Black Bass Habitat Use and Availability at Multiple Scales in Middle Chattahoochee River Tributaries

by

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Abstract

The focus of this study was on tributaries of the Middle Chattahoochee River where Shoal Bass *Micropterus cataractae* and Chattahoochee Bass *Micropterus chattahoochae* are experiencing declines, mainly due to anthropogenic disturbances of streams and introductions of non-native congeners. This study examined habitat use of black bass and the presence/absence of Shoal Bass and Chattahoochee Bass at multiple scales. Point and transect surveys, canoe surveys, side-scan sonar mapping techniques, and available land use data were used to measure habitat characteristics at each scale. Black bass were sampled by both backpack electrofishing and by canoe-mounted electrofishing. Results indicated that suitable habitat for Shoal Bass included rocky boulder habitats with shallow depths and wide stream banks in heavily forested areas of large watersheds and Chattahoochee Bass were found in highly natural and forested land cover areas small watersheds in wider sections of the stream in rocky and shallow fast-moving shoal habitats. Surveys revealed that Shoal Bass populations can persist in smaller watersheds with enough ideal habitat. Chattahoochee Bass would likely benefit from habitat restoration for Shoal Bass in streams where they are sympatric. Side-scan sonar surveys were conducted on smaller streams, smaller than previously attempted, and results indicated that this method was useful to map habitat in these systems. Conclusions of this study indicated that priority streams for Shoal Bass and/or Chattahoochee Bass restoration, restocking efforts, and the reduction in non-native bass populations included the Dog River, Centralhatchee, Hillabahatchee, Wehadkee, Mountain Oak, and Osanippa creeks.

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List of Abbreviations

ALDWFF	Alabama Division of Wildlife and Freshwater Fisheries
BD	Bedrock
BR	Boulder
COB	Cobble
CPE	Catch-per-effort
GADNR	Georgia Department of Natural Resources
GLM	Generalized Linear Model
GPC	Georgia Power Company
GR	Gravel
MMU	Minimum Mapping Unit
MSW	Mean stream width
NFWF	National Fish and Wildlife Foundation
NLCD	National Land Cover Database
NBBI	Native Black Bass Keystone Initiative
RRET	Representative Reach Extrapolation Technique
SARP	Southeast Aquatic Resource Partnership
SD	Sand
WRD	Wildlife Resources Division
USGS	United States Geological Survey

Definitions of Note

Mesohabitat	An intermediate scale of habitat in streams defined by laminar or turbulent flow, depth, and substrate particle size. Examples include: pools, riffles, runs, and shoals.
Microhabitat	A small scale measure of physical conditions in a localized area of a stream. Examples include: depth, fluid velocity, stream width, and substrate particle size.
Pool	A type of stream mesohabitat defined by slow-moving laminar flow, moderate to deep depth, and typically consists of sand and silt substrates.
Reach	A section of stream defined arbitrarily or based on geology, stream access, or area of concern that typically consists of multiple stream mesohabitats.
Riffle	A type of stream mesohabitat defined by moderate turbulent flows, shallow depths and typically smaller diameter substrates.
Run	A type of stream mesohabitat defined by relatively laminar flow, moderate to shallow depth, and typically lack rocky substrates.
Shoal	A type of stream mesohabitat defined by highly turbulent flow and rapids, eddie currents, shallow to moderate depth, and rocky substrates.
Side-Scan Sonar	Use of a boat-mounted sonar device that emits a pulse towards the stream bottom and sends back an acoustic image that allows the viewer to interpret habitat from the stream floor based on shape, intensity, and pattern of images.

I. INTRODUCTION

Types of anthropogenic disturbances affecting native communities of aquatic organisms include biological introduction of non-native species, river impoundments by dams, channelization of rivers, bank erosion caused by changes in land use, water withdrawal, and nutrient point-source pollution caused by farming and urban practices (Webster et al. 1992; Doyle et al. 2005; Simon and Rinaldi 2006). Shoal Bass *Micropterus cataractae* are a native black bass that is experiencing declines through their native range. Once prolific throughout the Chattahoochee River, Alabama-Georgia, construction of numerous dams resulted in widespread declines in Shoal Bass populations. Currently, Shoal Bass in the Chattahoochee Basin south of Atlanta, Georgia, persist in small isolated populations below dams in the main channel and in tributaries streams (Boschung and Mayden 2004; Stormer and Maceina 2008; Sammons and Maceina 2009). This study focused on populations of black bass in tributary streams of the Middle Chattahoochee River and their habitat use and habitat availability.

I.1. ***Black Bass in the Chattahoochee River Basin***

Shoal Bass are endemic to the Apalachicola River drainage, which includes the Apalachicola, Chattahoochee, and Flint rivers in portions of Alabama, Georgia, and Florida. Additionally, the species was introduced in the 1970s into the Ocmulgee River, Georgia, a major river in the Altamaha River Basin (Sammons et al. 2015). The holotype for the Shoal Bass was collected in the upper Chipola River, Florida, a tributary of the Apalachicola River (Williams and Burgess 1999). Shoal Bass are considered to be fluvial specialists that prefer rocky riffles, shoals, and runs, are typically found in small to medium rivers and streams, and are intolerant to lentic conditions (Williams and Burgess 1999).

In 1989 Shoal Bass were assigned a status of Special Concern by the American Fisheries Society Endangered Species Committee (Williams et. al 1989). In Alabama, Shoal Bass were historically found in Osanippa, Halawakee, Little Uchee, Wacoochee, and Wehadkee creeks (Williams and Burgess 1999; Boschung and Mayden 2004), but surveys in the mid-2000s revealed that Shoal Bass had been nearly extirpated from three of these streams (Stormer and Maceina 2008). In 2004 the species was assigned a status of High Conservation Concern in Alabama (Mirarchi et al. 2004), their harvest was consequently prohibited on October 1, 2006, and in 2007 the Alabama Division of Wildlife and Freshwater Fisheries (ALDWFF) initiated a restocking program in an attempt to restore populations in these tributaries. However, follow-up surveys conducted to determine the success of restocking found few stocked Shoal Bass (Sammons and Maceina 2009). Severe droughts before, during, and after restocking may have influenced the success of the stocking effort by reducing abundance in prey species and increasing the potential for competition by native and introduced congeneric species (Stormer and Maceina 2008).

The Chattahoochee Bass *M. chattahoochae* is a black bass that was recently described by Baker et al. (2013) as being endemic to the Chattahoochee River and as member of the Redeye Bass *M. coosae* species group. It differs from all other members by having broad margins of bright orange pigment on posterior dorsal, caudal, and anal fins and by a wider head than other species within the group. The holotype for Chattahoochee Bass was collected in Centralhatchee Creek in March 2009, and they have since been collected during this study in Whooping Creek, Snake Creek, and Dog River within the Middle Chattahoochee River.

