is limited throughout the Black Warrior watershed and resource managers should consider prioritizing Warrior Bass conservation and management if this species is to continue to persist into the future.

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TABLES

Table 2.1 Correlation matrix for all continuous detection covariates. Seconds (Sec) was the total amount of time spent sampling at each reach. Max Depth was the deepest depth recorded within the reach. Conductivity (Cond), and Turbidity (Turb) were measured at the beginning of each reach using Hanna Combo PH/EC meter and SPER turbidity meter. Large Woody Debris (LWD) was scored at each reach based on the Georgia Stream Team Protocol.

	Sec	Depth (m)	Cond (µS)	Turb (NTU)
Depth (m)	-0.10	-	-	-
Cond (µS)	-0.17	0.03	-	-
Turb (NTU)	-0.31	0.13	-0.24	-
LWD	-0.05	0.29	-0.08	0.30

Table 2.2. Results from the top ranked detection model with occurrence held constant and the highest weight. p_{ij} is the estimated detection probability of Warrior Bass, β_0 is the grand intercept, β_1 to β_x are slopes for the continuous covariates including, conductivity (Cond), effort (seconds), depth, large woody debris (Lwd), and turbidity (Turb). Also, α_1 is the fixed effect for gear.

Detection Model	*K*	AIC_c	ΔAIC_c	Likeli-hood	W_i
$logit(p_{ij}) = \beta_0 + \beta_1 \text{Cond} + \beta_2 Effort + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	4	145.3	0.00	-68.33	0.70
$logit(p_{ij}) = \sim 1$ $\text{logit}(\psi_{ij}) = \sim 1$	2	149.5	4.18	-72.64	0.09
$logit(p_{ij}) = \beta_0 + \beta_1 \text{Depth} + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	3	150.5	5.24	-72.08	0.05
$logit(p_{ij}) = \beta_0 + \alpha_1 \text{Gear} + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	3	150.9	5.64	-72.28	0.04
$logit(p_{ij}) = \beta_0 + \beta_1 \text{Cond} + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	3	151.3	6.05	-72.48	0.03
$logit(p_{ij}) = \beta_0 + \beta_1 \text{Lwd} + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	3	151.6	6.36	-72.64	0.03
$logit(p_{ij}) = \beta_0 + \beta_1 \text{Depth} + \beta_2 Effort + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	4	152.3	6.99	-71.83	0.02
$logit(p_{ij}) = \beta_0 + \beta_1 \text{Lwd} + \beta_2 Turb + \varepsilon_i$ $\text{logit}(\psi_{ij}) = \sim 1$	4	153.0	7.68	-72.17	0.02

Table 2.3. Correlation matrix (rho) resulting from Pearson's correlations test for all continuous occurrence covariates. Seconds (Sec) is the total amount of time spent sampling at each site. Pool, run, and riffle were the average percent of each mesohabitat visually assessed in the site. Depth was the deepest depth recorded within the site. Large Woody Debris (LWD), rock, and bank was scored at each site based on the Georgia Stream Team Protocol. Order and slope was measures on the segment scale based on 2nd order stream segments above and below the site. DA is drainage area (km^2) and dams is the number of dams within the drainage area.

	Sec	Pool	Run	Riffle	Depth	LWD	Rock	Bank	Order	Slope
Pool	-0.056	-	-	-	-	-	-	-	-	-
Run	0.001	-0.336	-	-	-	-	-	-	-	-
Riffle	0.200	-0.251	-0.128	-	-	-	-	-	-	-
Depth	-0.094	0.368	-0.028	-0.450	-	-	-	-	-	-
LWD	0.045	0.357	0.0539	-0.322	0.170	-	-	-	-	-
Rock	0.154	-0.197	-0.337	0.343	0.085	-0.509	-	-	-	-
Bank	0.222	-0.024	-0.278	0.059	0.073	-0.427	0.589	-	-	-
Order	0.002	-0.092	0.244	-0.150	0.468	0.095	0.130	0.057	-	-
Slope	-0.217	-0.137	-0.388	0.344	-0.308	-0.316	0.296	0.214	-0.547	-
DA	-0.100	0.084	0.248	-0.306	0.541	0.031	0.127	0.060	0.805	-0.601
Dams	-0.213	-0.047	-0.002	-0.247	0.332	-0.171	0.234	0.165	0.336	-0.105

Table 2.4. Summary statistics and descriptions for multiscale environmental factors collected for each stream survey, reach, and catchment in the Black Warrior Watershed in Alabama.

Detection

Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Survey	Gear Type	Canoe (1) or backpack electrofishing units (0) used to sample the reach	0.00-1.00	0.40 ± 0.49
Survey	Mean Stream Width	Average width of stream reach	3.4 – 25.2	9.93 ± 5.34
Survey	Temperature	Average temperature ºC per stream site	14.54 – 25.85	19.77 ± 3.11
Survey	Effort (seconds)	Total amount of time spent electrofishing the reach	429.50-3,783.80	1,495.40 ± 827.35
Survey	Conductivity (µS)	Point in time measurement of how well the water is able to pass an electrical current. Measured using Hanna Combo PH and EC meter	17.00-1,070	153.90 ± 198.68
Survey	Turbidity (ntu)	Point in time measurement of the relative clarity of the water. Measured using SPER Turbidity meter	0.00-34.22	4.24 ± 5.46
Survey	Max Depth (m)	Depth estimate of the deepest pool within the reach	0.58-2.20	1.11 ± 0.40
Survey	Large Woody Debris Score	The proportion of large wood observed within the reach	1.00-10.00	3.86 ± 2.24
Segment	Slope (m/km)	Difference in elevation between upstream and downstream end of segment divided by total length of segment	0.57-19.89	3.91 ± 3.10
Survey	Percent Pool	The average proportion of pool estimated within each site	3.00-90.00	15.15 ± 13.10
Survey	Percent Run	The average proportion of run estimated within each site	10.00-91.25	58.21 ± 18.33

Occurence

Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Survey	Percent Riffle	The average proportion of riffle estimated within each site	0.00-65.00	18.30 ± 15.07
Survey	Percent Shoal	The average proportion of shoal habitat estimated within each site	0.00-59.00	8.44 ± 14.53
Survey	Large Woody Debris Score	The average proportion of large wood observed within the site	1.00-10.00	3.86 ± 2.24
Survey	Rock Score	The average proportion of rock observed within the reach	1.00-10.00	6.97 ± 2.37
Survey	Bank Stability Score	The overall erosion potential (i.e., steepness, exposed soil, crumbling) of the bank throughout the site	0.00-8.50	5.08 ± 2.13
Survey	Bank Vegetative Protection Score	The average amount of stream bank covered by vegetation within the site	0.00-10.00	5.28 ± 2.12
Segment	Stream Order	Relative size of the stream within the drainage area	2.00-6.00	3.629 ± 0.90
Segment	Sinuosity Index	Stream channel distance divided by straight line distance	0.98-3.20	1.53 ± 0.39
Catchment	Drainage Area (km^2)	The area of land draining to the stream site	1.62-405.75	66.76 ± 91.02
Catchment	Drainage Area Landscape Disturbance Index	The relative amount of disturbance within the area of land draining to the stream site	1.07-6.15	2.310 ± 1.21

Occurrence				
Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Reach	Floodplain Landscape Disturbance Index	The relative amount of disturbance adjacent to the stream channel at the stream site	1.00-7.80	1.50 ± 1.08
Catchment	Shale	The proportion of shale within the drainage area of the site	0.00-1.00	0.28 ± 0.34
Catchment	Sandstone	The proportion of sandstone within the drainage area of the site	0.00-1.00	0.53 ± 0.38
Catchment	Limestone	The proportion of limestone within the drainage area of the site	0.00-0.70	0.10 ± 0.17
Catchment	Sand	The proportion of sand within the drainage area of the site	0.00-1.00	0.04 ± 0.15
Catchment	Dolostone	The proportion of dolostone within the drainage area of the site	0.00-0.93	0.06 ± 0.17
Catchment	Conglomerate	The proportion of conglomerate within the drainage area of the site	0.00-0.03	0.00 ± 0.00
Catchment	Hydrological Soil Group A	Proportion of hydrological soil group A within the drainage area of the site	0.00-0.45	0.09 ± 0.12
Catchment	Hydrological Soil Group B	Proportion of hydrological soil group B within the drainage area of the site	0.00-0.90	0.29 ± 0.27
Catchment	Hydrological Soil Group C	Proportion of hydrological soil group C within the drainage area of the site	0.00-0.53	0.13 ± 0.15
Catchment	Hydrological Soil Group D	Proportion of hydrological soil group D within the drainage area of the site	0.00-0.95	0.34 ± 0.30

Occurrence

Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Catchment	Number of Dams in the Drainage Area	Summation of the number of dams found within the drainage area of the site	0.00-31.00	4.81 ± 7.73
Reach	Downstream Distance to Nearest Dam	Distance of nearest downstream impoundment to the site	560.8-165,465.20	58,551.60 ± 37,617.02

Table 2.5. The coefficient estimates (logit scale), standard errors (SE), and 95% confidence intervals (CI) for detection model relating the probability of Warrior Bass detection to sampling effort (seconds). The intercept represents the probability of detecting Warrior Bass (logit scale) at mean levels of effort.

Predictor variable	Estimate	SE	95% CI	p value
Intercept	2.04	0.41	1.23, 2.85	<0.001
Effort	0.281	0.39	-0.49, 1.05	<0.001

Table 2.6. Coefficient estimates (logit scale), standard errors (SE), and 95% confidence intervals (CI) for my occurrence model relating the probability of Warrior Bass occupancy to environmental variables and year. LDI represents the landscape disturbance index greater than 2 and limestone represents >10% limestone in the drainage area. The intercept represents the occupancy probability of Warrior Bass (logit scale) in 2020 in streams with drainage areas containing ≤10% limestone and a disturbance index < 2 at mean levels of rock and run%. Year is a fixed effect.

Predictor variable	Estimate	SE	95% CI	p value
Intercept	-1.89	0.65	-3.16, -0.62	0.003
Rock (%)	1.28	0.59	0.12, 2.45	0.03
Run (%)	1.03	0.54	-0.02, 2.09	0.06
Limestone (high, low)	1.97	0.93	0.14, 3.80	0.03
LDI	-2.04	0.87	-3.73, -0.34	0.02
Year 2021 (fixed effect)	2.93	0.86	1.24, 4.62	<0.001

FIGURES

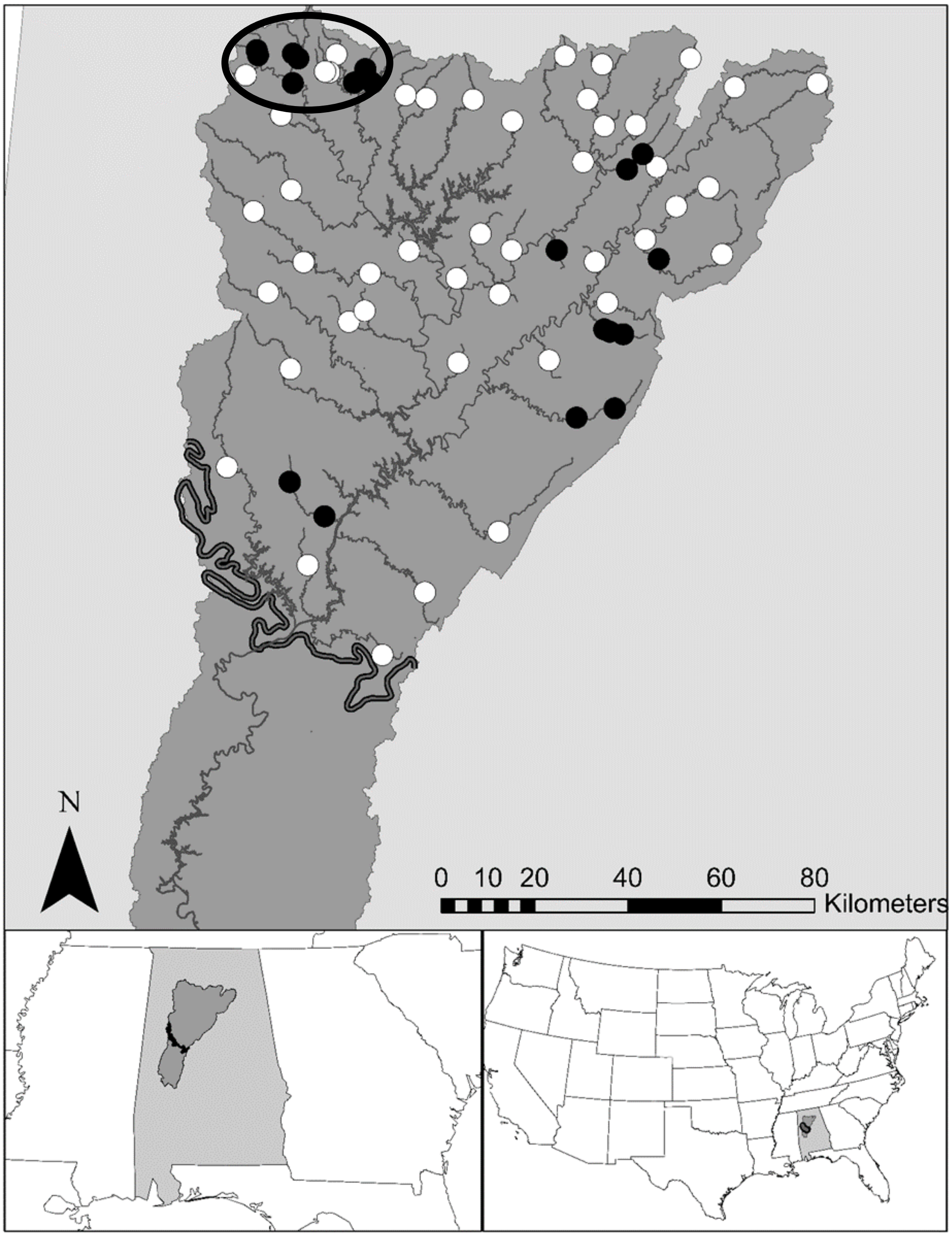

Figure 2.1. My study area within the Black Warrior River watershed, Alabama. Black circles are sites where Warrior Bass were detected and white circles are sites where Warrior Bass were not detected. The fall line is represented by the dark gray, thicker line. Large black circle in top left corner of map is Bankhead National Forest.

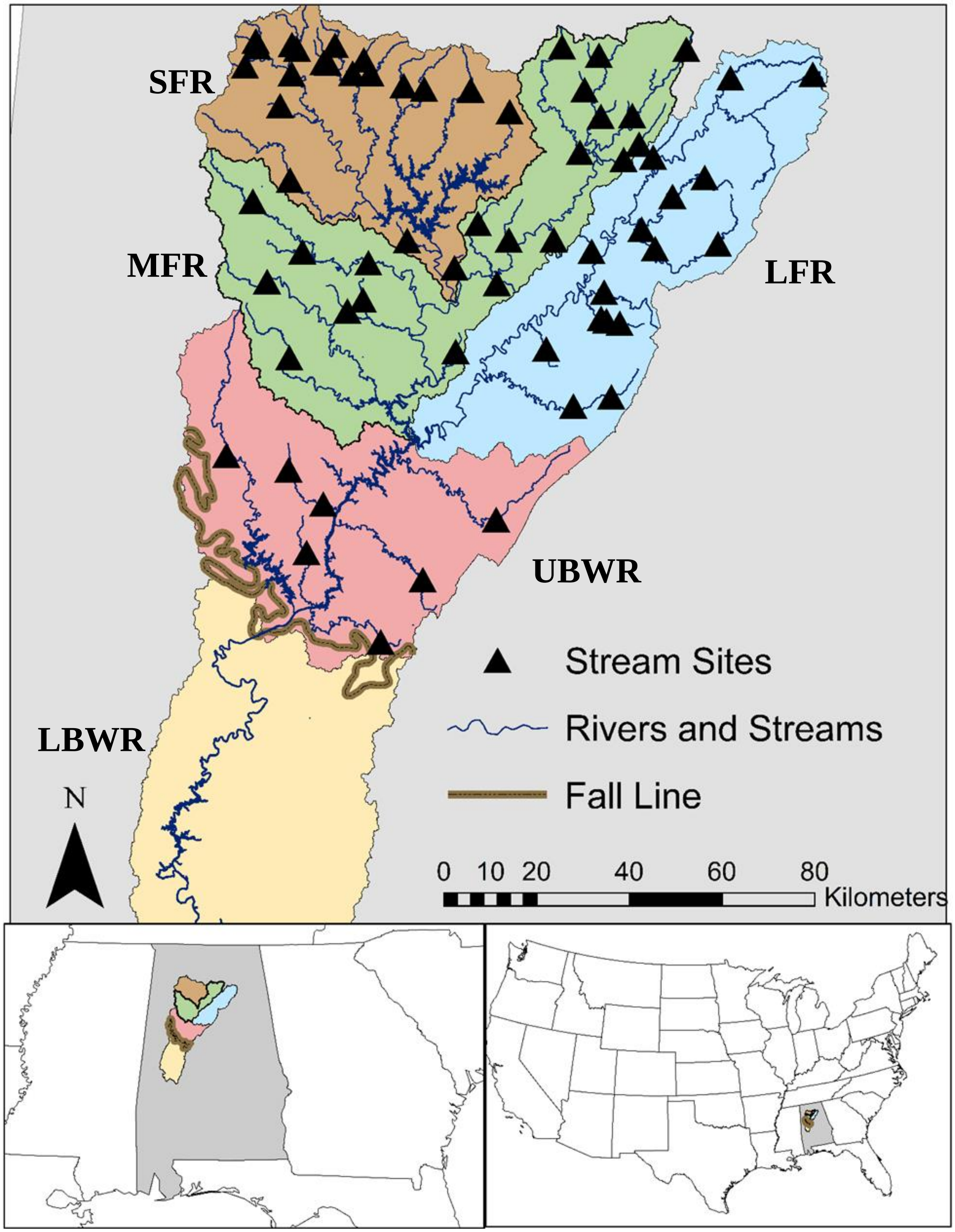

Figure 2.2. Catchments in the Black Warrior River watershed, Alabama, and sites sampled in each catchment from 2020 and 2021. Catchments include the Sipsey Fork River (SFR), Mulberry Fork River (MFR), Locust Fork River (LFR), Upper Black Warrior River (UBWR), and the Lower Black Warrior River (LBWR).

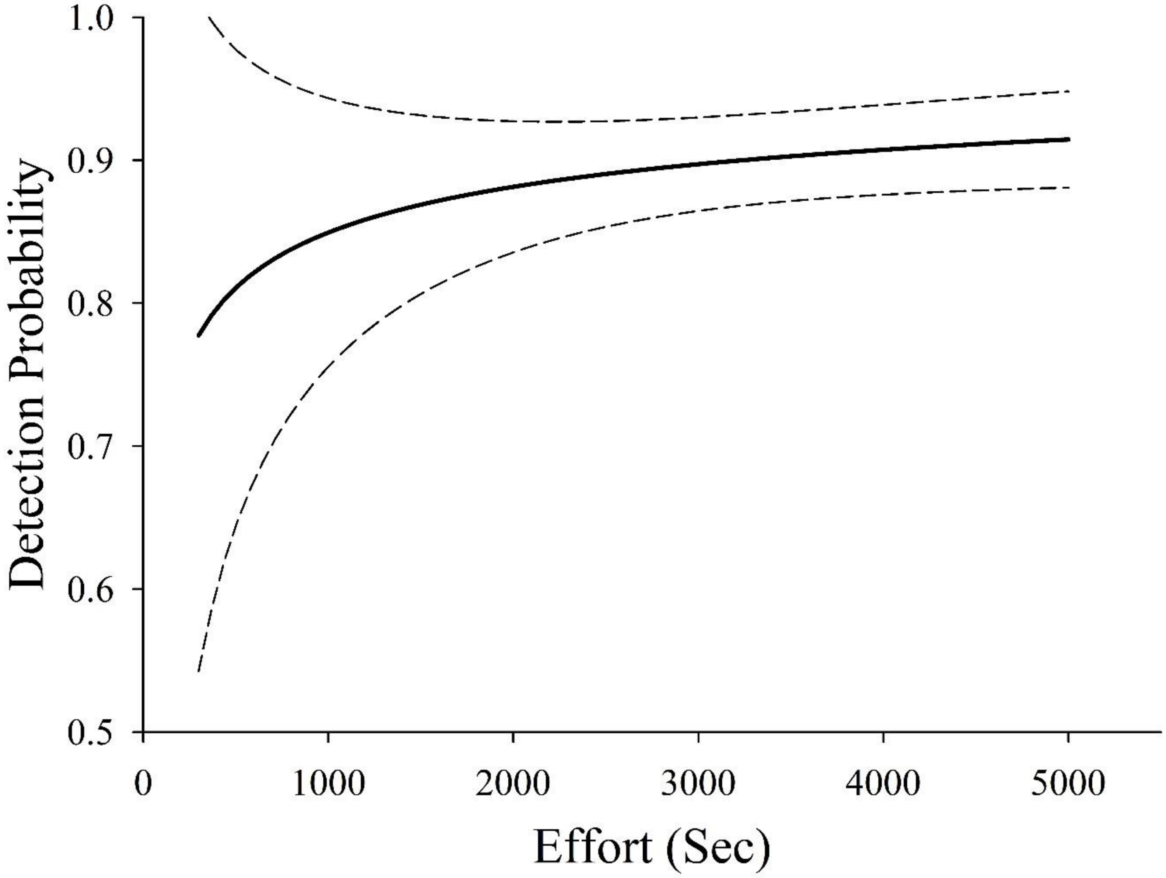

Figure 2.3. Warrior Bass detection probability as a function of effort in seconds. Dotted lines represent the standard errors.

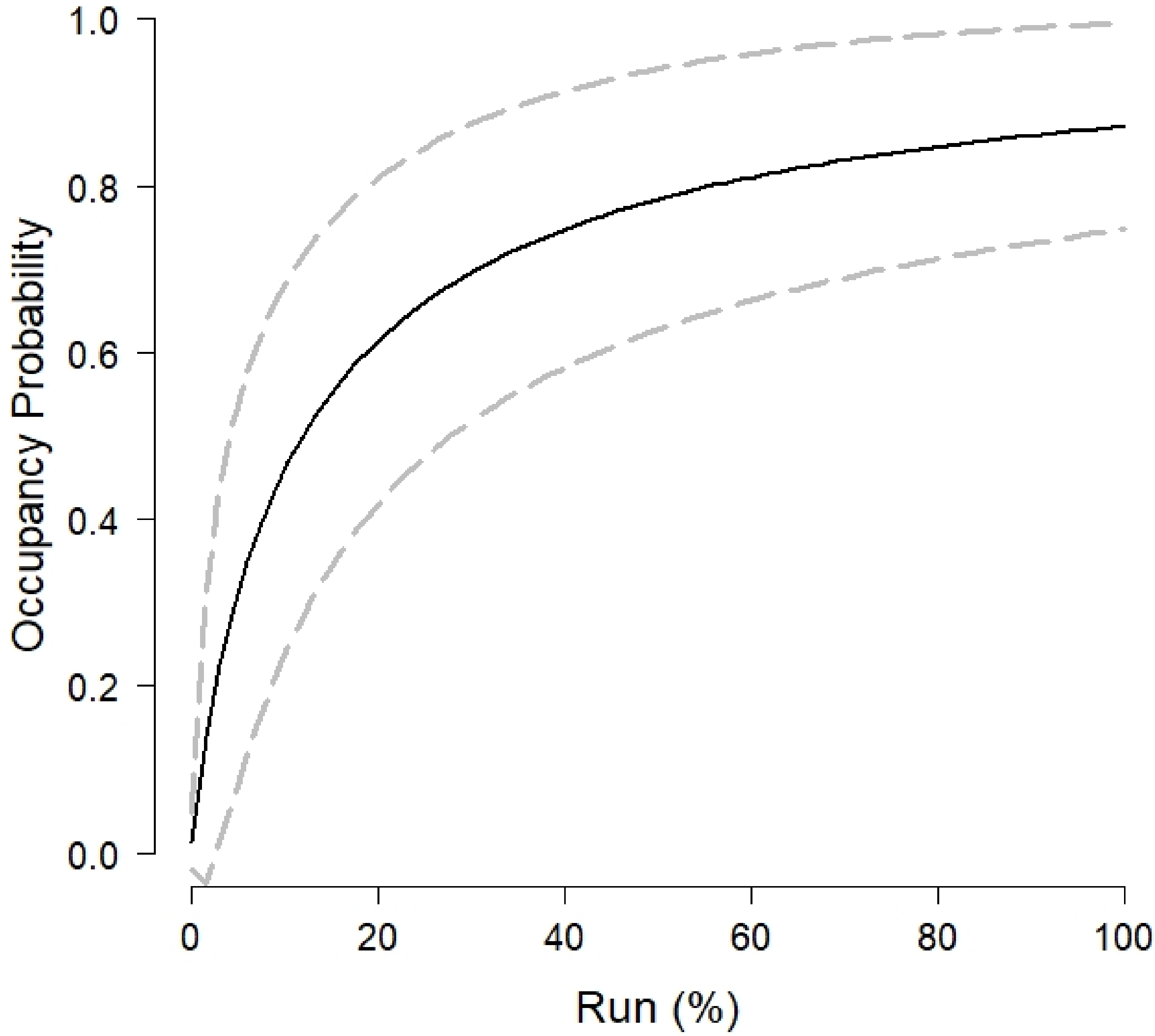

Figure 2.4. Warrior Bass predicted occupancy probability and percent run at mean levels of rock in year 2021 for streams with limestone proportions greater than 10% and landscape disturbance indices greater than 2. Dotted lines represents standard errors.

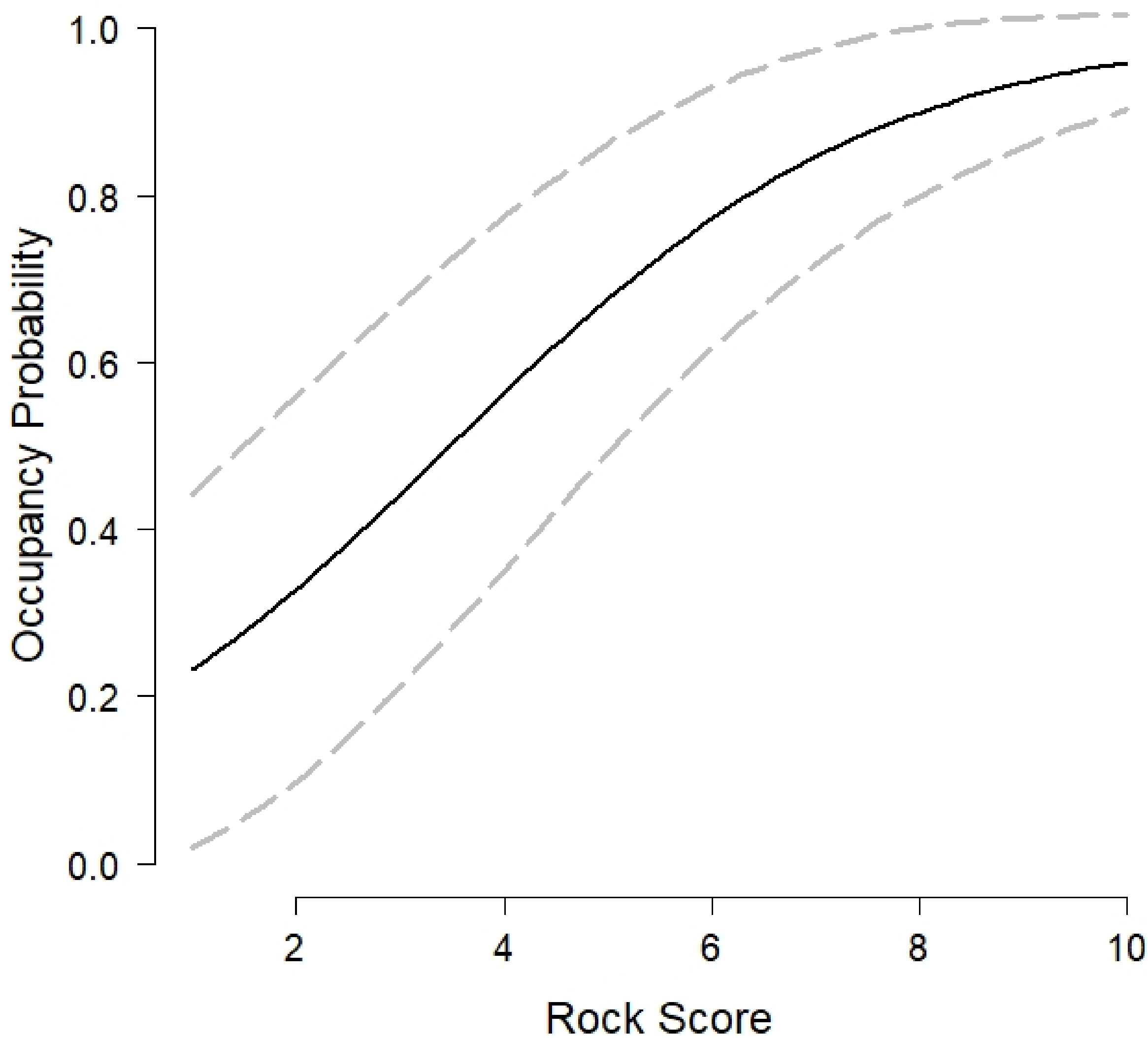

Figure 2.5. Warrior Bass occupancy probability and rock score with other continuous covariates (run) held at mean levels and categorical variables at reference (disturbance, limestone, year) levels. Dotted lines represent standard errors.