The Spotted Bass *M. punctulatus* was introduced into the Apalachicola River Basin below the Fall Line in the Flint River sometime prior to 1941, near the present day location of

Lake Seminole (Williams and Burgess 1999). A second introduction of Spotted Bass in the 1960s occurred above the Fall Line in the Chattahoochee River upstream of hydropower dams near Columbus, Georgia. Additional collections of Alabama Bass *M. henshalli* occurred in the 1970s on the upper Chattahoochee River above Atlanta, Georgia (Williams and Burgess 1999). The threat of introgressive hybridization is a well-documented, serious concern for the genetic integrity of native black bass populations that could lead to major shifts in the specialization of well-adapted endemic fish species (Koppelman 1994; Avise et al.1997; Barwick et al. 2006). Morizot et al. (1991) documented the loss of genetic integrity of native Guadalupe Bass *M. treculi* through multispecies hybridizations with introduced Smallmouth Bass *M. dolomieu* and Florida Largemouth Bass *M. salmoides floridanus*. However, the effects of introduced Spotted Bass on native Shoal Bass have been little studied. Habitat partitioning occurs naturally between native Shoal Bass and Largemouth Bass M. salmoides (Wheeler and Allen 2003); but, Goclowski et al. (2013) found that the introduced Spotted Bass in Flint River, Georgia, functioned as an intermediate habitat generalist, suggesting that Spotted Bass could serve as a competitor for resources for either native species. Spotted Bass are highly adaptable, able to persist equally well in reservoirs and small streams (Churchill and Bettoli 2015); whereas Shoal Bass populations have been fragmented into relatively discrete populations between reservoirs because of their intolerance to lentic conditions (Wheeler and Allen 2003; Boschung and Mayden 2004; Stormer and Maceina 2008).

I.2. *Black Bass Business Plan and Habitat Importance*

The National Fish and Wildlife Foundation (NFWF) Native Black Bass Keystone Initiative (NBBI) selected the Middle Chattahoochee River as an area of focus for conserving native endemic black bass species in the southeastern United States (Birdsong et al. 2010; Figure

1). Efforts to protect charismatic species, like Shoal Bass and Chattahoochee Bass, in aquatic environments may also help in protecting other sympatric species such as other fishes, mussels, plants, and crayfish. Shoal habitats appear to be important for the persistence of these native black bass in tributaries of the Middle Chattahoochee River and Shoal Bass were documented traveling up tributary streams via radio telemetry, presumably to spawn (Sammons and Earley 2015). Georgia Power Company biologists have also collected large numbers of age-0 Shoal Bass in large shoals within Chattahoochee River tributaries (J. Slaughter, Georgia Power Company, unpublished data). Larval, juvenile, and adult Shoal Bass have also been shown to express ontogenetic shifts in the use of distinct microhabitats (boulder substrates at varying depth) within shoals (Johnston and Kennon 2007), so differing microhabitat availability may be important for future restoration efforts.

There have been numerous studies documenting the effects of habitat alteration on the imperilment of freshwater fishes e.g., (Warren et al. 2000; Sullivan et al. 2004; Diana, Allan, and Infante 2006; Hrodey 2009), and Middle Chattahoochee River tributaries are suffering similar habitat loss from increased sedimentation (siltation and impacted rocky substrate) and altered hydrology from changing land use (Walser and Bart 1999). Determining habitat suitability can assist biologists in finding optimum habitat for fish species, including velocity, depth, substrate, and cover use (Freeman et al. 1997).

I.2. *Habitat Surveys*

A widely-used method for measuring habitat is the representative reach extrapolation technique (RRET), where biologists measure habitat in a particular reach of stream and extrapolate those metrics to larger scales. Reaches selected in the RRET are assumed to yield habitat estimates that are representative of the entire stream or watershed, and the location, length, and number of reaches can vary depending on the expected heterogeneity of the stream habitat (Doloff and Jennings 1997). The RRET assists in identifying discrete hydraulic channel units, provides quantitative descriptions of each channel unit, and identifies statistical differences in microhabitat characteristics. Stream reaches are typically sampled by some form of point and transect surveys which are a standardized method for collecting data specific to a reach that represents a stream (Simonson 1994; Perkin 2010; Fore et al. 2011). Data collected included metrics of microhabitat, and black bass species catch data within multiple mesohabitats. Data collected informs conditions of microhabitat and catch of black bass species within specific mesohabitats (Sammons and Maceina 2009). Until recently, use of methods like the RRET were difficult in larger, non-wadeable streams due to the logistics and manpower required to quantify habitat in these streams. Kaeser and Litts (2010) developed a side-scan sonar technique for mapping continuous instream habitat across broad aquatic basins. Side-scan sonar is typically used for mapping larger streams, rivers, and reservoirs but little use of this technique has been done at smaller stream sizes (Kaesar and Litts 2010).

This research explores the plausibility of mapping small 4th order streams to larger 5th order streams to estimate habitat characteristics of substrate type, surface area, depth, and amount of large woody debris within the bank-full channel of each stream. Mapping the entire navigable section, rather than within single or multiple reaches within a stream can assist in defining critical habitat associations of imperiled species of fish for future restoration work. Side-scan sonar surveys are a cost-effective method because the unit, required software, and time spent in the field are inexpensive when compared to the labor and time that would be required for manual field measures of the same habitat (Kaesar and Litts 2010).

The snapshot method of side-scan sonar mapping uses images of the habitat taken in the field survey where images are slightly overlapped so they can be stitched together in post-processing. Images are overlapped to maintain the maximum habitat in an image while having enough overlap for rectification in post-processing. Time between image captures is determined by scanning distances of each stream bank relative to canoe position in the center of a stream, with larger scanning distances having longer time between captures and vice versa. Time between captures is standardized by the use of an interval timer that repeatedly signals a specific time interval (Kaesar and Litts 2010). In this method, sonar image processing consists of extracting the GPS path from the sonar files using Hummingbird software and geo-referencing each stream path in ArcGIS (Hummingbird 2012; ESRI 2011); then removing the image collar from the raw imagery that included data such as depth, GPS coordinates, speed, and temperature, leaving just the imaged portion (Figure 2). Then side-scan sonar software developed for ArcGIS is used to generate a 30-point control point network that warps, or rectifies, the image to follow the GPS path generated in the field with different set of points representing one separate captured images. Images are then georeferenced and stitched together to create a single image of the entire mapped stream (Figure 2). For both video and snapshot methods, habitat is interpreted and delineated to quantify the amount of microhabitat and mesohabitats of each stream and to generate an instream habitat map (Figure 3).

The video recording method of side-scan sonar is a simpler approach, where scanning width is set similar to what was described above, recording starts, and the canoe is navigated to the end of the desired stream section. It records the instream imagery similar to a video and can be viewed as one large image. Sonar TRX (2015) is a relatively inexpensive software developed to take the recorded imagery and georeferenced it to aerial imagery and allow it to be loaded into ArcGIS. Delineation of habitat is performed in the same manner as above.

Many stream restoration endeavors base their restoration efforts on habitats of importance at the microhabitat scale and often ignore habitats of importance at larger scales often leading to failed population recovery because they missed something of greater or equal importance to a species at a larger watershed scale (Bond and Lake 2003; Petty 2001; Miller et al. 2009). Studies in the past have often focused on one scale while ignoring parameters that are important to a community at multiple spatial scales. Restoration work based on a single scale approach have often failed due to habitat factors not measured at a different, often larger, scale important to the survival of a species or community (Thomas et al. 2015). The cost of failed restorations is substantial and includes monetary costs, localized loss of species, and the loss of public support of restoration efforts (Bond and Lake 2003). A multi-scale approach increases the efficiency in restoration efforts by understanding what streams are ideal for restoration while eliminating poor candidate streams that don’t meet criteria necessary to prevent black bass species extirpation (Cheek et al. 2015). Multi-scale approaches also increases explanatory power in what might be affecting a species and its habitat at higher or lower spatial scales.

Cheek et al. (2015) found that the finest spatial scale and the intermediate scale had the greatest explanatory power in the fish assemblage structure and that few studies have measured habitat using a system-wide approach to capture what was important to the persistence of a black bass species. Measures taken over subsequent years, or when compared to historical data, can show losses of quality habitat over time (Petty et al. 2001). For instance, Villarini et al. (2015) studied land use changes and projected probable future conditions based on historical trends in land use from past and current satellite imagery. Frick and Beull (1999) studied the main source of nutrient input in the Upper Chattahoochee River and selected tributaries based on predominant land use practices and found that the main sources of nutrient input came from poultry and livestock production followed by urbanized development, and found that tributaries with silviculture management produced the lowest yields of nutrient input. Schleiger (2000) created an index of biotic integrity based on land use and samples of the entire stream community with streams ranging from relatively pristine to heavily disturbed. Nonpoint source and point source runoff negatively influenced the number of fish species of several guilds, and high levels of suspended solids had a negative influence on the number of sensitive species, fish density, proportion of lithophilic spawners, and proportion of omnivores.

I.3. *Research Goals*

The purpose of my research was to determine the habitat use, availability of habitat, and distribution of black bass, specifically the endemic black bass species found in the Middle Chattahoochee River, (i.e. Shoal Bass and Chattahoochee Bass) at multiple scales to determine suitable streams for future restoration of their habitat and native restocking of the population. Habitat scales included microhabitat, mesohabitat, and macrohabitat that each give specific information that will be important in determining target streams for future restoration. At the microhabitat scale I attempted to determine what microhabitats (depth, velocity, stream width, wood cover, rock cover, and substrate) native endemic black bass were associated, estimate how much of each microhabitat was available for each stream, and compare microhabitat in streams where they are absent to streams where they are present. At the mesohabitat scale I attempted to determine which mesohabitats native endemic black bass were associated with, estimate how much of each mesohabitat was present in each stream, and compare mesohabitat in streams where they are absent to streams where they are present. At the macrohabitat or watershed scale the goal was to determine what land use patterns existed in watersheds where native endemic black bass were present and compare them to land use patterns in watersheds where native endemic black bass were absent. This information will greatly help to fill critical information gaps in the habitat use of Shoal Bass and Chattahoochee Bass as part of the NBBI proposed by NFWF. Some of the specific objectives of the NBBI included a need for better understanding of native endemic black bass habitat use, land use patterns in watersheds Shoal Bass are found, and determine the degree of invasion of the non-native Spotted Bass (Birdsong et al. 2010). This study had four objectives: 1) determine presence and abundance of black bass in selected Middle Chattahoochee River tributaries, 2) estimate habitat of these streams at three spatial scales, 3) determine habitat associations of black bass, and 4) determine priority streams for restoration of Shoal Bass populations and their habitat.

II. Methods

II.1. *Study Area*

Surveys at each scale were conducted in tributaries of the Middle Chattahoochee River from Atlanta, Georgia downstream to Walter F. George Reservoir, Alabama-Georgia (Figure 1; Table 1). All Streams were sampled at each spatial scale for habitat and five streams below West Point Reservoir were mapped with a side-scan sonar unit for instream habitat (Figure 1; Table 1). All streams were located in the Piedmont physiographic region with the exception of Uchee Creek, Alabama, which was in the Upper Coastal Plain. Little Uchee, Mulberry, Wacoochee, Standing Boy, Mulberry, Halawakee, Mountain Oak, Osanippa, and Flat Shoals creeks enter the Chattahoochee River in the Fall Line area, which is a transition region approximately 32 km long boundary that separates the Piedmont from the Upper Coastal Plain physiographic region.

Streams in this area are generally characterized by rocky substrates, high gradient, and greater velocity flows.

II.2. *Field Surveys*

II.2.1. *Microhabitat Survey*

Habitat was surveyed in wadeable reaches of Middle Chattahoochee River tributaries from May-September 2014. Surveys used the point and transect method (Tillman et al. 1998; Gillette et al. 2006). Mean stream width (MSW) was determined by measuring 5-8 transects along the reach, and habitat was surveyed along a reach approximately 40 MSW long. Reaches were chosen to encompass each mesohabitat present (shoal, riffle, run, pool), and habitat measurements were taken along transects placed every 2 MSW apart perpendicular to flow along a sampling reach (Simonson et al. 1994). Each transect measured stream width (bank-full and current [wetted] flow), water depth, velocity, and substrate particle size along five equidistant points along each transect. Water depth and velocity (measured using a Hach FH950 flow meter and wading rod) were measured at 60% depth if depth was <0.75m, or at greater depths was measured at 20% and 80% depth and then averaged (Tillma et al. 1998). Dominant substrate particle size was classified according to a modified Wentworth scale and habitat estimates were made by a single observer to maintain consistency (Table 2; Cummins 1962; Roper and Scarnecchia 1995). The reach was visually divided into mesohabitats (pool, run, shoal, and riffle) during habitat mapping. Percent rocky substrate and instream woody debris were visually estimated for each mesohabitat. Data sheets of habitat surveys and backpack electrofishing are available in the appendix.

Black bass were sampled from each mesohabitat using a Smith-Root backpack electrofishing unit and seine. Black bass sampling generally took place the same day habitat surveys were conducted, but in a few of the larger streams these samples were conducted on the following day. All black bass collected were identified, measured (total length [TL]), weighed (g), and fin clipped for further genetic analysis in an associated study. Catch-per-effort (CPE; number/h) was calculated for bass species in each sampled mesohabitat within each stream. Single-pass sampling was used, which has been shown to collect most species present (Paller 1995; Liefferinge et al. 2010). Habitat and catch data were collected in 2008 for Osanippa, Little Uchee, Halawakee, and Wacoochee creeks. Data collected was used to characterize the habitat within discrete mesohabitats, which was then associated with the presence of a black bass species to determine habitat use of those species (Perkin 2010; Fore et al. 2011).

II.2.2. ***Mesohabitat Survey and Side-Scan Sonar Survey***

In summer 2013-2015, all study streams were sampled for black bass using a canoe-mounted DC-electrofishing unit and handheld anode (Sammons et. al 1999). Sampling was conducted during periods of navigable flows with >1 m water clarity along 1.40 to 7.64 km reaches; 2 to 17 fifteen-minute transects were collected from each sample reach, spaced at least 10 m apart. Start and end points were mapped for each transect and percent mesohabitat was estimated (shoal, run, and pool). All black bass collected were identified, measured (total length [TL]), weighed (g), and fin clipped. Canoe electrofishing transect datasheets are available in the appendix.