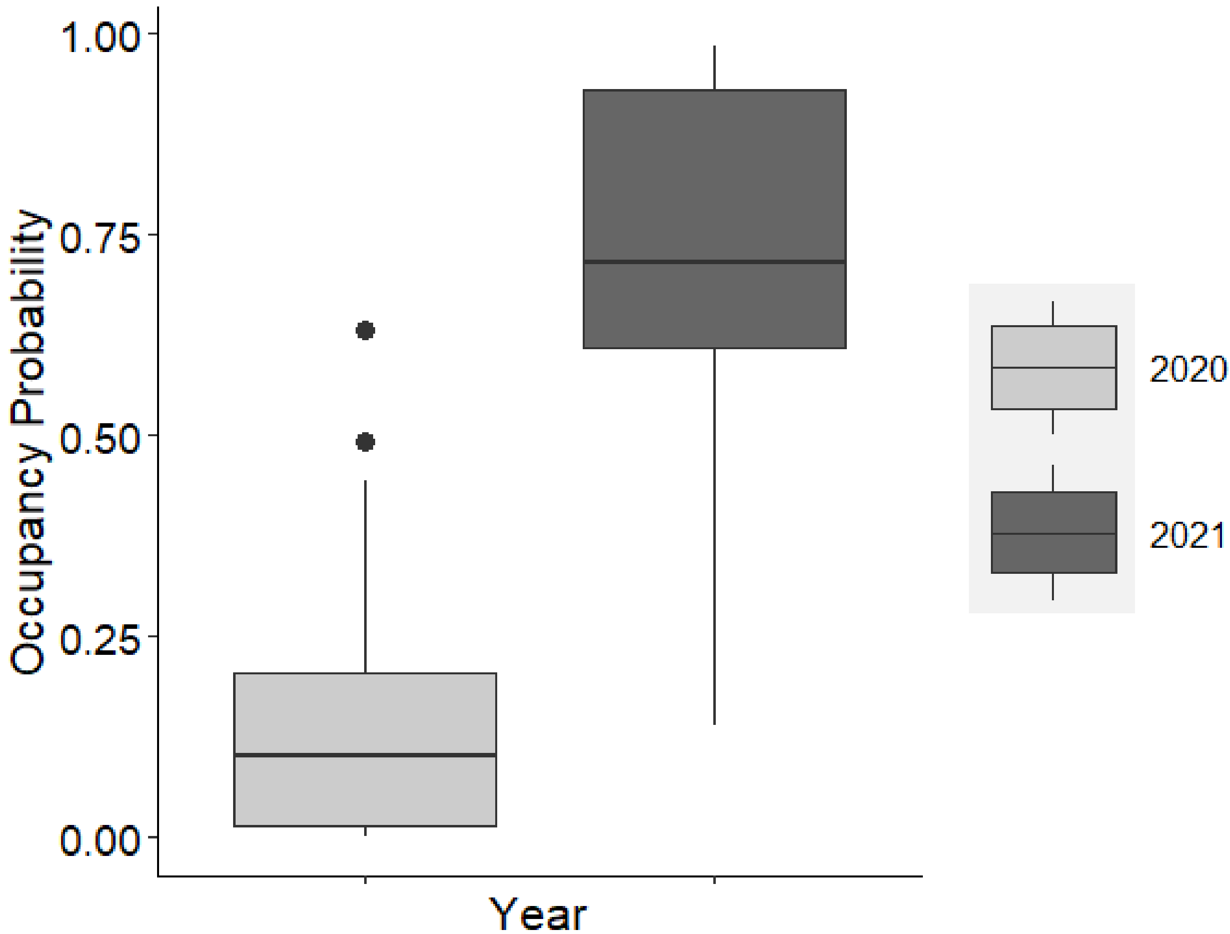

Figure 2.6. Warrior Bass predicted occupancy probability and year at mean levels of run and rock for streams with limestone proportions greater than 10% and landscape disturbance indices greater than 2 in the drainage area. The light gray box is year 2020 and dark gray box is year 2021. Both boxes represent the interquartile range of the 25th, 50th, and 75th percentiles. The line in the middle of the boxes represents the median (i.e., 50th percentile) and whiskers represent highest and lowest values unless there are outliers in which case the whiskers are the highest and lowest value within the 1.5* interquartile range (Q3-Q1). Black dots are outliers that are greater than 1.5 *interquartile range.

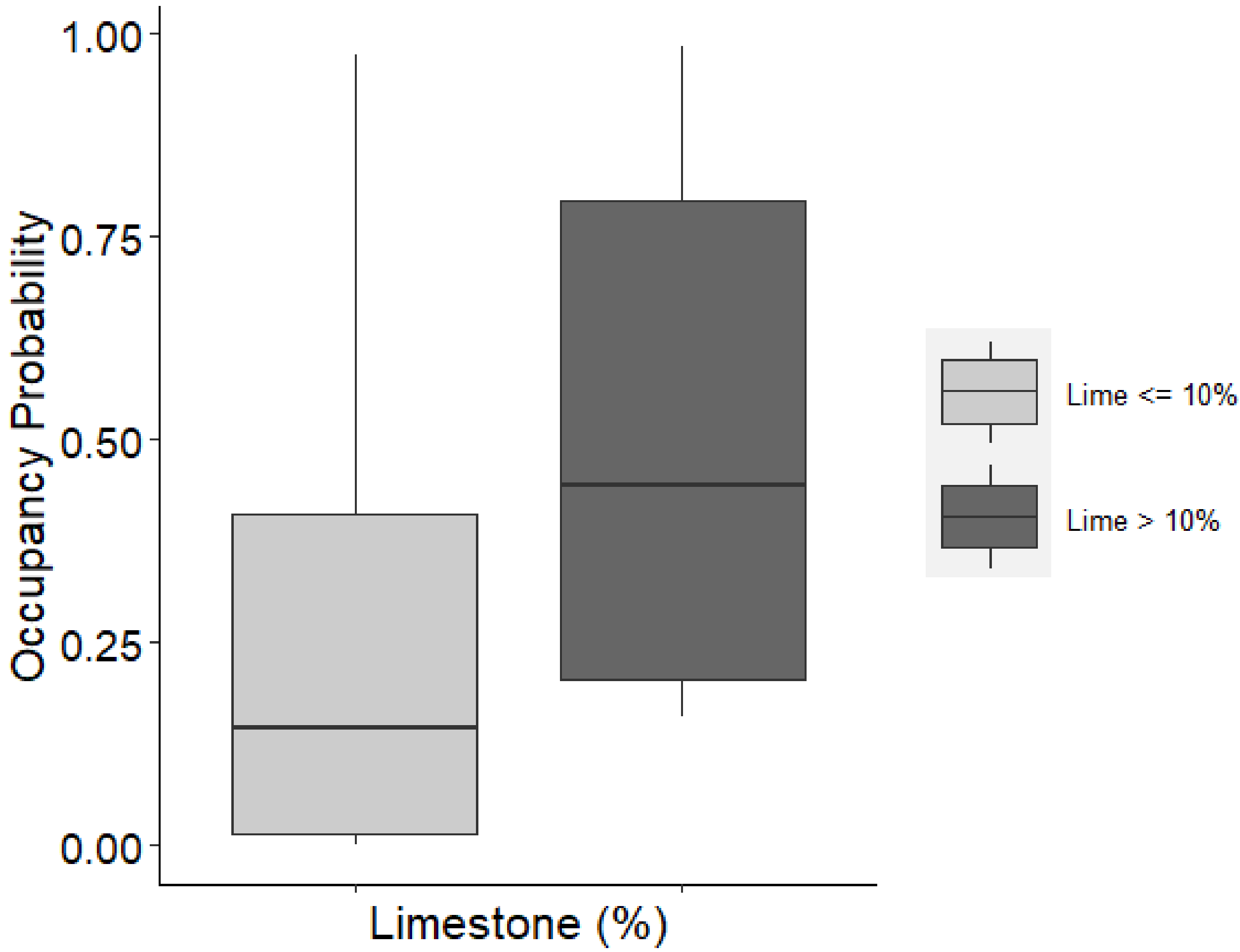

Figure 2.7. Warrior Bass predicted occupancy probability and limestone at mean levels of run and rock in year 2021 for streams with landscape disturbance indices greater than 2 in the drainage area. The light grey box is limestone proportions ≤ 10% and dark grey box is limestone proportions >10%. Both boxes represent the interquartile range of the 25th, 50th, and 75th percentiles. The line in the middle of the boxes represents the median (i.e., 50th percentile) and whiskers represent highest and lowest values unless there are outliers in which case the whiskers are the highest and lowest value within the 1.5* interquartile range (Q3-Q1). Black dots are outliers that are greater than 1.5 *interquartile range.

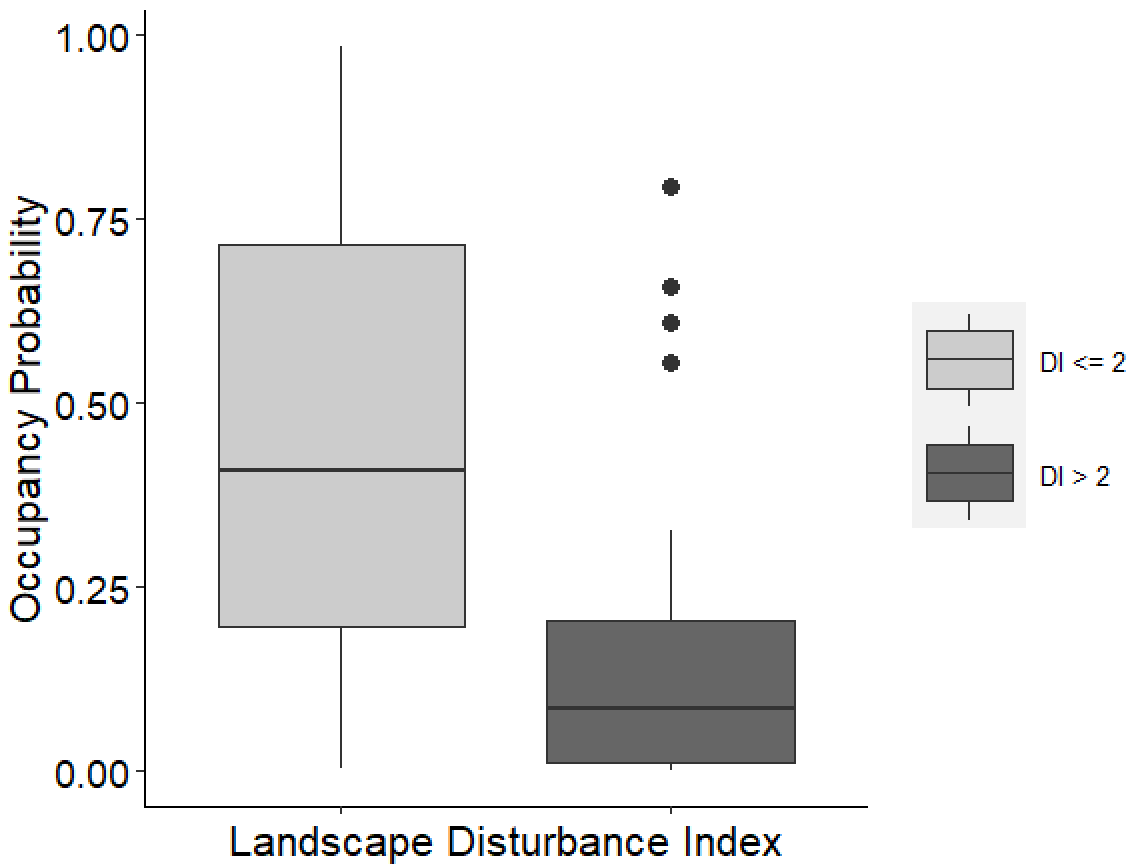

Figure 2.8. Warrior Bass predicted occupancy probability and landscape disturbance index at mean levels of run and rock in year 2021 for streams containing > 10% limestone in the drainage area. The light grey box is landscape disturbance indices less than or equal to 2 and dark grey box is landscape disturbance indices > 2. Both boxes represent the interquartile range of the 25th, 50th, and 75th percentiles. The line in the middle of the boxes represents the median (i.e., 50th percentile) and whiskers represent highest and lowest values unless there are outliers in which case the whiskers are the highest and lowest value within the 1.5* interquartile range (Q3-Q1). Black dots are outliers that are greater than 1.5 *interquartile range.

CHAPTER III

WARRIOR BASS RELATIVE ABUNDANCE AND HABITAT ASSOCIATIONS IN THE BLACK WARRIOR WATERSHED, ALABAMA

INTRODUCTION

Abundance (number of individuals in population) is an important indicator of a population's status as well as monitoring its recovery. Several organizations such as the International Union for Conservation of Nature (IUCN) and U.S. Fish and Wildlife Service (USFWS) use abundance and distribution data to determine the status of a species and to predict if a species will continue to persist over time. For instance, Species Status Assessments (SSA) include abundance, distribution, and ecological data and are used by the USFWS to describe and hypothesize causes for a species current condition. This information is then used to predict persistence by forecasting population changes (i.e., decline and/or recovery) in response to environmental alterations and conservation (USFWS 2016). However, abundance data can be hard to obtain because they are often expensive, difficult to collect, and time consuming. Therefore, surrogates such as relative abundance (e.g., catch per unit effort) are often used as a proxy for abundance data because they are easier and less expensive to obtain (Stephens et al. 2015). For instance, Guignion et al. 2010 used relative abundance to provide insight concerning the population status of juvenile Brook Trout *Salvelinus fontinalis*, Atlantic Salmon *Salmo salar*, and Rainbow Trout *Oncorhynchus mykiss* in Canada. State and federal agencies use relative abundance data to monitor populations and track changes (decline and/or recovery) in population's sizes over time (Poole et al. 2019; Homan and Tindall 2020; Yung and Martin 2021). Thus, surrogates such as relative abundance can be useful to determine a population's decline, recovery, and status.