During the winter months of 2015 when water levels were high, a Hummingbird side-scan sonar unit, with a boat-mounted transducer (Hummingbird 2012) was employed to map the instream habitat of selected Middle Chattahoochee River tributaries (Figure 1; Table 1). Images are then digitized and georeferenced in ESRI ArcGIS 10 to quantify the habitat (ESRI 2011). Mapping was conducted in accordance with methods described by Kaeser and Litts (2010). Start and end GPS points are listed in the appendices for each stream. For each selected stream the canoe began at upstream bridge crossings and was navigated downstream with a stern-mounted boat motor. The scanning distance on either side of the boat was determined by finding the mean and maximum stream width of measured stream widths from aerial imagery using ArcGIS on the mapping section scanning distances included several meters of bank habitat so no instream information was lost (Kaeser and Litts 2010). The unit recorded a GPS path for use in post-processing and recorded the instream imagery by either the snapshot or the video recording method. Substrate was classified into six distinct groups based on the percent a given area included the particular substrate, and the size of the substrate. Kaeser and Litts (2010) determined a minimum mapping unit (MMU) by extensive manual stream surveys of mapped habitat and compared it with sonar mapped habitat. A MMU, which was a 3-m radius, was used to determine when an area was large enough to be delineated as a particular substrate. All substrates follow the modified Wentworth scale listed in Table 2. Bedrock substrates were defined by areas of instream habitat where > 75% of an area was bedrock substrate. Boulder, cobble, and sand/ gravel substrates were defined by mapped habitats where the substrate was greater than the MMU. Areas where the imagery was distorted and substrate was not classified were defined as ‘unsure,’ and areas where the sonar beam cast a shadow and masked the substrate were defined as shadow. Mesohabitats were determined by depth and habitat characteristics of mapped streams. During the summer months at low water conditions, I conducted an accuracy assessment of representative mapped substrates (bedrock, boulder, cobble, and gravel/sand) in Mulberry Creek to assess the dimensional accuracy of transformed imagery by methods described by Kaeser and Litts (2010). Locations of multiple substrates were recorded to a GPS unit from transformed imagery in ArcGIS and then field measures of substrate were performed to verify the classification of each substrate.

II.3. ***Macrohabitat and Overall Habitat Analyses***

All statistical data analyses were conducted using Program R statistics software (R Core Team 2015). Catch of black bass species and habitat features was correlated to measured habitat features of data at each scale (Layher et al. 1987; Tillma et al. 1998). Streams were separated based on the presence/absence of Shoal Bass and distributions of microhabitat variables (depth, velocity, stream width, estimated rock cover, estimated wood cover) were compared using a Kolmogorov–Smirnov test (K-S test) with significance set at $P < 0.05$. Mean microhabitat variables were measured using a Welch Two Sample t-Test (R Core Team 2015). Streams were separated based on the presence/absence of Shoal Bass and distributions of mean substrate composition (bedrock, boulder, cobble, gravel, sand) were compared using a Chi-squared test. Mean substrate composition was compared between streams with and without Shoal Bass using an analysis of variance (ANOVA) with a Student-Newman-Keuls Test (R Core Team 2015; $P < 0.10$). Microhabitat variables were compared among streams with and without Chattahoochee Bass using only streams above West Point Reservoir. The distributions of the species is mostly known to be upstream of this reservoir (Baker et al. 2013), thus absence of this species from streams further down in the watershed may not indicate habitat associations. Mean overall catch of each black bass species was examined by pooling the mean catch of each black bass species across streams, with associated standard deviations (R Core Team 2015). Mean CPE of each black bass species was examined for each black bass species, for each stream, and for all streams; and their sample standard deviations were calculated (R Core Team 2015).

Multiple regression analysis examined relationships among stream habitat data at the microhabitat scale and black bass species catch with a generalized linear model using a Poisson distribution for count data without overdispersion that converged or negative binomial distribution for count data with overdispersion when Poisson distributions failed to converge (O'Neil and Faddy 2002), of the form:

$$\boldsymbol{Black\ Bass\ Catch = \beta_0 + \beta_1(Hab_1) + \beta_2(Hab_2\ ) \ldots + \beta_k(Hab_k) + \varepsilon_{stream} + \varepsilon_r} \tag{1}$$

where $\boldsymbol{\beta_0}$, $\boldsymbol{\beta_1}$, $\boldsymbol{\beta_2}$, and $\boldsymbol{\beta_k}$ were the regression coefficients for the intercept and slope coefficients, $\boldsymbol{Hab_{(1,2,\ldots k)}}$ was a single measure or multiple measures of habitat, $\boldsymbol{\varepsilon_{stream}}$ was the random effect of stream (Mary Freeman, USGS, personal communication). Catch data at the microhabitat scale was offset by the amount of effort used for models using microhabitat scale data due to effort differing for each mesohabitat within each stream (Todd Steury, Auburn University, personal communication). Model selection was determined based on Akaike's Information Criterion (AIC) for habitat variables fitted by maximum likelihood and models that failed to converge using the Poisson distribution were fitted with a negative binomial model to incorporate for overdispersion and model selection was also carried out using AIC and maximum likelihood (Akaike 1973; Burnham and Anderson 2002; R Core Team 2015). Model predictions were made by the equation:

$$\boldsymbol{Black\ Bass\ Catch}\ (\hat{y}) = \boldsymbol{e^{(\beta_0 + \beta_1[Hab_1] + \beta_2[Hab_2] \ldots + \beta_k[Hab_k])}} \tag{2}$$

where $\boldsymbol{\beta_0}$, $\boldsymbol{\beta_1}$, $\boldsymbol{\beta_2}$, and $\boldsymbol{\beta_k}$ are the regression estimates for the intercept and slope, and $\boldsymbol{Hab_{(1,2,\ldots k)}}$ were values of microhabitat used to predict catch. Regression analysis assessed relationships among estimates of mesohabitat to black bass species presence/ absence with a binomial generalized linear model (Vasconcelos et al. 2013):

$$\boldsymbol{Spp. Presence = \beta_0 + \beta_1(Hab_1) + \ \beta_2(Hab_2) \ldots + \beta_k(Hab_k) + \varepsilon_{stream} + \varepsilon_r \sim B(1, \hat{y})} \tag{3}$$

where β_0, β_1, β_2, and β_k were the regression coefficients for the intercept and slope coefficients, $Hab_{(1,2,\ldots k)}$ was a single measure of mesohabitat, $\varepsilon_{\text{stream}}$ was the random effect of stream, and $\sim B(1,\hat{y})$ was the binomial distribution (R Core Team 2015). Model predictions for black bass species presence are made by the equation:

$$\textit{Black Bass Probability of Catch} = \frac{e^{(\beta_0+\beta_1[Mesohabitat])}}{\left[1+e^{(\beta_0+\beta_1[Mesohabitat])}\right]} \tag{4}$$

where β_0, β_1, were the regression coefficients for the intercept and slope coefficient, and ***Mesohabitat,*** was the proportion of a given mesohabitat.

Sand and gravel substrate from the point/transect surveys were combined to make comparisons between point/transect and side-scan sonar surveys, hereafter referred to as sonar surveys, because it was difficult to separate sand from gravel substrate in sonar surveys (Thom Litts, GADNR-WRD, personal communication). Mean substrates between point/transect surveys, and overall sonar surveys of the same streams were measured to determine what substrates were generally under- or over-represented in the point/transect surveys.

Land use data were acquired by use of the National Land Cover Database (NLCD). The database contains land use maps from 2011 that were created by a consortium of federal agencies within the U.S. Department of the Interior (DOI), U.S. Army Corps of Engineers, and National Aeronautical and Space Administration (NASA). Land use raster imagery was derived from analysis of decadal Landsat satellite imagery. Anthropogenic disturbance and land use patterns were measured by analyzing NLCD raster imagery of land use categories of each stream watershed within ArcGIS. Land cover was separated into area (km^2) categories of: watershed, developed, forested, agriculture, wetland, herbaceous, and shrub with multiple subcategories of type or intensity (*see appendices*).

Mean land use for each stream was separated into categories of percent developed, forested, natural, and agricultural. Percent developed land use included open, low, medium, and high developed land cover areas; percent forested included deciduous, evergreen, and mixed forest land cover areas; percent natural included forested, herbaceous, shrub, wooded wetland, and herbaceous wetland land cover areas; and percent agriculture included pasture, and crop land cover areas. Categories of developed land cover were separated by the percent of impervious surface compared to percent vegetation, and the degree of anthropogenic construction. Open development accounted for areas with < 20% impervious surface with little construction material. Low development accounted for areas with 20%-49% impervious surface with a mixture of constructed material and vegetation. Medium development accounted for areas with 50%-79% impervious surface with a mixture of constructed material and vegetation. High development accounted for areas with 80%-100% impervious surface of mostly constructed surfaces and less vegetation (*see appendices*). Percent land cover distributions for streams with a high concentration of Shoal Bass (> 25 fish collected during the study) were compared to streams with a low concentration of Shoal Bass(< 25 fish collected), and streams where they were considered absent. Also land cover distributions for streams where Chattahoochee Bass were found were compared to distributions where they were absent. Although Little Uchee Creek had greater than 25 Shoal Bass when sampled in 2005-2009 (Sammons and Maceina 2009), recent samples indicate the population is in decline (Steve Rider, ALDWFF, personal communication), so it was considered to be a low population. Similarly, although a few Shoal Bass were collected in Wacoochee Creek in 2008-2009, those fish were all stocked (Sammons and Maceina 2009), and for my study was considered a stream where Shoal Bass are absent. Although no Shoal Bass were found during our samples of Whooping Creek, Georgia DNR-

WRD biologists recently found Shoal Bass there (P. Lanford, GADNR, unpublished data) so it was classisfied as a low population of Shoal Bass.

III. RESULTS

III.1. *Microhabitat Scale*

Streams were sampled from May to September in 2014. A total of 249 Shoal Bass, 92 Spotted Bass, 41 Largemouth Bass, and 22 Chattahoochee Bass were collected during this survey with a total effort of 45.12 hours (Table 3). Mean overall catch of Shoal Bass was 1.25 fish/hr (N= 106, SD= 4.38), Spotted Bass 1.92 fish/hr (N= 106, SD=5.20), Largemouth Bass 1.77 fish/hr (N= 106, SD= 3.98), and Chattahoochee Bass was 3.39 fish/hr (N= 43, SD= 1.54) with an overall mean backpack electrofishing effort of 1.85 hours (SD= 1.54; Table 3). Depth, velocity, and substrate were measured from 106 mesohabitats at 305 transects and MSW measures (ranging from 12-21 per stream) with 1,515 points (ranging from 60-105 per stream) of 16 Middle Chattahoochee River tributaries sampled. For backpack electrofishing surveys collected Shoal Bass, Spotted Bass, and Largemouth Bass in eight, ten, and seven of the 16 study streams. Chattahoochee Bass were found in 4 of 7 streams above West Point Reservoir (Table 3).

Riffles generally had a high percentage of gravel, some bedrock and cobble, and relatively low sand, boulder, and wood cover (N=166). Shoal habitats had high percentages of boulder and bedrock, and low percentages of cobble, sand, gravel, and wood cover (N=546). Run and pool habitats generally had relatively even distributions of substrates and wood cover with lower gravel and higher sand substrates (N=561, 242; Figure 4; and Table 4). Streams with high percentages of bedrock generally had relatively low percentages of sand, gravel, and cobble substrates (Figure 4, and Table 4).

Mean velocity varied from 0.05- 0.17 m/s, mean depth varied from 0.1-0.7 m, and mean width varied from 9-53 m across streams. Stream velocity distribution was significantly faster in streams where Shoal Bass were present versus where they were absent (D= 0.066; df= 948, 565; P=0.0465; Figure 5), as was mean velocity (0.120 m/s vs 0.097, t= 2.881, df= 1380.8, P< 0.01). Stream depth distribution was significantly deeper in streams where Shoal Bass were present versus where they were absent (D= 0.177; df= 948, 565; P< 0.001; Figure 6), as was mean depth (0.366 m vs 0.275, t= 6.390, df= 1413.6, P< 0.001). Stream width distribution was significantly wider in streams where Shoal Bass were present versus where they were absent (D= 0.337; df= 948, 565; P< 0.001; Figure 7), as was mean stream width (22.752 m vs 13.314, t= 14.665, df= 1393.6, P< 0.001).

Stream velocity distribution was significantly faster in streams where Chattahoochee Bass were present versus where they were absent (D= 0.117; df= 500, 257; P< 0.01; Figure 5), but mean velocity was similar (0.111 m/s vs 0.124, t= -1.0005, df= 479.06, P= 0.3176). Stream depth distribution was significantly shallower in streams where Chattahoochee were present versus where they were absent (D= 0.19728; df= 500, 257; P< 0.001; Figure 6), but mean depth was similar (0.329 m vs 0.307, t= 1.0568, df= 385.74, P= 0.291). Stream width distribution was significantly narrower in streams where Chattahoochee Bass were present versus where they were absent (D= 0.437; df= 500, 257; P< 0.001; Figure 7), as was mean stream width (12.417 m vs 28.747, t= -10.228, df= 267.24, P< 0.001).

Cobble composed a higher proportion of substrate in streams where Shoal Bass were present than in those where they were absent (χ^2= 63.781, df= 4, P< 0.0001; Figure 8). Mean substrate in streams where Shoal Bass were found was composed of 31.4% bedrock, 21.2% boulder, 14.5% cobble, 9.7% gravel, and 23.2% sand substrates; whereas, substrate in streams where they were absent was composed of 34.0% bedrock, 21.1% boulder, 3.0% cobble, 11.5% gravel, and 30.4% sand (Figure 8). Bedrock and boulder composed a lower proportion of substrate, and cobble and gravel composed a higher proportion of substrates in streams where Chattahoochee Bass were present than in those where they were absent (χ^2= 224.51, df= 4, P< 0.0001; Figure 8). Mean substrate in streams where Chattahoochee Bass were found was composed of 10.2% bedrock, 14.4% boulder, 12.0% cobble, 29.0% gravel, and 34.4% sand substrates; whereas, substrate in streams where they were absent was composed of 36.6% bedrock, 27.6% boulder, 0.0% cobble, 0.0% gravel, and 35.8% sand (Figure 8).

Habitat variables generally showed weak or no correlations among each other across all streams (Table 5). Bedrock was correlated with a visual estimate of percent rock cover, current stream width, and inversely correlated with percent boulder, percent cobble, percent gravel, percent sand, and a visual estimate of wood cover. Percent boulder was weakly correlated with depth and inversely correlated with percent cobble, percent gravel, and percent sand. Mesohabitats with wide stream widths tended to have more bedrock and less cobble, gravel, and sand substrates. Sand was correlated with wood cover, and depth and inversely correlated with rock cover, current width, and velocity; meaning fast moving wide shoals tend to have fewer areas with sand, as expected. Mesohabitats with high rock cover tend to have a smaller amount of wood cover and vice versa (Table 5).