Stream habitats are arranged in a hierarchical framework where coarse-scale factors constrain finer spatial scales (Allan 2004). Coarse-scale factors such as geology, climate, soils, and land use influence the structure, chemistry, temperature, and hydrology of streams (Hynes 1975; Frissell et al. 1986; Ward 1989; Poff 1997). For instance, streams with greater amounts of limestone in their watersheds are typically more productive because weathering of limestone results in streams with higher pH and alkalinity (Hamid et al. 2020). Furthermore, anthropogenic land use such as agriculture and urbanization can decrease water quality by altering nutrients and sediment loads in streams (Brown et al. 2005; Blann et al. 2009; Chapman et al. 2014; Hamid et al. 2020). Thus, understanding how physicochemical conditions are dictated by coarse-scale features is important for identifying the relationships between local stream habitat and fish abundance (Frissell et al. 1986; Ward 1989; Allan and Johnson 1997). If coarse-scale factors are not included, key relationships between fish and their habitat may be missed, resulting in incomplete or misleading information that could hinder the effectiveness of management and conservation.

Redeye Bass *Micropterus coosae* is one of the least studied species within the black bass genus. They were described by Hubbs and Bailey (1948) and historical distribution of Redeye Bass ranged from the upper Savannah River Basin, Georgia and South Carolina, to the upper Mobile Basin in Alabama (Hubbs and Bailey 1940). However, in 2013 Redeye Bass from the Chattahoochee and Mobile River basins were elevated to five new species (i.e., Cahaba Bass, Redeye Bass, Chattahoochee Bass, Tallapoosa Bass, and Warrior Bass) with each species occurring in a single watershed (Baker et al. 2013). This resulted in each putative species now occupying relatively small ranges within each basin, raising concerns regarding higher risks of imperilment (Taylor et al. 2019). Thus, basic distribution and environmental factors influencing the abundance of these recently described Redeye Bass species need to be determined to properly address the conservation needs of these fish.

Warrior Bass are found above the fall line within the Black Warrior watershed in Alabama (Leitner and Earley 2015). However, little is known about their status or the environmental variables that may influence their abundance. Therefore, before any management or conservation actions can take place, resource managers need a better understanding of Warrior Bass abundance in the Black Warrior watershed and how this abundance relates to local and coarse environmental factors. Thus, the objective of this study was to assess the relationships between Warrior Bass relative abundance and multiscale environmental factors.

METHODS

Site Selection, Study Design, and Fish Sampling

Warrior Bass were sampled from the same stream surveys and reaches described in Chapter II (Table A1; Figure 3.1). Likewise, stream surveys, reaches, and fish were sampled following the same methods in Chapter II. Briefly, surveys were sampled using electrofishing gear and were separated by 10 MSW. Percent channel units, bank stability, vegetative protection, rock, and LWD were measured during each survey and were averaged for each stream reach. Segment and watershed scale covariates (i.e., lithology, soils, landscape disturbance index, etc.) were collected using multiple datasets in ArcGIS. Mean stream width (MSW) and reach lengths were used to calculate the area of the stream reaches and seconds were averaged across surveys to get overall effort for the stream reach. All black bass were measured for total length and weight, fin clipped, and released downstream of each survey.

Physiochemical Conditions

Survey- and reach-scale occupancy covariates were collected to determine multiscale habitat factors associated with Warrior Bass relative abundance (Table 3.1). All survey-scale variables were averaged across stream surveys to get an overall estimate for the stream reach. At each survey, I measured temperature using a Hanna Combo pH and EC meter. Water temperature was collected because Redeye Bass species are thought to be associated with cool water streams (Leitner and Earley 2015). Bank stability and vegetative cover were visually assessed and scored for each survey based on the Georgia Stream Team Protocol (Tables A3 and A4; GADNR Stream Team 2005). Rock and large woody debris (LWD) composition were also scored for each survey; scoring criteria were derived for a 1 to 10 scale following similar metrics found within the Georgia Stream Team Protocol (Tables A2 and A5; See Chapter II for details). Rock and LWD habitat are commonly associated with black bass presence in streams (Earley and Sammons 2015; Thompson 2021). Additionally, bank stability and vegetative cover were measured because sediment loads in streams are related to unstable banks (Rosgen 2001). Channel units (i.e., pool, riffle, run) were defined following the general classification of Rabeni and Jacobson (1993) and shoal habitat was characterized by a mosaic of relatively shallow sections of stream with small cascades and deep to moderate micro-pools, all of which are dominated by large sheets of bedrock. Percent of each channel unit type was visually assessed for each survey and averaged across surveys for the stream reach (as described in Chapter II).

I used the National Hydrography Dataset Plus High Resolution (NHD Plus HR) to calculate several reach- and segment- scale covariates for Warrior Bass relative abundance (Moore et al. 2019). Stream segments were defined as a section of stream between two second order confluences (Frissell et al. 1986). Stream order, gradient, and sinuosity were measured at the segment scale to obtain reliable measurements but were considered reach-level covariates. Drainage area (km^2) was calculated upstream of each reach as a measure of stream size and to determine the location of the stream within the network. Gradient was measured because Redeye Bass species are suspected to be more abundant in higher gradient streams (Leitner and Early 2015).

I calculated the proportion of lithology and hydrological soil groups within each drainage area using the United States Department of Agricultural National Resources Conservation Service Gridded Soil Survey Geographic Database (USDA NRCS gSSURGO) and Preliminary Integrated Geologic Map Databases for the United States (Dicken et al. 2005; USDA NRCS 2012).

Additionally, I calculated the land-use proportions (i.e., forested/natural, agriculture/cropland, or developed/urban) for the floodplain and drainage area of each reach using the USDA Crop National Agricultural Statistics Service dataset (USDA 2017). Following the methods of Brown and Vivas (2005), I calculated a disturbance index from the land-use proportions. The landscape disturbance index (LDI) was calculated by simplifying the Brown and Vivas (2005) landscape development intensity index (LDI) into three main land-use categories: forested/natural (1.00), agriculture/cropland (3.91), and developed/urban (7.86; as described in Chapter II). Coefficients for the disturbance index ranged from 1 to 10 with higher values indicating increased disturbance.

Data Analysis:

I used a zero inflated poisson model to account for zero inflation (i.e., increased number of zeros preventing data from fitting standard distributions) in my dataset (Figure 3.2) and to determine possible environmental factors influencing Warrior Bass relative abundance. Zero inflation is common in ecological studies, and if not accounted for, can cause over dispersion that results in over estimation of standard errors, inflated *p* values, and biased parameter estimates (Gelman and Hill 2007; Kery and Royle 2015). Zeros can be classified into two groups, true zeros and false zeros (Lambert 1992; Blasco-Moreno 2019). False zeros correspond to observer error that can bias parameter estimates and prevent accurate inferences about species abundance and habitat relationships (Mackenzie et al. 2002). True zeros arise from more natural processes and can be classified into two groups; structural zeros and random zeros (Lambert 1992; Blasco-Moreno 2019). Structural zeros arise from sites that were never suitable for the species and random zeros arise when the species was not found in a suitable site by chance. ZIP models account for true zeros by describing the suitability of a site, where $w_i = 1$ represents a suitable site and $w_i = 0$ represents a non-suitable site (Kery and Royle 2015). Suitable sites can have either an abundance greater than or equal to zero (i.e., random zeros), whereas unsuitable sites always have an abundance of zero (i.e., structural zeros; Lambert 1992). Furthermore, unsuitable sites are removed from the abundance component of the model to fit a Poisson distribution (Kery and Royle 2015; Hofstetter et al. 2016). The ZIP model described by Kery and Royle 2015 is as follows:

$$s_i \sim \text{Bernoulli}\ (1-\theta)\ \text{“Suitability” component}$$

$$N_i \sim \text{Poisson}\ (s_i \lambda_i)\ \text{“Abundance” component}$$

Where s_i is site suitability, λ_i is the mean response, θ is the estimated proportion of unsuitable sites that cannot be occupied by the species.

Prior to building my ZIP model, I transformed the data, examined preliminary plots, checked for correlations, and standardized continuous covariates. Shoal and riffle proportions, segment slope, drainage area, and large woody debris were $\log_{10}$ transformed to reduce skewness (Gelman and Hill 2007) but LDI, limestone proportions, and hydrological soil group D proportions were highly skewed and not improved after transformations. Therefore, these covariates were turned into categorical variables to meet linear assumptions. The LDI was a two level categorical variable with low LDI ≤ 2 and high LDI > 2 in the drainage area. Limestone was also made into a two level categorical variable. Similar categories were created for limestone proportions (≤ 0.1 = low, > 0.1 = high) and hydrological soil group D (≤ 0.4 = low, $>$ 0.4 = high. Preliminary plots of continuous covariates against counts showed that rock score needed to be a quadratic term. Therefore, I included a higher order quadratic term for rock score in the abundance model. Temperature, segment sinuosity, shoal%, and floodplain disturbance index were not used in the analysis because of low variation among streams. I used Pearson's correlation coefficients to check for multicollinearity among continuous covariates (Table 3.2). If two covariates were highly correlated $|r| \geq 0.50$, only one covariate was retained for the model. Independence among categorical variables was examined using scatter plots to display relationships among continuous and categorical covariates. Next, I standardized all continuous covariates to a mean of zero and a standard deviation of 1. Retained covariates included run%, riffle%, rock score, drainage area, drainage area DI, proportion of limestone, and proportion of hydrological soil group D. These variables were used to form candidate models to examine variation in Warrior Bass abundance.

Before building my candidate models, some streams were removed from the dataset and fish counts were capped for three streams. Similar to Brewer et al. (2007), some streams (i.e., Flannagin, Blue, and Murphy creeks) in my data were capped at 30 fish per stream because fish counts from those streams (i.e., 60-70 Warrior Bass) were more than double those from all other streams (i.e., 0-30 Warrior Bass; Figure 3.2). Furthermore, three streams (i.e., Five-mile, Valley, and Blue Springs Creeks) were removed from the analysis because they were extreme outliers in the dataset, and were driving covariate relationships (Gelman and Hill 2007).

I built 10 ZIP models with fixed and random effects and ranked the models using Akaike Information Criterion corrected for small sample size (AICc; Table 3.3; Burnham and Anderson 2002). I did not include environmental covariates in the zero inflation side of the model because none of the covariates explained the structural zeros in my dataset. Therefore, the zero part of the model removed sites with extreme zeros from the dataset that did not fit the Poisson distribution (Hofstetter et al. 2016). To prevent over-parameterization of the candidate models, I only included three environmental covariates and a random effect of catchment, which was included to account for spatial correlation among sites (i.e., sites nested within catchments). Lastly, I included an offset for site area (m^2) in the abundance model to account for variation among the size of the stream sites that were sampled. Offsets change the interpretation of the abundance model's response to density estimates that are relative to the offset (e.g., fish per m^2). The ZIP model can be expressed as:

Zero-inflation model:

$$s_i \sim Bernoulli\ (1 - \theta_i)$$

$$logit(\theta_i) = \beta_0$$

Where s_i denotes whether site i is suitable ($s_i = 1$) or unsuitable ($s_i = 0$), θ is the estimated proportion of unsuitable sites that cannot be occupied by the species, and β_0 is the intercept in the null model.

Relative Abundance model (given suitability):

$$N_i|s_i \sim Poisson\ (s_{i^*}\lambda_i)$$

$$Log(\lambda_i) = \beta_0 + \beta_1 X + \beta_2 X + \beta_3 X + \omega_h$$

$\omega_h \sim t(0, \sigma\sigma_h^2, v)$, for h = 1, 2, ... H (Catchments grouping factor)

where λ_i is the estimated mean density of Warrior Bass (where abundance was offset for stream site area, expressed as fish per m^2) within the i^{th} site, β_0 is the grand intercept, β_1, $\beta_{2,}$ and β_3 are slopes for environmental covariates and ω_h represents the random effect of catchments. After 10 candidate models were built, I used AICc to rank my candidate models (Table 3.3). The model with the lowest AICc value was ranked as the top model and any model within 2.0 AICc values of the best model was also considered top models (Burnham and Anderson 2002).

I checked the top model for over dispersion by plotting the observed versus predicted residuals using the R package “DHARMa”. The DHARMa package plots the observed versus predicted residuals using a scatted plot and also includes a QQ-plot for residual diagnostics (Rizopoulos 2018, Hartig 2019). A lack of pattern in the scatter plot and a uniform distribution in the QQ-plot indicate adequate fit (Rizopoulos 2018).

RESULTS

I sampled 57 streams and 70 stream reaches above the fall line in the Black Warrior watershed. Forty-eight stream sites were sampled from May-August 2020 and 22 stream sites from May-July 2021. Sampled stream sites ranged from 400 - 14,700 m and MSW ranged from 3 - 25 m (Table A7). Twenty-nine stream sites were sampled with canoe electrofishing gear and 41 sites were sampled with backpack electrofishing gear. Shocking time ranged from 429 – 3,784 seconds and the average stream area shocked was 2.5 ha. Of those stream sites that were sampled, 31% contained Warrior Bass. In total 530 Warrior Bass were collected from 13 streams between 2020 and 2021. Streams in Bankhead National Forest within the Sipsey Fork catchment had the highest counts of Warrior Bass (i.e., 239), followed by LFR = 143, MFR=120, and UBWR=28, respectively. Warrior Bass lengths ranged from 300 - 30 mm in total length (Figure 3.3) and estimated average density of Warrior Bass was 2.07 fish/ ha (LCI 1.04; UCI 3.09). Also, 406 Alabama Bass X Warrior Bass hybrids were collected from 24 streams (Table A7).

Mean, standard deviation, and range of covariates varied among streams and catchments. Stream orders for sampled sites ranged from 2-6 and drainage areas ranged from 1.62 – 405.75 km^2. Stream sites in the Sipsey Fork catchment generally had smaller drainage areas when compared to sites in other catchments. Limestone proportions averaged 10% and varied from 0-70% for drainage areas. The LDI also ranged from 1.07 to 6.15 and the average LDI was 2.31. The Mulberry and Locust Fork catchments generally had the highest average disturbance indices for stream sites when compared to stream sites in the other catchments. Rock score also ranged from 1-10 with a mean of 6.97. Stream sites sampled in the Locust Fork catchment generally were characterized by higher average rock scores and limestone proportions compared to the other three catchments.

The logistic regression model accounted for unsuitable sites in the dataset using an intercept only model with an estimate of 0.70 (Table 3.4). The final count model contained drainage area, limestone, and a random effect of catchment. When sites were suitable, the number of Warrior Bass per m^2 decreased with increasing drainage area (Figure 3.4). Also, Warrior Bass density increased by 2.33% in drainage areas containing greater than 10% limestone when all other covariates were held at mean levels (Figure 3.5). After examination of observed versus predicted residuals and the QQ-plot, neither plot showed over dispersion in the model indicating adequate model fit (Figure 3.6).

DISCUSSION

The inverse relationship between Warrior Bass relative abundance and drainage area suggest Warrior Bass are associated with smaller headwater streams. Drainage area can influence fish abundance because it is related to stream size, flow, temperature, and gradient (Gordon et al. 1994; Moyle and Cech 2000). Streams located higher in a drainage network typically have steeper gradients, coarser substrates, cooler temperatures, and lower discharge. Redeye bass species are thought to be more common in smaller streams that are cooler and contain coarser substrates (Leitner and Earley 2015; Thompson 2021). Warrior Bass relative abundance was higher in streams sites with drainage areas <100 km^2 similarly to what Thompson (2021) found for Tallapoosa Bass. Although smaller streams have more hydrological variation and are less stable habitats, Warrior Bass may be better adapted to these systems and are able to outcompete other black bass species that are typically found in higher order streams (Brewer 2007; Claussen 2015; Rider and Maceina 2015). Although point-in-time water temperature measurements did not vary enough in this study to use in the analysis, long term temperature measurements should be collected in the future to determine if headwater streams are providing thermal refuge for Warrior Bass. Measuring water temperature over multiple seasons and sites will capture more variation in temperature fluctuations and provide managers with a general idea of Warrior Bass thermal tolerance.

The positive relation between Warrior Bass relative abundance and limestone suggests that streams with higher amounts of limestone in the drainage area could be more productive than other streams. The weathering of geology and soils in a watershed is a key source of buffering substances in streams which in turn influences the streams pH (Hamid et al. 2020). Streams with increased amounts of limestone in the drainage area can have high alkalinity which stabilizes pH and improves nutrient availability for lower trophic levels (Wurts and Durborow 1992). Weathering of limestone can result in streams that are highly productive and provide more food resources, thus increasing the carrying capacity of Warrior Bass (Allan 2021).

Warrior Bass counts were lower in the Upper Black Warrior and Mulberry Fork catchment. The Upper Black Warrior catchment and lower portions of the Mulberry Fork catchment contain a large portion of the Warrior Coal Field which is the biggest coal field in Alabama. The Warrior Coal Field has been mined since the late 1800's (McCalley 1886). Waste from coal mines can introduce metals, such as iron, manganese, copper, and zinc into streams which can be harmful to stream ecosystems by increasing stream acidity and reaching concentrations that toxic to aquatic organisms (Goldhaber and Hatch 2001). Limestone is known to neutralize acidity from mine effluent (Powell 1988; Hamid 2020) and could be the reason

Warrior Bass are associated with streams with increased amounts of limestone. Currently, data are not available to adequately assess relationships with coal mines and Warrior Bass relative abundance. I was unable to detect any changes in water quality from streams within these catchments because I collected point-in-time water quality measurements. The LDI did not include mines therefore, I was unable to determine if there was a relationship between mines and the relative abundance of Warrior Bass. Furthermore, mine density within stream catchments did not vary enough among streams to use in the relative abundance model. Future studies should consider collecting long term water quality measurements to trace any heavy metals that could have been introduced from current or historic coal mines to determine if they have any influence on Warrior Bass relative abundance (Bott et al. 2012).

Landscape disturbance was not an important predictor of Warrior Bass relative abundance. However, landscape disturbance has been an important predictor for the relative abundance of other *Micropertus* spp. (Brewer and Rabeni 2011; Thompson 2021). For instance, Brewer and Rabeni (2011) found that land use explained the greatest variation in Smallmouth Bass relative abundance and that relative abundance was highest in forested stream segments. Conversely, Thompson (2021) found that Tallapoosa Bass relative abundance was positively associated with land-use disturbance. Although present day land use disturbances were not an important predictor of Warrior Bass abundance, historical land use or legacy effects could still be influencing the relative abundance of Warrior Bass (Harding et al. 1998).

Unlike other *Micropterus* species, Warrior Bass relative abundance was not associated with instream channel units. However, other studies have found black bass abundance to be associated with various channel units (Brewer and Orth 2015; Thompson 2021). Substrate and channel unit use may vary ontogenetically with juvenile and adult fish using different habitats

(Johnston and Kennon 2007; Brewer and Orth 2015; Sammons and Maceina 2009). Warrior Bass were not aged in this study, and little is known about their age structure in these streams. Relatively few age-0 fish were collected, thus models were constructed across all age classes of fish. Channel units may be important to certain age classes of Warrior Bass that would not have been captured in my study.

Because I did not account for catchability, bias could exist in my relative abundance estimates due to sampling error (Anderson 2001; Mackenzie 2002). Sampling error exists when an animal is failed to be detected at a site which can cause an underestimation of relative abundance estimates (Thompson et al. 1998). One main assumption of relative abundance indices is that they are proportional to absolute population abundance. However, there are numerous factors influencing catchability of a fish species and how these factors influence catch can differ depending on physical structure, behavior of individuals, size of individuals, observers, etc. Therefore, these factors should be accounted for when estimating abundance (Anderson 2001; Mackenzie 2002). However, due to the design of this study, capture probability could not be accounted for and estimates of Warrior Bass relative abundance should be considered with caution (Bayley and Dowling 1993; Anderson 2001; Peterson et al. 2011). Uncorrected bias from capture probability can compromise validity and usefulness of relative abundance estimates (Anderson 2001; Peterson et al. 2011).

Hybridization between Warrior Bass and Alabama Bass appears to be common in the Black Warrior watershed based on genetic results (Lewis, AU, unpublished). Four streams in the Locust Fork catchment and two streams in the Mulberry Fork catchment contained populations of Warrior Bass (Table A7). However, these six streams also contained Alabama Bass X Warrior Bass hybrids (Table A7). Highly altered habitats have been theorized to increase hybridization among congeners, although this has rarely been empirically tested (Heath et al. 2010; Hasselman et al. 2014; Muhlfeld et al. 2014). Future studies should consider investigating the multiscale habitat factors related to Alabama Bass X Warrior Bass hybrids to determine the distribution, frequency, and environmental factors that are associated with hybridization between these two native species.

Streams in the Sipsey Fork catchment, more specifically Bankhead National Forest, had the highest counts of pure Warrior Bass found within the Black Warrior watershed whereas, streams outside of Bankhead National Forest pure Warrior Bass were sparse or non-existent and many contained hybrid bass. Therefore, persistence of Warrior Bass is largely reliant on protecting Warrior Bass populations in Bankhead National Forest. Furthermore, future research should consider investigating habitat factors driving hybridization of Warrior Bass and Alabama Bass in the Black Warrior watershed. I observed large quantities of hybrid bass in several streams outside of Bankhead National Forest that otherwise appeared to be good Warrior Bass habitat. Once environmental factors associated with hybridization have been identified, restocking of streams with pure Warrior Bass populations should be considered in an effort to restore pure Warrior Bass to the system. Similarly to what Texas Parks and Wildlife Department has done for Guadalupe Bass (Fleming et al. 2015).

Future research and management efforts should consider prioritizing seasonal variation, life history, and anthropogenic land use effects on Warrior Bass relative abundance and habitat use. The current study was conducted only during summer, thus future studies should consider investigating Warrior Bass habitat use throughout multiple seasons. Furthermore, relative abundance and habitat associations of young fish should be quantified to determine habitat suitability for early life stages. Future studies should consider investigating legacy effects from agriculture, silviculture, and coal mining in the Black Warrior watershed by using historical land use maps or aerial photographs to quantify past land use disturbances (Burgi et al. 2017). Additionally, managers should consider a monitoring protocol for Warrior Bass populations and prioritize streams with smaller watersheds (<100 km^2) that contain increased amounts of limestone. These streams could be useful for restocking of Warrior Bass and may play a pivotal role in the persistence and recovery of the species.

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TABLES

Table 3.1. Summary statistics and descriptions for covariates measured at the reach and survey scale.

Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Survey	Gear Type	Canoe (1) or backpack electrofishing units (0) used to sample the reach	0.00-1.00	0.40 ± 0.49
Survey	Mean Stream Width	Average width of stream reach	3.4 – 25.2	9.93 ± 5.34
Reach	Temperature	Average temperature ºC per stream site	14.54 – 25.85	19.77 ± 3.11
Survey	Max Depth (m)	Depth estimate of the deepest pool within the reach	0.58-2.20	1.11 ± 0.40
Survey	Large Woody Debris Score	The proportion of large wood observed within the reach	1.00-10.00	3.86 ± 2.24
Reach	Slope (m/km)	Difference in elevation between upstream and downstream end of segment divided by total length of segment	0.57-19.89	3.91 ± 3.10
Survey	Percent Pool	The average proportion of pool estimated within each site	3.00-90.00	15.15 ± 13.10
Survey	Percent Run	The average proportion of run estimated within each site	10.00-91.25	58.21 ± 18.33
Survey	Percent Riffle	The average proportion of riffle estimated within each site	0.00-65.00	18.30 ± 15.07
Survey	Percent Shoal	The average proportion of shoal habitat estimated within each site	0.00-59.00	8.44 ± 14.53
Reach	Large Woody Debris Score	The average proportion of large wood observed within the site	1.00-10.00	3.86 ± 2.24

Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Survey	Rock Score	The average proportion of rock observed within the reach	1.00-10.00	6.97 ± 2.37
Survey	Bank Stability Score	The overall erosion potential (i.e., steepness, exposed soil, crumbling) of the bank throughout the site	0.00-8.50	5.08 ± 2.13
Survey	Bank Vegetative Protection Score	The average amount of stream bank covered by vegetation within the site	0.00-10.00	5.28 ± 2.12
Watershed	Stream Order[c]	Relative size of the stream within the drainage area	2.00-6.00	3.629 ± 0.90
Watershed	Sinuosity Index[c]	Stream channel distance divided by straight line distance	0.98-3.20	1.53 ± 0.39
Watershed	Drainage Area (km^2)[c]	The area of land draining to the stream site	1.62-405.75	66.76 ± 91.02
Watershed	Drainage Area Landscape Disturbance Index[d,c]	The relative amount of disturbance within the area of land draining to the stream site	1.07-6.15	2.310 ± 1.21
Reach	Floodplain[d] Landscape Disturbance Index	The relative amount of disturbance adjacent to the stream channel at the stream site	1.00-7.80	1.50 ± 1.08
Watershed	Shale[a]	The proportion of shale within the drainage area of the site	0.00-1.00	0.28 ± 0.34
Watershed	Sandstone[a]	The proportion of sandstone within the drainage area of the site	0.00-1.00	0.53 ± 0.38

Scale	*Covariate*	*Description*	*Range*	*Mean ± SD*
Watershed	Limestone[a]	The proportion of limestone within the drainage area of the site	0.00-0.70	0.10 ± 0.17
Watershed	Sand[a]	The proportion of sand within the drainage area of the site	0.00-1.00	0.04 ± 0.15
Watershed	Dolostone[a]	The proportion of dolostone within the drainage area of the site	0.00-0.93	0.06 ± 0.17
Watershed	Conglomerate[a]	The proportion of conglomerate within the drainage area of the site	0.00-0.03	0.00 ± 0.00
Watershed	Hydrological Soil Group A[b]	Proportion of hydrological soil group A within the drainage area of the site	0.00-0.45	0.09 ± 0.12
Watershed	Hydrological Soil Group B[b]	Proportion of hydrological soil group B within the drainage area of the site	0.00-0.90	0.29 ± 0.27
Watershed	Hydrological Soil Group C[b]	Proportion of hydrological soil group C within the drainage area of the site	0.00-0.53	0.13 ± 0.15
Watershed	Hydrological Soil Group D[b]	Proportion of hydrological soil group D within the drainage area of the site	0.00-0.95	0.34 ± 0.30

[a]https://datagateway.nrcs.usda.gov/
[b]https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053629
[c]https://apps.nationalmap.gov/downloader/
[d]https://nassgeodata.gmu.edu/CropScape/

Table 3.2. Correlation matrix for all continuous detection covariates. Seconds (Sec) is the total amount of time spent sampling at each site. Pool, run, and riffle were the average percent of each mesohabitat visually assessed in the site. Depth was the deepest depth recorded within the site. Large woody debris (LWD), rock, and bank was scored at each site based on the Georgia Stream Team Protocol. Order and slope were measured on the segment scale based on 2nd order stream segments above and below the site.

	Sec	Pool	Run	Riffle	Depth	LWD	Rock	Bank	Order	Slope
Pool	-0.056	-	-	-	-	-	-	-	-	-
Run	0.001	-0.336	-	-	-	-	-	-	-	-
Riffle	0.200	-0.251	-0.128	-	-	-	-	-	-	-
Depth	-0.094	0.368	-0.028	-0.450	-	-	-	-	-	-
LWD	0.045	0.357	0.0539	-0.322	0.170	-	-	-	-	-
Rock	0.154	-0.197	-0.337	0.343	0.085	-0.509	-	-	-	-
Bank	0.222	-0.024	-0.278	0.059	0.073	-0.427	0.589	-	-	-
Order	0.002	-0.092	0.244	-0.150	0.468	0.095	0.130	0.057	-	-
Slope	-0.217	-0.137	-0.388	0.344	-0.308	-0.316	0.296	0.214	-0.547	-
DA	-0.100	0.084	0.248	-0.306	0.541	0.031	0.127	0.060	0.805	-0.601

Table 3.3 Results from the top ranked ZIP model with the highest weight. Y_i is the estimated number of Warrior Bass per area on the log scale, β_0 is the grand intercept, β_1 to β_x are slopes for the continuous covariates including, rock, drainage area, riffle, and run. Also, α_1 is the fixed effect for either limestone, hydrological soil group D, or landscape disturbance index.