Pearson’s R correlations of Black bass CPE were weakly correlated to a variety of microhabitat variables (Table 6). Shoal Bass CPE was correlated with bedrock, rock cover, current stream width, and velocity and was inversely correlated with gravel and sand substrates. Spotted Bass CPE was correlated with bedrock and rock cover, and inversely correlated with proportions of sand substrate, and wood cover. Largemouth Bass CPE was correlated with bedrock and inversely correlated with depth. Chattahoochee Bass CPE was only correlated with current stream width (Table 6).

The best predictive model for Shoal Bass was Poisson distributed, and showed that catch was higher in mesohabitats with shallow depths, low proportions of wood cover and cobble substrate, and high proportions of boulder substrate (Table 7). This model included a non-significant parameter of current stream width because it significantly improved the AIC and log likelihood of the model compared to the model without current stream width (Table 7). The best predictive model for Spotted Bass was also Poisson distributed, and showed that catch was higher in mesohabitats with higher proportions of boulder, relatively shallow depths with low stream velocity, current stream width, and proportion of wood cover (Table 8). The best predictive model for Largemouth Bass was negative binomial distributed, and showed that catch was higher in mesohabitats with shallow depth, high proportions of bedrock, and low proportions of wood cover (Table 9). This model included non-significant parameters for proportions of sand and gravel because it significantly improved the AIC and log likelihood of the model compared to the model without sand and gravel substrates (Table 9). The best predictive model for Chattahoochee Bass was Poisson distributed, and showed that catch was higher in mesohabitats with higher proportions of sand and rock cover and a wider current stream width (Table 10).

III.2. *Mesohabitat Scale*

Streams were sampled using a handheld canoe electrofisher in summer 2013-2015. Effort ranged from 1.5 to 4.75 hours across streams, with a mean of 3.41 hours (SD=1.10; Table 11). A total of 62 Shoal Bass, 207 Spotted Bass, 97 Largemouth Bass, and 61 Chatttahoochee Bass were caught with a total effort of 54.5 hours over 218 15-minute transects. Mean CPE of Shoal Bass was 1.14 (N= 218, SD= 3.74), Spotted Bass 3.8 (N= 218, SD=4.77), Largemouth Bass 1.78 (N= 218, SD= 3.52), and Chattahoochee Bass was 3.01(N= 91, SD= 5.19) with mean electrofishing effort for each stream at 3.41 hours (sd= 1.10; Table 11). Shoal Bass were collected in 6 of 16 streams, Spotted Bass were found in all streams, Largemouth Bass were found in 14 of 16 streams, and Chattahoochee Bass were found in 4 of 7 streams during canoe electrofishing samples (Table 11). Mean mesohabitat composition across all streams was 50% run (range= 15%-86%, N= 218, SD=0.216), 20% pool (range= 8%-43%, N= 218, SD= 0.135), and 29% shoal (range= 0%-57%, N= 218, SD= 0.170; Table 11).

Black bass species CPE showed weak or no correlation among percent mesohabitat (Table 12). There were no significant correlations between Shoal Bass CPE and percent mesohabitat parameters. Spotted Bass CPE was correlated with percent run mesohabitat and inversely correlated with percent pool mesohabitat. Largemouth Bass CPE was correlated with percent pool mesohabitat and inversely correlated with run mesohabitat. Chattahoochee Bass CPE was correlated with percent shoal mesohabitat and inversely correlated with both percent run and percent pool mesohabitats (Table 12).

The binomial-distributed predictive model of Shoal Bass at the mesohabitat scale showed the probability of catching Shoal Bass increased in transects with higher proportions of shoal mesohabitat and decreased in higher proportions of run mesohabitat (Table 13). The binomial-distributed predictive model of Largemouth Bass at the mesohabitat scale showed the probability of catching Largemouth Bass increased in transects with higher proportions of pool mesohabitat and decreased in transects with higher proportions of run mesohabitat (Table 13). The binomial-distributed predictive model of Chattahoochee Bass at the mesohabitat scale showed the probability of catching Chattahoochee Bass increased in transects with higher proportions of shoal mesohabitat, and decreased in transects with higher proportions of pool and run mesohabitat (Table 13). The probability of catching Spotted Bass was not related to the proportions of any mesohabitat.

On average, streams where Shoal Bass were found were composed of 49.5% run, 16.4% pool, and 34.0% shoal mesohabitat (N= 119), whereas, streams where they were absent were composed of 48.4% run, 22.1% pool, and 29.7% shoal mesohabitat (N= 99); mean difference in mesohabitat percentage for Shoal Bass was +1.1% run, -5.6% pool, and +4.3% shoal mesohabitat. Shoal Bass were found in streams with higher proportions of shoal mesohabitat (χ^2=40.51, df= 22, P< 0.01) and lower proportions of pool mesohabitat (χ^2=27.30, df= 17, P< 0.10; Figure 9). On average, streams where Chattahoochee Bass were found were composed of 45.8% run, 13.5% pool, and 41.0% shoal mesohabitat (N= 66),whereas, streams where they were absent were on average composed of 48.6% run, 35.2% pool, and 16.2% shoal mesohabitat (N= 25); mean difference in mesohabitat percentage for Chattahoochee Bass was +2.8% run, -21.7% pool, and +24.8% shoal mesohabitat. Chattahoochee Bass were found in streams with higher proportions of shoal mesohabitat (χ^2=54.60, df= 20, P< 0.0001), lower proportions of run mesohabitat (χ^2=31.12, df= 15, P< 0.01), and lower proportions of pool mesohabitat (χ^2=38.85, df= 13, P< 0.001; Figure 9).

III.3. *Macrohabitat Scale*

Agricultural land cover ranged from total areas of 13.2 km² to 125.7 km² among watersheds where Shoal Bass were absent, with a mean of 50.2 km²; whereas, it ranged from 13.1 km² to 138.7 km² with a mean of 59.9 km² for watersheds with Shoal Bass present (Table 14). Developed land cover ranged from total areas of 5.6 km² to 48.9 km² among watersheds where Shoal Bass were absent, with a mean of 27.0 km²; whereas, it ranged from 9.6 km² to

404.8 km² with a mean of 71.5 km² for watersheds with Shoal Bass present. Forested land cover ranged from total areas of 73.9 km² to 342.2 km² among watersheds where Shoal Bass were absent, with a mean of 187.1 km²; whereas, it ranged from 70.0 km² to 464.6 km² with a mean of 281.9 km² for watersheds with Shoal Bass present (Table 14). Natural land cover ranged from total areas of 99.4 km² to 532.2 km² among watersheds where Shoal Bass were absent, with a mean of 248.9 km²; whereas, it ranged from 83.7 km² to 700.6 km² with a mean of 367.0 km² for watersheds with Shoal Bass present. Total watershed area ranges from total areas of 119.5 km² to 715.7 km² among watersheds where Shoal Bass were absent, with a mean of 331.2 km²; whereas, it ranged from 117.2 km² to 991.1 km² with a mean of 504.2 km² for watersheds with Shoal Bass present (Table 14).