ZIP Model	*K*	AIC_c	ΔAIC_c	Likelihood	W_i
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 \text{DrainageArea} + \alpha_1 Limestone + v_t + \varepsilon_i$	5	299.44	0.00	-144.19	0.96
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 \text{DrainageArea} + \beta_2 Rock + \beta_3 Rock\text{^}2 + v_t + \varepsilon_i$	6	305.68	6.24	-146.09	0.04
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 DrainageArea + \alpha_1 DI + v_t + \varepsilon_i$	5	322.52	23.08	-155.73	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 DrainageArea + v_t + \varepsilon_i$	4	330.96	31.52	-161.14	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 DrainageArea + \alpha_1 D + v_t + \varepsilon_i$	5	339.41	39.97	-164.18	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \alpha_1 Limestone + \beta_1 Rock + \beta_2 Rock\text{^}2 + v_t + \varepsilon_i$	6	449.78	150.34	-218.14	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 \text{Run} + \beta_2 \text{Riffle} + \alpha_1 Limestone + v_t + \varepsilon_i$	6	485.30	185.86	-235.90	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 Rock + \beta_2 Rock\text{^}2 + v_t + \varepsilon_i$	5	548.43	248.98	-268.68	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $\log(Y_i) = \beta_0 + \beta_1 Rock + \beta_2 Rock^2 + \alpha_1 DI + v_t + \varepsilon_i$	6	550.03	250.59	-268.26	0.00
$logit(\theta_i) = \beta_0 + \varepsilon_i$ $logit(\theta_i) = \beta_0 + v_t + \varepsilon_i$	3	640.33	340.88	-316.95	0.00

Table 3.4. Coefficients estimates for abundance (log scale), zero-inflation (logit scale), standard error (SE), and 95% confidence intervals (CI) for my mixed-effects zero inflated poisson regression model relating Warrior Bass relative abundance (fish/m^2) to environmental covariates. The intercept for the abundance model represents the estimated number of Warrior Bass per m^2 at mean values of drainage area (km^2). Drainage area was standardized to a mean of zero and SD of 1.

Abundance Model				
Predictor variables	Estimate	SE	95% CI	p value
Intercept	-7.16	0.18	-7.52, -6.80	< 0.001
Drainage Area	-0.99	0.07	-1.13, -0.85	< 0.001
Limestone	0.85	0.14	0.57, 1.13	<0.001

Zero-inflation Model				
Predictor variables	Estimate	SE	95% CI	p value
Intercept	0.82	0.27	0.28, 1.37	0.0028

FIGURES

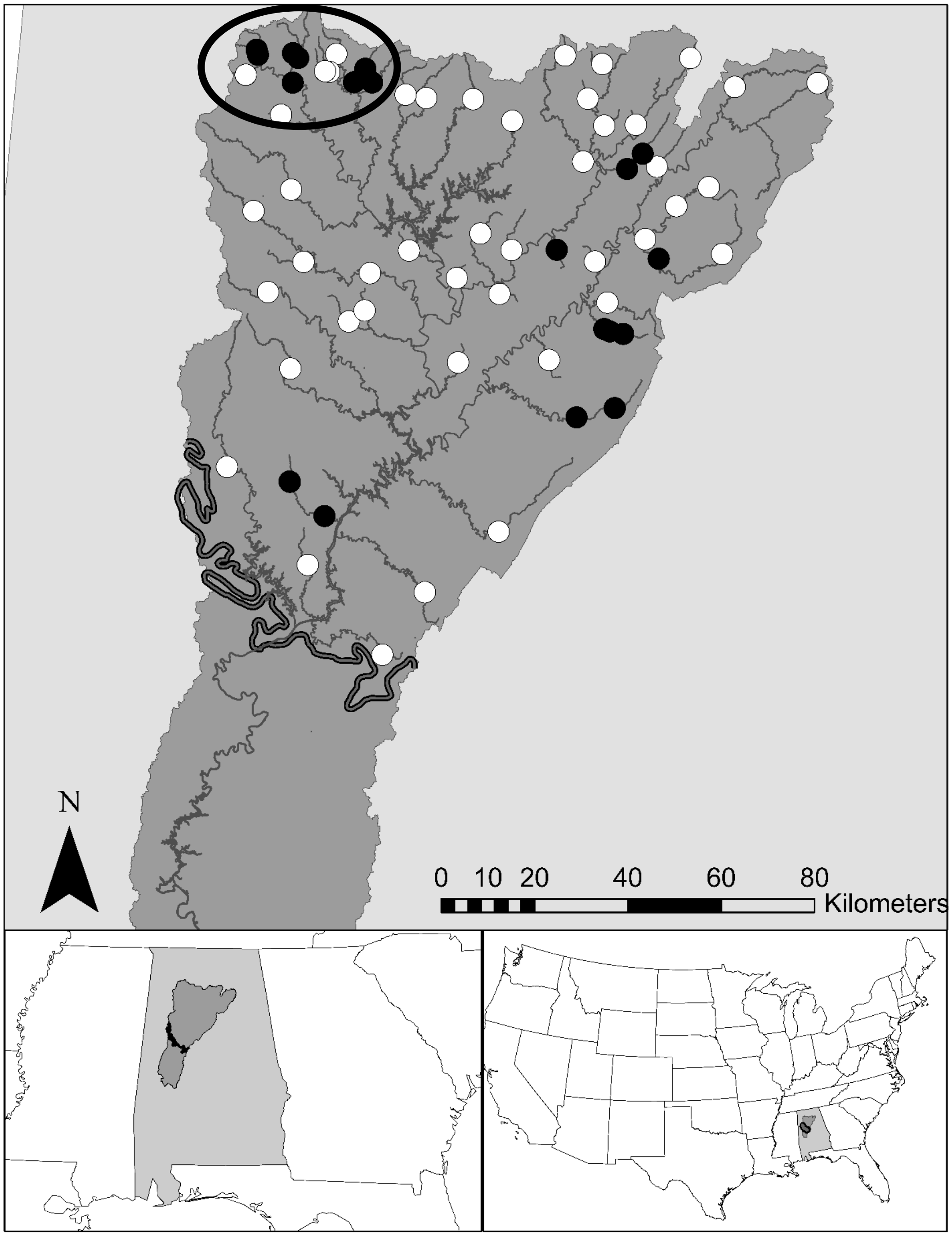

Figure 3.1. My study area within the Black Warrior Watershed of Alabama. Black circles are sites where Warrior Bass was detected and white circles are sites where Warrior Bass was not detected. The fall line is represented by the dark gray, thicker line. Large black circle in top left corner of map is Bankhead National Forest.

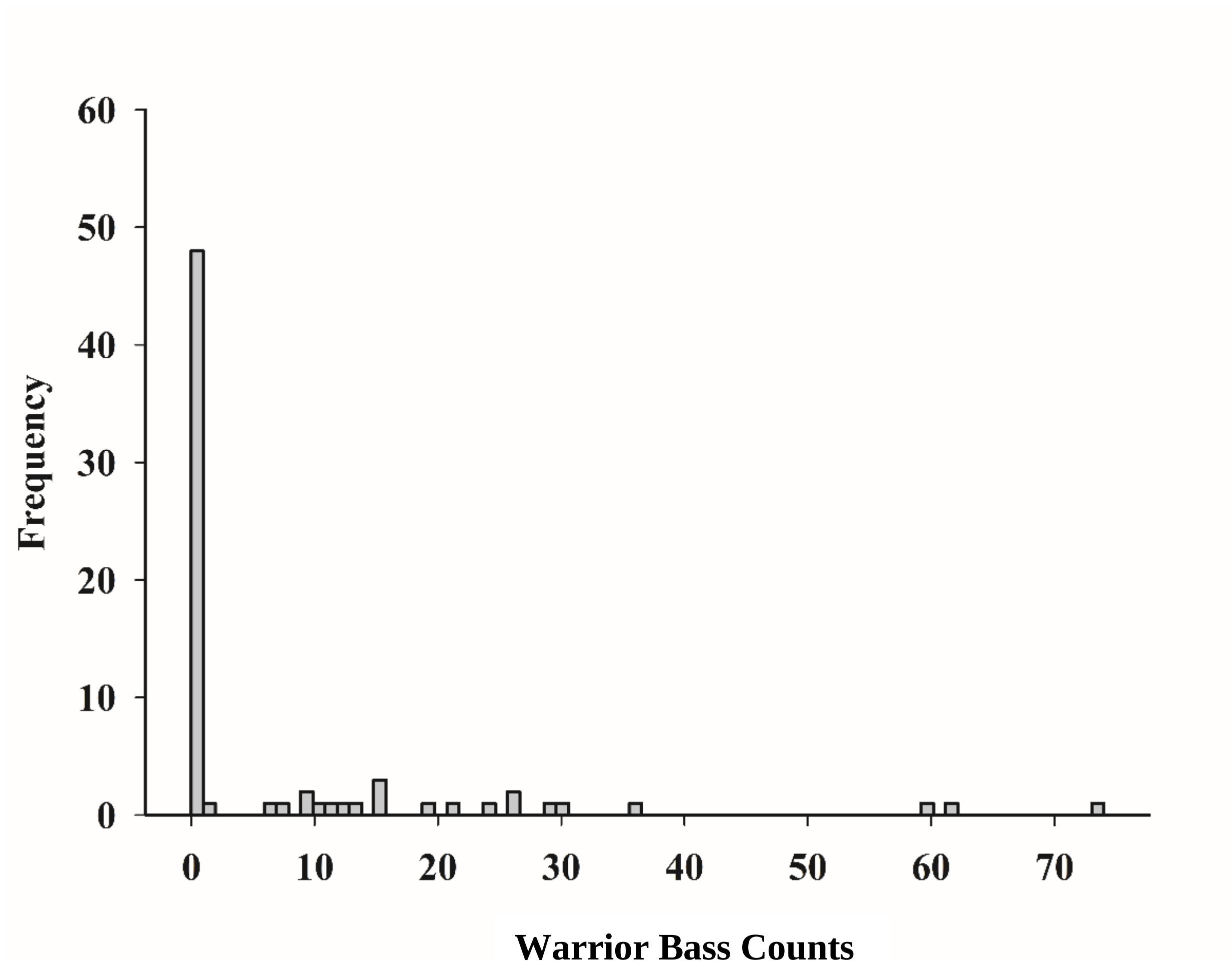

Figure 3.2. Frequency of Warrior Bass counts from 2020 and 2021. The high frequency of zeros indicates the data is zero-inflated. Counts that were greater than 30 were considered outliers and were capped at 30 for modeling purposes.

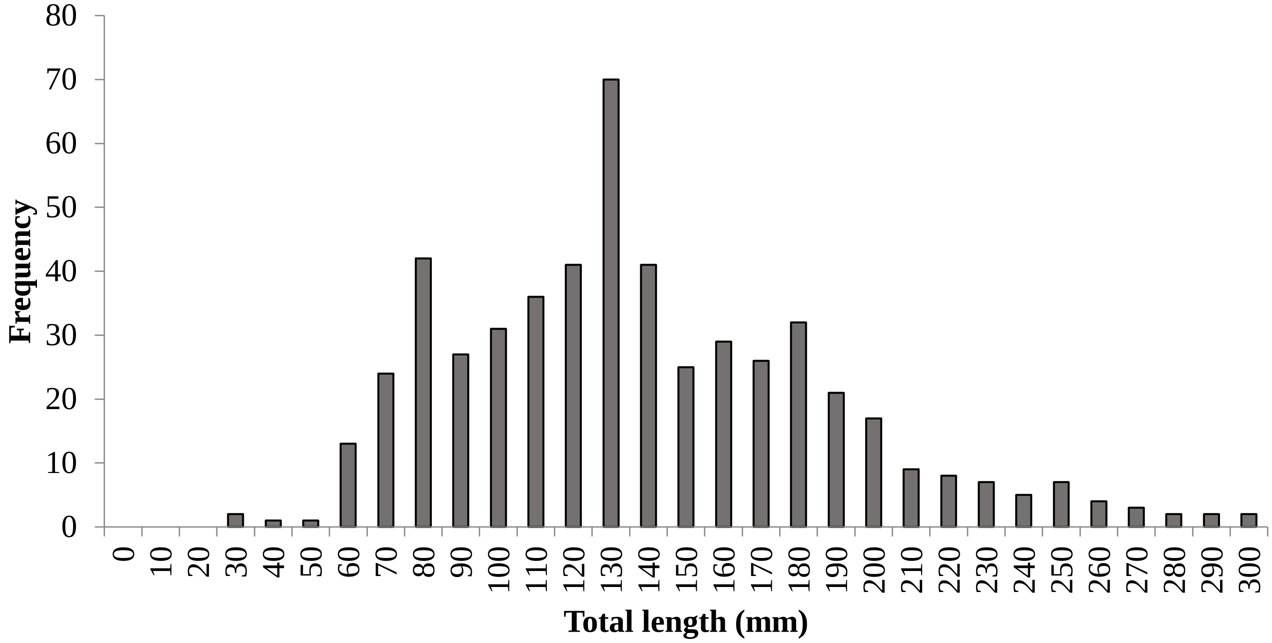

Figure 3.3. Length frequencies (10 mm bins) of Warrior Bass collected in 2020 and 2021 from streams in the Black Warrior Watershed, AL.

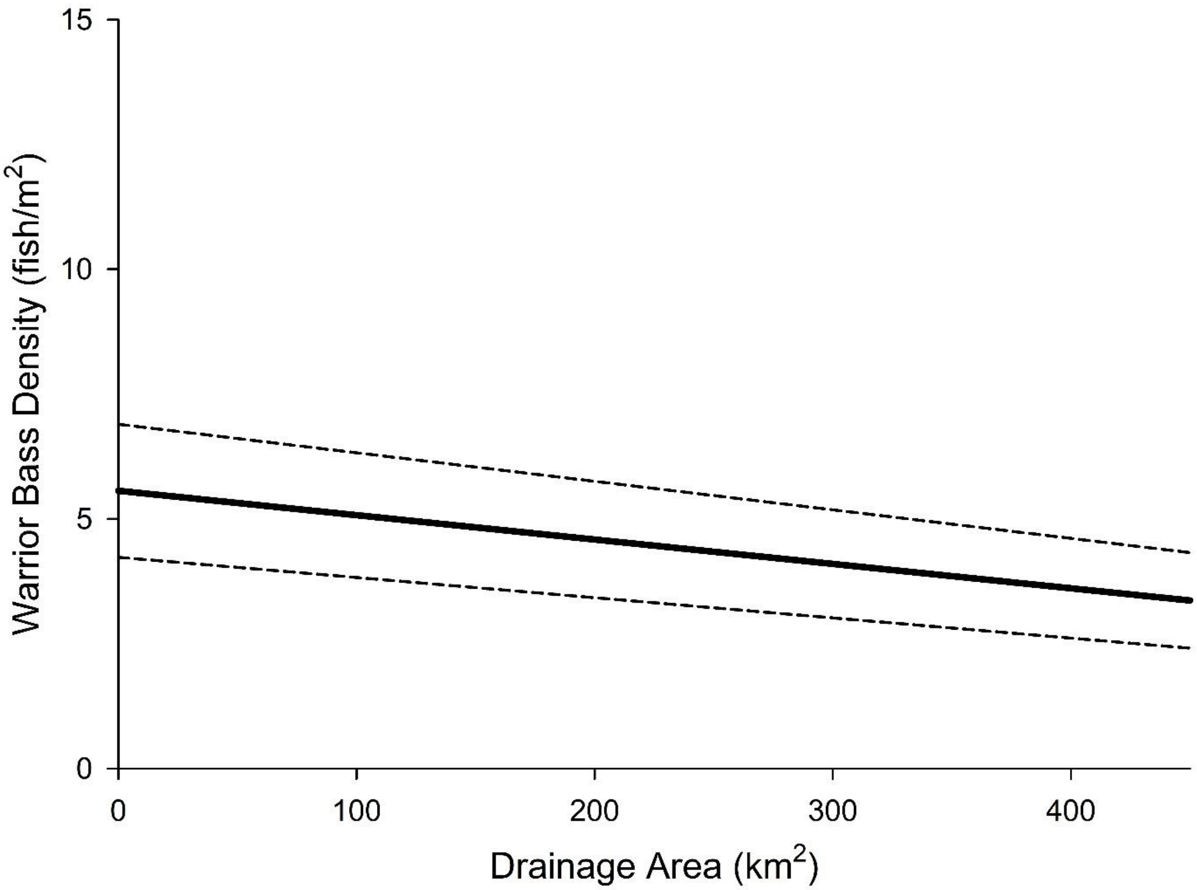

Figure 3.4. Relationship between Warrior Bass relative density and drainage area (km^2) of study streams in the Black Warrior Watershed, Alabama. Dotted lines represent standard errors.

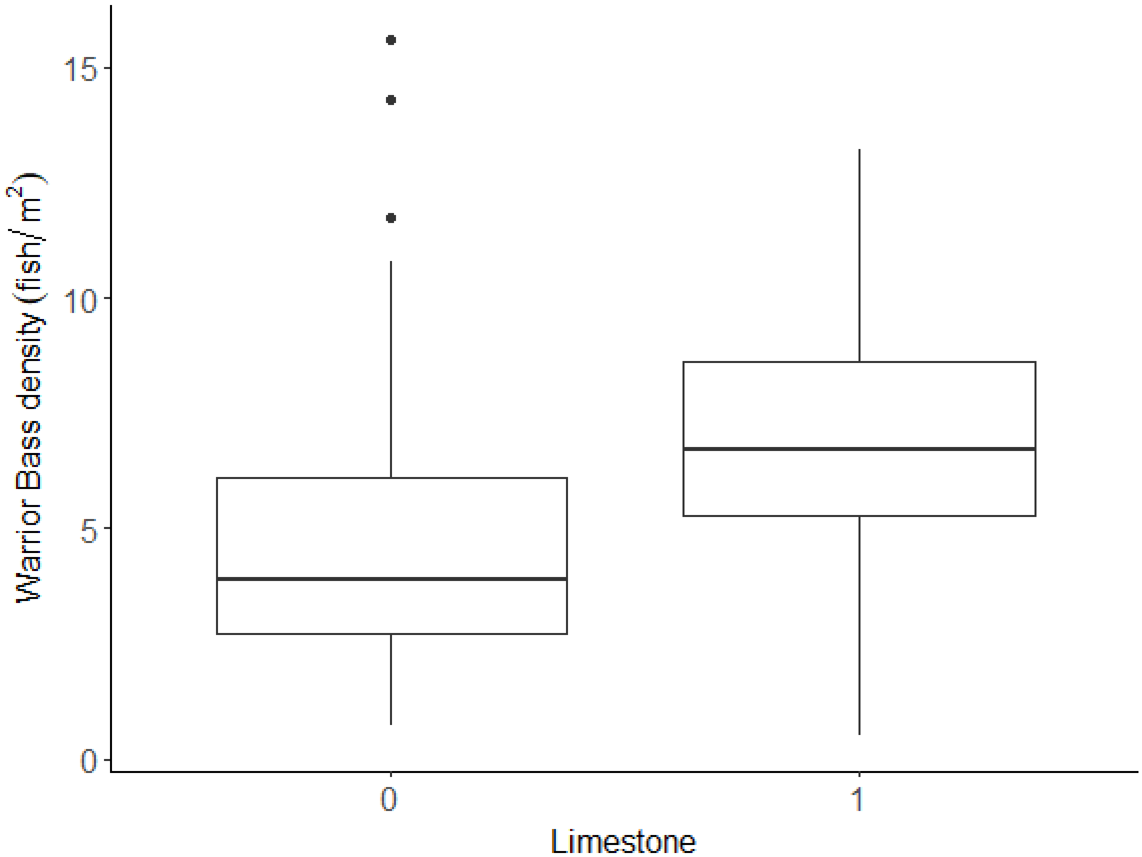

Figure 3.5. Relationship between Warrior Bass relative density and the proportion of limestone in the drainage area. Limestone 1 represents stream sites with drainage areas containing greater than 10% limestone and limestone 0 represents stream sites with drainage areas containing less than or equal to 10% limestone. The boxes represent the upper and lower quartiles, dark line in boxes is the median, whiskers represent highest and lowest values unless there are outliers in which case the whiskers are the highest and lowest value within the 1.5* interquartile range (Q3-Q1). Black dots are outliers that are greater than 1.5 *interquartile range.

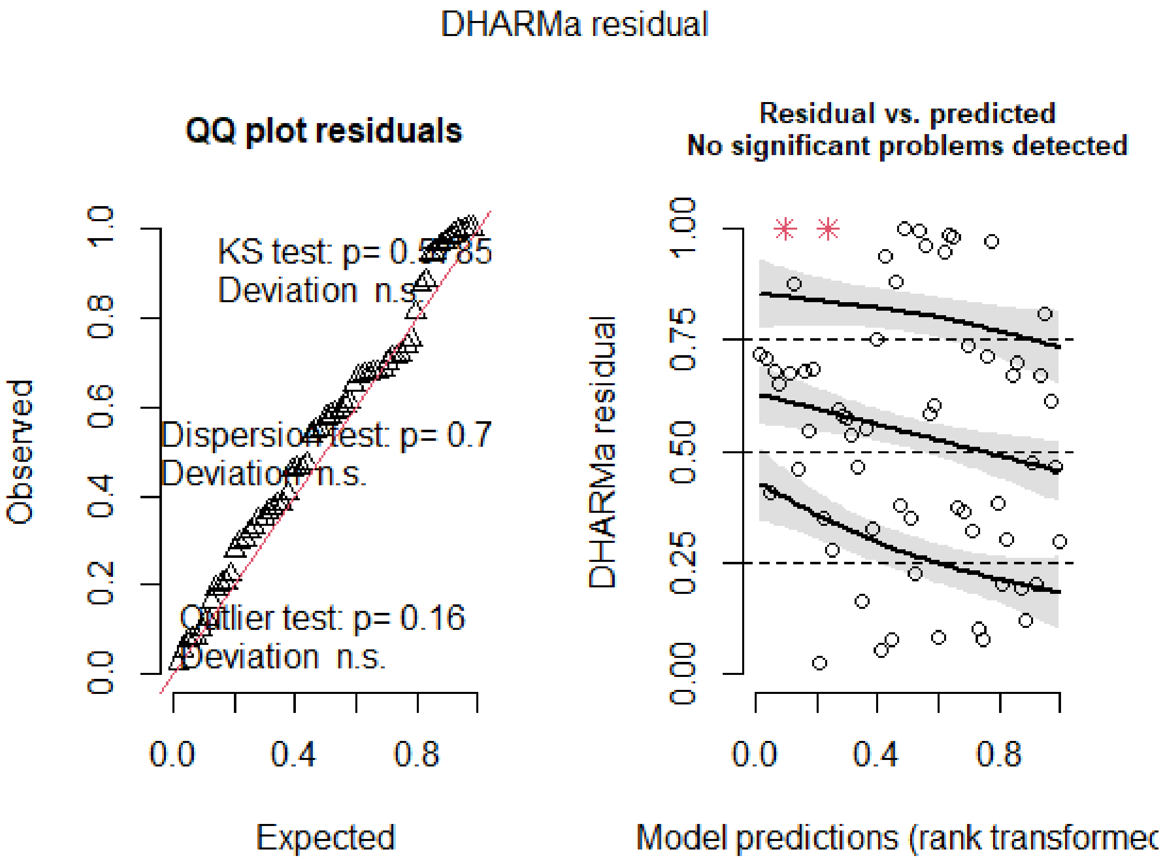

Figure 3.6. DHARMa residual diagnostic plots for the top ZIP model showing adequate fit for the model. The left plot (QQ- plot) of the observed versus expected residuals shows a uniform distribution (0,1) with no over dispersion of outliers. The p value that is reported is calculated from the Kolmogorov-Smirnov test. The right plot (residuals vs. predicted) shows no patters in the residuals and indicates an adequate model fit. As a visual aid a quantile regression is also ran which provides the black and dashed quantile lines. These lines should line up and be horizontal at the y-values of 0.25, 0.5, and 0.75. However, some deviation are expected, even for a perfect model. The red stars show two outliers that were not statically significant according to the outlier test (p = 0.16).

APPENDIX

Table A1. Potential sampling streams for Warrior Bass in the Black Warrior watershed. Streams are listed from upstream to downstream and approximate location in the watershed and county(ies) are given. Indented stream names followed by a (T) denote that they are tributaries of the stream named above them.

Area	Stream Name	County(ies)
Locust Fork Tributaries	Little Cove Creek	Etowah
	Clear Creek	Marshall
	Slab Creek	Blount/Marshall
	Graves Creek	Blount
	Little Warrior River	Blount
	Blackburn Fork (T)	Blount
	Calvert Prong (T)	Blount
	Whites Creek	Blount
	Hayes Creek	Blount
	Gurley Creek	Jefferson/Blount
	Self Creek (T)	Jefferson
	Turkey Creek	Jefferson
	Crooked Creek	Jefferson
	Cane Creek	Jefferson
	Five Mile Creek	Jefferson
	Village Creek	Jefferson
Mulberry Fork Tributaries	Hurricane Creek	Cullman
	Roswell Creek	Blount/Marshall
	Pan Creek	Cullman
	Lick Creek	Cullman
	Duck River	Cullman
	Two Mile Creek (T)	Cullman
	Indian Creek (T)	Cullman
	Broglan River	Cullman
	Eight Mile Creek (T)	Cullman
	Blue Springs Creek	Blount

Area	Stream Name	County(ies)
	Rice Creek	Cullman
	Dorsey Creek	Cullman
	Sloan Creek	Walker/Blount
	Blackwater Creek	Walker/Winston
	Rock Creek (T)	Walker
	Clear Creek (T)	Walker
	Browns Creek (T)	Winston
	Splunge Creek (T)	Winston
	Buck Creek (T)	Walker
	Cane Creek	Walker
	Burnt Cane Creek	Walker
	Baker Creek	Walker
	Wolf Creek	Walker/Fayette
	Lost Creek (T)	Walker
	Murphy Creek	Blount
	Town Creek	Walker
Sipsey Fork Above Lewis Smith	Thompson Creek	Lawrence
	Hubbard Creek	Lawrence/Winston
	Borden Creek	Winston/Lawrence
	Caney Creek	Winston
	Sandy Creek	Winston
	Tedford Creek	Lawrence
	West Fork Beech	Lawrence
	East Fork Beech	Lawrence
	Sipsey River	Lawrence
	Rush Creek	Lawrence/Winston
	Flannagin Creek	Lawrence/Winston
	Holmes Chapel	Lawrence/Winston
	Capsey	Lawrence
Lewis Smith Lake Tributaries	Brushy Creek	Winston/Lawrence
	Clear Creek	Winston
	Rock Creek	Winston/Cullman

Area	**Stream Name**	**County(ies)**
	Blevens Creek (T)	Winston/Cullman
	White Oak Creek (T)	Winston/Cullman
	Crooked Creek (T)	Cullman
	Ryan Creek	Cullman
Sipsey Fork Below Lewis Smith	Mill Creek	Walker
	Boyd Creek	Cullman
	Leeth Creek	Walker/Cullman
Black Warrior Above Tuscaloosa	Valley Creek	Jefferson
	Mud Creek (T)	Jefferson
	Blue Creek	Tuscaloosa
	Davis Creek	Tuscaloosa
	Yellow Creek	Tuscaloosa
	North River	Tuscaloosa/Fayette
	Binion Creek (T)	Tuscaloosa/Fayette
	Hurricane Creek	Tuscaloosa
	Little Hurricane Creek (T)	Tuscaloosa
Black Warrior Below Tuscaloosa	Big Sandy Creek	Tuscaloosa
	South Sandy Creek (T)	Tuscaloosa/Hale/Bibb
	Elliots Creek	Hale
	Grant Creek	Tuscaloosa
	Arthur Creek (T)	Tuscaloosa
	Buck Creek	Pickens/Tuscaloosa
	Little Buck Creek(T)	Pickens/Tuscaloosa
	Gabriel Creek	Hale
	Big Brush Creek	Hale

Table A2. Habitat scores used in this study to characterize the amount and complexity of large woody debris in each stream reach sampled. Scores were derived following a similar protocol used by the GADNR Stream Team Protocol for other variables.