Agricultural land cover ranged from total areas of 59.8 km² to 87.4 km² among watersheds where Chattahoochee Bass were absent, with a mean of 74.1 km²; whereas, it ranged from 20.2 km² to 53.3 km² with a mean of 32.9 km² for watersheds with Chattahoochee Bass present (Table 14). Developed land cover ranged from total areas of 16.4 km² to 404.8 km² among watersheds where Chattahoochee Bass were absent, with a mean of 154.1 km²; whereas, it ranged from 8.8 km² to 48.9 km² with a mean of 18.7 km² for watersheds with Chattahoochee Bass present. Forested land cover ranged from total areas of 164.8 km² to 400.2 km² among watersheds where Chattahoochee Bass were absent, with a mean of 297.9 km²; whereas, it ranged from 70.0 km² to 192.2 km² with a mean of 135.9 km² for watersheds with Chattahoochee Bass present (Table 14). Natural land cover ranged from total areas of 237.5 km² to 485.7 km² among watersheds where Chattahoochee Bass were absent, with a mean of 381.0 km²; whereas, it ranged from 83.7 km² to 255.2 km² with a mean of 167.7 km² for watersheds with Chattahoochee Bass present. Total watershed area ranges from total areas of 315.6 km² to 991.1

km^2 among watersheds where Chattahoochee Bass were absent, with a mean of 617.2 km^2; whereas, it ranged from 117.2 km^2 to 298.1 km^2 with a mean of 222.6 km^2 for watersheds with Chattahoochee Bass present (Table 14).

Streams with high Shoal Bass populations included Flat Shoals, Mulberry, and Sweetwater creeks. Streams with low Shoal Bass populations included Dog River, and Hillabahatchee, Little Uchee, Mountain Oak, Osanippa, and Whooping creeks. Streams where Shoal Bass were absent included New River, and Centralhatchee, Halawakee, Standing Boy, Uchee, Snake, Wacoochee, and Wehadkee creeks (Table 15). Streams where Chattahoochee Bass were present included Dog River, and Centralhatchee, Hillabahatchee, Snake, and Whooping creeks. Streams where Chattahoochee Bass were absent included Sweetwater and Wehadkee creeks, and the New River. Nearly all land-cover categories had greater areas in high versus absent populations of Shoal Bass with the exception of mixed forests and crop agriculture; however, streams with high Shoal Bass populations were in larger watersheds (Table 15). Conversely, land-cover categories in streams with low Shoal Bass populations had similar land cover areas versus streams where Shoal Bass were absent, with more developed area, less agricultural area and less natural area. Nearly all land-cover categories had greater areas in high versus low populations of Shoal Bass with the exception of crop agriculture and mixed forested areas (Table 15).

The average stream had 9.5% developed land cover, 75.6% natural land cover, 13.8% agricultural land cover, and 58.4% forested land cover (Table 16). Mean streams with high populations of Shoal Bass versus streams where Shoal Bass were absent had more developed land cover and less natural, agricultural, and forested land cover; however the majority of developed land cover came from the Sweetwater Creek watershed which also had low forested and natural land cover. Mean streams with low populations of Shoal Bass versus streams where Shoal Bass were absent had less agricultural land cover, and more developed, natural, and forested land cover. Mean streams with high populations of Shoal Bass versus streams with low populations had more developed land cover and less natural, agricultural, and forested land cover (Table 16). Mean streams where Shoal Bass were present versus absent had more developed and forested land cover, and less natural and agricultural land cover (Table 16). Mean streams where Chattahoochee Bass were present on average had less developed land cover and more natural, agricultural, and forested land cover (Table 16).

III.4. *Side-Scan Sonar Analysis*

The accuracy assessment of multiple samples of each substrate confirmed that all substrates types in the field conformed to what was determined by analyzing the side-scan sonar imagery in ArcGIS. Flat Shoals Creek pool and run mesohabitats had more sand/gravel substrate than other substrates, riffle mesohabitats had more evenly distributed substrates with less bedrock substrate, and shoal mesohabitats had more bedrock and boulder substrates than other substrates (Table 17 and 18). Mountain Oak Creek pool and run mesohabitats had more sand/gravel substrate than other substrates, riffle mesohabitats had more cobble and boulder substrate than other substrates, and shoal mesohabitats had more bedrock and boulder substrates than other substrates (Table 17 and 18). Osanippa Creek pool mesohabitats had more sand/gravel and bedrock substrate than other substrates, run mesohabitats had more sand/gr substrates than other substrates, riffle mesohabitats had more boulder substrate than other substrates, and shoal mesohabitats had more bedrock and boulder substrates than other substrates (Table 17 and 18). Halawakee Creek pool mesohabitats had more sand/gravel and bedrock substrate than other substrates, run mesohabitats had more sand/gr substrates than other substrates, riffle mesohabitats had more evenly distributed substrates with less bedrock substrate, and shoal mesohabitats had more bedrock and boulder substrates than other substrates (Table 17 and 18). Mulberry Creek pool mesohabitats had more sand/gravel and boulder substrate than other substrates, run mesohabitats had more sand/gr substrates than other substrates, riffle mesohabitats had more sand/gravel and boulder substrate than other substrates, and shoal mesohabitats had more bedrock and boulder substrates than other substrates (Table 17 and 18). Every creek is dominated by sand/gravel, all of which are primarily in the dominant run mesohabitats. Bedrock and boulder substrates are intermediate to sand and cobble substrate, and they are found primarily in shoal mesohabitats. There are lower proportions of cobble substrate in every stream except for Halawakee and Mountain Oak creeks. Cobble is found primarily in riffle mesohabitats, which occur less often than any other mesohabitat in mapped streams Table 17 and 18).

In Flat Shoals and Mulberry creeks, which both have similar watersheds, point and transect surveys overestimated the proportion of bedrock and boulder substrate, and underestimated the proportion of sand/gravel substrate in comparison to sonar survey data (Figure 10). Mountain Oak Creek point and transect surveys overestimated the proportion of bedrock and boulder substrate, and underestimated the proportion of sand/gravel substrate in comparison to sonar survey data. Halawakee Creek point and transect surveys overestimated the proportion of cobble substrate, and underestimated the proportion of boulder and sand/gravel substrate in comparison to sonar survey data (Figure 11). Osanippa Creek point and transect surveys overestimated the proportion of bedrock substrate, and underestimated the proportion of boulder and sand/gravel substrate in comparison to sonar survey data (Figure 12). For all mapped creeks point and transect surveys on average overestimated boulder and cobble substrates, and underestimated sand/gravel substrates in comparison to sonar survey data (Figure 13).

V. DISCUSSION

V. 1. General Conclusions for Endemic Black Bass Species

Shoal Bass were associated with faster stream velocity, shallower depths, and wider streams widths with high proportions of boulder substrate, and low proportions of cobble substrate and wood cover at the microhabitat scale, and at the mesohabitat scale they were positively associated with shoals, and negatively associated with run mesohabitats. Further, available substrate in streams were on average 22.0% boulder and the mesohabitats with the lowest proportion of boulder substrate were run and riffle mesohabitats. Sonar surveys suggested that sand substrates were under-represented in point and transect reaches and sand substrates were generally found at higher proportions in run mesohabitats. Macrohabitat analysis of stream watersheds indicated that Shoal Bass were present in higher proportions of forested land cover in larger watersheds. Based on the results at each scale, habitat restoration should focus on the addition of boulder substrates to run mesohabitats in highly forested larger watersheds. However, Shoal Bass are abundant in the larger watersheds sampled and some smaller watersheds had Shoal Bass populations that persist, so habitat restoration should focus on small to medium watersheds.