Large Woody Debris **Description**	**Score**
No woody debris encountered during transect	**1**
Wood very rare during the transect, less than 5% of the transect had woody debris	**2**
Wood rare during the transect, 5-10% of the transect had woody debris	**3**
Wood somewhat rare during the transect, 10-20% of the transect had woody debris OR 5-10% coverage and one cluster was considered complex, covering more than 2 m^2 in area with lots of interstitial spaces	**4**
Average woody debris encountered during the transect, about a third of the transect had woody debris	**5**
Higher than average woody debris encountered during the transect; approximately 50% of the transect had woody debris OR average density with at least one complex cluster	**6**
Wood commonly encountered during the transect, usually each grouping was < 10 m apart and overall about 66% of the transect had woody debris OR higher than average density with at least one complex cluster	**7**
Wood commonly encountered during the transect and one cluster was considered complex	**8**
Wood commonly encountered and two clusters were considered complex	**9**
Wood commonly encountered and three or more clusters were considered complex	**10**

Table A3. Bank stability scores from used in this study, developed by the GADNR Stream Team

Bank Stability Description	Score
A. Bank stable, erosion absent or minimal, with little potential for future problems. Slopes are generally less than 30°. Banks may be reinforced by rock thus increasing the slope to >30° while providing stability.	
1. No evidence of erosion or bank failure	**10**
2. Less than 10% of bank affected by erosion	**9**
B. Moderately stable bank; small areas of erosion or bank slumping visible. Most areas are stable with only slight potential for erosion at flooding stages. Slopes up to 40°. Banks may be reinforced by rock thus increasing the slope to >40 while providing stability.	
1. 10% – 20% of bank has erosional areas	**8**
2. 20% – 30% of bank has erosional areas	**7**
3. 30% – 40% of bank has erosional areas	**6**
C. Moderately unstable bank; frequency and size of raw areas are such that high water events have eroded some areas of the bank. Medium size areas of erosion or bank slumping visible. Slopes up to 60°. High erosion potential during floods.	
1. 40% – 50% of bank has erosional areas	**5**
2. 50% – 60% of bank has erosional areas	**4**
3. 60%– 70% of bank has erosional areas	**3**
D. Unstable bank; mass erosion and bank failure are evident; erosion and pronounced undercutting present at bends and along some straight channel areas. Slopes > 60 are common. Areas of distinct slumping visible. Many raw areas are present and 70% - 100% of bank has erosional scars.	
1. 70% – 80% of bank has erosional areas	**2**
2. 80% – 90% of bank has erosional areas	**1**
3. > 90% of bank has erosional areas	**0**

Table A4. Bank vegetative protection scores used in this study, developed by GADNR Stream Team

Bank Vegetative Protection Description	Score
A. More than 90% of the stream bank surface is covered by healthy, living vegetation. A variety of different types of vegetation is present (e.g. trees, shrubs, understory, and non-woody macrophytes). Any bare or sparsely vegetated areas are small and evenly dispersed.	
1. 100% plant cover on stream bank	**10**
2. > 90% plant cover on the stream bank	**9**
B. A variety of vegetation is present and covers 70 – 90% of the stream bank surfaces, but one class of plants is not well represented. Some open areas with unstable substrate are present. Disruption evident but affecting full plant growth potential. Few barren or thin areas are present.	
1. 90% plant cover on the stream bank	**8**
2. 80% - 90% plant cover on stream bank	**7**
3. 70% - 80% plant cover on stream bank with fewer plant species	**6**
C. 50% - 70% of stream bank surface is covered by vegetation; typically composed of scattered shrubs, grasses, and forbes. Disruption obvious, with patches of bare soil and/or closely cropped vegetation common.	
1. 60% – 70% vegetation cove, typically of shrubs, grasses, and forbes	**5**
2. 50% – 60% vegetation cove, typically of shrubs, grasses, and forbes	**4**
D. Less than 50% of the stream bank surface covered by vegetation. Disruption of vegetation is prevalent. Any shrubs or trees on bank exist as individuals or widely scattered clumps.	
1. 40% – 50% vegetation cover with many bare spots/rock	**3**
2. 30% – 40% vegetation cover with many bare spots/rock	**2**
3. 20% – 30% vegetation cover with many bare spots/rock	**1**
4. <20% vegetation cover	**0**

Table A5. Habitat scores used in this study to characterize the amount and complexity of rock in each stream reach sampled. Scores were derived following a similar protocol used by the GADNR Stream Team Protocol for other variables.

Rocky Substrate Description	**Score**
No rocky substrate encountered	**1**
Very little rock encountered during transect, composed < 5% of the transect	**2**
Rock relatively rare during transect, composed 10-15% of the transect	**3**
Rocky substrate found in 25-30% of the transect but is mostly composed of small cobble or gravel with few boulders OR rock is rare in the transect but is grouped in 2-3 small rocky complexes covering around 2-3 m^2 each	**4**
Fine rocky substrate (cobble/gravel) comprises up to 50% of the transect OR substrate is mostly sandy but 4-6 isolated rocky complexes occur within transect	**5**
Fine rocky substrate comprises 60-75% of the transect OR boulder/bedrock substrate composes about 20-25% of the transect OR substrate is mostly sandy but more than 6 isolated rocky complexes occur within transect	**6**
Entire transect is composed of fine rocky substrate OR boulder/bedrock substrate composes about a third of the transect OR sandy substrate with more than 12 isolated rocky complexes within transect	**7**
Boulder/bedrock substrate comprises about half of the transect OR if less, multiple large rocky complexes exist within the transect, each covering more than 10 m^2	**8**
Boulder/bedrock substrate comprises about 66-75% of the transect OR if between 50-60%, multiple large rocky complexes exist within the transect, each covering more than 10 m^2	**9**
Virtually the entire transect contains rocky substrate, most of it composed of bedrock, boulders, and large rocky complexes	**10**

Table A6. National Land Cover Database classes with original landscape disturbance index (LDI) values (Brown and Vivas, 2005) that were used to calculate the new LDI classes and values.

New LDI Class	New LDI	Original LDI Class	Original LDI
Natural /Forested	1.00	Natural open water	1.00
Developed / Urban	7.86	Recreational / open space – low-intensity	1.83
Agriculture / Crop	3.91	Single family residential – low-density	6.90
		Low-intensity commercial	8.00
		Single family residential – medium density)	7.47
		Mobile home (medium density)	7.70
		Recreational / open space – high-intensity	6.92
		Single family residential – high density	7.55
		Mobile home (high density)	8.29
		High-intensity commercial	9.18
		Industrial	8.32
		Natural system	1.00
		Natural system	1.00
		Natural system	1.00
		Natural system	1.00
		Natural system	1.00
		Woodland pasture (with livestock	2.02
		Improved pasture (without livestock)	2.77
		Improved pasture – low-intensity (with livestock)	3.41
		Improved pasture – high-intensity (with livestock)	3.74
		Row crops	4.54
		Natural system	1.00
		Natural system	1.00

Table A7. Stream sites sampled in 2020 and 2021 with the number of surveys conducted, number of black bass species caught, gear type used and coordinates of each site. WB is Warrior Bass, WBH is Warrior Bass hybrids, ALB is Alabama Bass, LMB, is Largemouth Bass, SMB is Smallmouth Bass

Stream	Coordinates	Reach	Gear	WB	WBH	ALB	LMB	SMB
Blackburn	33.88135; -86.5821	2	C	13	13	0	0	0
Blackburn 2	33.87816; -86.43382	5	C	0	2	4	0	0
Blackwater	33.90674; -87.25587	4	C	0	3	22	0	0
Blevins	34.2308; -87.08688	6	C	0	0	10	3	0
Blue	33.52282; -87.48618	4	BP	7	7	0	1	0
Blue 2	33.45061; -87.41269	4	C	6	5	2	2	0
Blue R	33.52282; -87.48618	4	BP	15	7	0	2	0
Blue Springs	34.08481; -86.59517	4	BP	21	8	0	2	0
Blue Springs 2	34.05849; 86.63438	5	C	1	15	5	1	0
Blue Springs R	34.08481; -86.59517	4	BP	36	12	0	5	0
Borden	34.32986; -87.37708	4	BP	19	1	0	0	0
Borden R	34.32986; -87.37708	4	BP	30	2	0	2	0
Broglan	34.08059; -86.73603	4	C	0	8	51	8	0
Brushy	34.33077; -87.28731	4	BP	0	2	0	2	0
Buck	33.93979; -87.40793	3	BP	0	0	1	3	0
Burnt Cane	33.72052; -87.07074	5	BP	0	0	1	5	0
Calvert Prong	33.97825; -86.52914	5	C	0	24	19	3	0
Calvert Prong 2	34.00826; -86.44925	5	C	0	18	3	1	0
Cane	33.81817; -87.31511	4	C	0	0	0	2	0
Capsey	34.27015; -87.20966	4	BP	26	6	1	0	0
Clear Locust	34.18538; -86.17095	4	BP	0	1	3	1	0
Clear Sipsey	34.07984; -87.42171	5	C	0	0	0	0	0
Crooked Lewis	34.22026; -86.97771	6	C	0	0	6	4	0
Crooked Locust	33.70876; -86.85932	4	BP	0	0	3	0	0
Davis	33.28738; -87.19723	3	BP	0	0	0	0	0

Stream	Coordinates	Reach	Gear	WB	WBH	ALB	LMB	SMB
Dorsey	33.96269; -86.99053	3	BP	0	0	0	0	0
Duck	34.26334; -86.66865	6	C	0	0	0	24	0
EF Beech	34.29791; -87.30752	5	BP	0	0	0	0	0
Eight Mile	34.28667; -86.75378	5	BP	0	0	0	1	0
Five Mile	33.59401; -86.80882	5	C	10	58	10	1	0
Five Mile 2	33.60463; -86.71817	5	C	60	4	0	0	0
Five Mile R	33.59401; -86.80882	4	C	15	52	5	1	0
Flannagin	34.33993; -87.38837	5	BP	74	8	0	0	0
Graves	34.05769; -86.56544	3	BP	0	0	0	2	0
Gurley	33.80725; -86.71120	5	C	0	18	16	3	0
Hayes	33.88797; -86.73070	5	BP	0	0	1	0	0
Holmes Chapel	34.2734; -87.25219	2	BP	0	0	0	0	0
Hubbard	34.30666; -87.50343	3	BP	0	0	0	3	0
Hurricane	34.14164;-86.60403	4	BP	0	0	0	0	0
Indian	34.19989;-86.71050	5	BP	0	0	0	0	0
Leeth	33.88191;-87.05540	5	BP	0	0	0	0	0
Little Buck	33.01234;-87.78304	4	BP	0	0	0	3	0
Little Hurricane	33.17553;-87.30836	4	BP	0	0	3	0	0
Little Mill	33.94270;-87.16079	2	BP	0	0	0	2	0
Little Warrior	33.92128;-86.60897	4	C	0	12	22	0	0
Lost	33.88836;-87.49688	5	C	0	17	3	5	2
Murphy	33.91769;-86.81697	4	BP	62	13	2	0	0
North River	33.56140;-87.62804	5	C	0	2	17	4	0
Rice	33.92544;-86.92278	3	BP	0	0	3	1	0
Rock Lewis	34.24086;-87.13436	5	C	0	0	1	1	0
Roswell	34.25809;-86.46182	3	BP	0	0	0	3	0
Rush	34.29762;-87.2225	4	BP	9	3	0	0	0
Rush 2	34.27394;-87.25167	5	BP	29	4	1	0	0
Ryan	34.17156;-86.89137	5	C	0	1	20	1	0
Sandy	34.22427;-87.42921	4	BP	0	0	0	0	0

Stream	Coordinates	Reach	Gear	WB	WBH	ALB	LMB	SMB
Self	33.75184;-86.71227	4	C	9	25	0	3	0
Self 2	33.74474;-86.68172	4	BP	24	14	0	1	0
Self R	33.75768;-86.7244	4	BP	12	21	0	0	0
Sipsey Fork	34.28374;-87.39533	5	C	11	1	16	0	0
Slab	34.19454;-86.36510	4	C	0	1	5	2	0
Sloan	33.84395;-86.95959	5	BP	0	0	0	0	0
Splunge	34.04549;-87.51348	4	C	0	0	0	1	0
Tedford	34.35263;-87.47267	5	BP	26	0	0	0	0
Thompson	34.34277;-87.47048	4	BP	15	2	0	0	0
Town	33.83641;-87.27622	4	BP	0	0	0	11	0
Two Mile	34.14553;-86.67819	5	BP	0	0	0	0	0
Valley	33.39000;-87.01404	6	C	0	16	51	0	0
WF Beech	34.2998;-87.31705	4	BP	0	0	0	0	0
Wolf	33.73824;-87.46088	3	C	0	0	2	0	0
Yellow	33.36015;-87.46161	3	BP	0	0	0	2	0

Table 8. Covariate summaries for the Sipsey Fork River (SFR), Mulberry Fork River (MFR), Locust Fork River (LFR), and the Upper Black Warrior (UBW) catchments.

Catchments	Min	Max	Average	SD
Sipsey				
Order	2	6	3.681818	0.838727
Rock	2.75	10	6.961364	2.022783
Pool	5	26.25	12.82197	6.970521
Run	25	91.25	62.89394	15.88867
Riffle	3.333333	48	21.90152	14.13979
Shoal	0	16.66667	2.405303	4.622974
Soil Group D	0	0.9504	0.551073	0.339265
Limestone	0	0.351752	0.062032	0.120389
LDI	1.070307	4.250337	1.672175	0.825277
Mulberry				
Order	2	5	3.285714	1.101946
Rock	1	10	6.074603	2.682213
Pool	5	90	19.26515	20.84997
Run	10	88.75	57.14015	19.72467
Riffle	0	65	19.76515	18.73663
Shoal	0	28.75	4	7.67378
Soil Group D	0.016924	0.776306	0.359619	0.227645
Limestone	0	0.695513	0.090226	0.229155
LDI	1.180737	4.297739	2.629594	0.852573
Locust				
Order	3	5	3.923077	0.759555
Rock	5.4	9.75	7.816667	1.583465
Pool	5	23.75	14.02083	6.231528
Run	23.75	73	51.44792	15.29348
Riffle	0	42.5	17.09375	13.02781
Shoal	0	58.75	17.45313	20.53396
Soil Group D	0	0.406676	0.170047	0.125136

Catchment	Min	Max	Average	SD
Locust				
Limestone	0	0.546672	0.127528	0.144938
LDI	1.74913	2.732247	2.178146	0.341951
Upper Black Warrior				
Order	3	5	3.571429	0.786796
Rock	3.666667	10	7.459524	2.605618
Pool	3	27.5	14.15625	8.353836
Run	22.5	86.66667	62.59375	18.24179
Riffle	0	18.75	9.604167	6.348314
Shoal	0	34	13.95833	12.84786
Soil Group D	0.009221	0.635046	0.210787	0.246328
Limestone	0	0.127888	0.027691	0.050559
LDI	1.198034	2.646366	1.535843	0.520246