Chattahoochee Bass are generally found in higher-gradient areas in narrower streams above West Point Reservoir. The microhabitat model for Chattahoochee Bass shows that catch rates increased in wider stream widths, higher proportions of rocky cover, and higher proportions of sand. These estimates are relative to the width of the mesohabitats within the streams where they were found, so they were found in significantly wider mesohabitats of those streams and those streams also had higher proportions of sand habitat. The mesohabitat models showed that the probability of catching Chattahoochee Bass was greatest in shoal mesohabitats, so shoal habitat should be protected for both Shoal Bass and Chattahoochee Bass persistence. The models and the presence/absence data also suggest that there is a threshold where the stream size is too large for what they appear to prefer because streams where they were absent were also in larger watersheds with wider stream widths. Similar to Shoal Bass, Chattahoochee Bass were associated with streams with a higher proportion of forested area, however they also associated with smaller watersheds, so efforts to restore Shoal Bass populations where they are sympatric with Chattahoochee Bass will benefit both species. Two of the streams where Chattahoochee Bass were found in this study (Dog River and Snake Creek) have been impounded in what would have been ideal habitat. Bear Creek, which is directly across the Chattahoochee River from Dog River, was recently under consideration for impoundment and the impoundment would likely have a major impact on the presence of both Chattahoochee Bass and Shoal Bass if they were present, so prior to impoundment of additional streams in the Middle Chattahoochee River surveys should consider the impact impoundments would have on these endemic black bass.

V.1. ***Connectivity and Stream Habitat Restoration***

Successful restoration of an aquatic community depends on both regional (e.g., watershed) and local constraints (Palmer et al. 1997). Examples of regional constraints include anthropogenic disturbances such as altered stream hydrology and loss of connectivity such as stream impoundments. Localized constraints include local environmental constraints (e.g., temperature, dissolved oxygen, and turbidity), loss of quality micro- and mesohabitat, and changes in species interactions (e.g., species introductions leading to competition, and loss of preferred prey due to changes in the environment). Palmer et al. (1997) noted that many restoration efforts in the past have operated under the ‘Field of Dreams’ hypothesis, which refers to the notion that “if you build it, they will come;” i.e., if you restore the habitat the species will recolonize. However, the author determined that simply restoring habitat heterogeneity often fails to solve some of the larger problems associated with the decline of a community of species.

A “Field of Dreams” approach is unlikely to successfully restore endemic black bass within the Apalachicola-Chattahoochee-Flint River Basin. Little data exists on these species, although the knowledge base has been steadily increasing since the mid-2000s (Sammons et al. 2015). In particular, little is known about habitat needs of the species, and thus it is difficult to design appropriate restoration activities or even identify specific reasons for local species declines. Also, inter-relationships among habitat issues at varying ecological scales may compromise effectiveness of habitat restoration at the mesohabitat or reach scale (Bond and Lake 2003). For instance, Miller et al. (2009) conducted a meta-analysis studying the response of macroinvertebrates to instream habitat restoration and found that increasing habitat heterogeneity increased the richness of macroinvertebrates, but increases in density were negligible, and watershed-scale and land use conditions showed the strongest and most consistent response.

These considerations are relevant to the stream restoration of Shoal Bass and other endemic fish species. Sammons and Earley (2015) studied the movement of Shoal Bass for reproduction (e.g., Potamodromy) and suggested that Shoal Bass were highly migratory in connected systems, forming spawning aggregates in the spring. Further, the extent of movement was mediated by locations within the watershed; fish in piedmont areas exhibited lower movement compared to those further downstream, likely due to close proximity to spawning shoal complexes. So connectivity within a stream between shoal complexes is important for reproductive success. Recently, low-head dams were removed from sections of Chattahoochee

River in Columbus, Georgia, and more low-head dams are slated for possible removal in the Middle Chattahoochee River near Flat Shoals Creek. The dams located near Flat Shoals Creek are immediately above major spawning shoals for Shoal Bass that inhabit the area (Sammons and Earley 2015). Flat Shoals is in a large watershed with a relatively high density of forested area and a low proportion of developed area and it unlike other tributaries in this area, remains connected to the mainstem Chattahoochee River. Radio-tagged Shoal Bass from this area of the Chattahoochee River were found to swim 10-22 km upstream Flat Shoals Creeks (Sammons and Earley 2015), but most other streams in the Fall Line area flow into one of the many mainstem reservoirs. As Shoal Bass appear to be unwilling to move through these reservoirs (Sammons and Earley 2015), populations in the associated tributaries are now isolated, thus more vulnerable to extinction (Hanski et al. 1994; Jager et al. 2001). Mulberry Creek has a large watershed in a highly forested area with a low proportion of developed land cover and its connection with the Chattahoochee River includes a large high gradient shoal complex (25 m drop in 0.5 km), which impedes upstream movement. Similarly, Sweetwater Creek also is in a large watershed, but is located in a highly developed area and the connection with the Chattahoochee River is blocked by a low-head dam several km prior to reaching the Chattahoochee River.

V.2. *Land-use Conclusions*

Although my results indicated that Shoal Bass were associated with higher than average developed land cover, one of the three streams with high populations of Shoal Bass, Sweetwater Creek, is located near the major city of Atlanta, Georgia. Naturally the watershed of this creek had higher developed land cover (40.9%), compared to the other two streams with high Shoal Bass populations (4.8-6.4%). Further, Sweetwater Creek had the lowest percentage of both forested and natural land cover of all creeks sampled. However, the major shoal complex of

Sweetwater Creek is adjacent to a state park, protecting it from becoming further developed and protecting the littoral zone from further erosion. Thus, the presence of the state park may have preserved Shoal Bass in this stream, despite the unusually low amount of forested and natural land cover.

Large watersheds appeared to be a major factor in Shoal Bass persistence. The three streams with the highest Shoal Bass populations were also those with the largest watersheds. Large watersheds may have less flashiness in discharge following large rainfall events, leading to more stable environments (Hirpa, Gebremichael, and Over 2010). Larger streams in my study often tended to be wider with more extensive shoal habitats, which may constitute important spawning habitat for Shoal Bass (Sammons et al. 2015). Shoal Bass persisting in small numbers in streams with smaller watersheds may be due to the amount of forested watershed. Forested areas slow the velocity of runoff prior to reaching the stream by friction and root absorbance (Surfleet and Skaugset 2013).

The capacity of a stream to resist drought conditions should also be a considered prior to restoration. In 2008 tributary streams of the Middle Chattahoochee River in Alabama were stocked with Shoal Bass fingerlings and relatively few of the stocked Shoal Bass were recaptured in subsequent surveys (Sammons and Maceina 2009). Stocked Shoal Bass may have experienced declines due to extreme drought conditions following stocking (Johnston and Maceina 2009). Low stream flow can be attributed to several conditions including; irrigation and drinking water withdrawals out of the system and out of the water table, global warming and extreme weather conditions, increased stream channelization, and increased water velocity over impervious surfaces in developed watersheds. Watersheds studied in the Middle Chattahoochee River on average are less than 15% agriculture and less than 10% developed so currently water losses due to urbanization and agriculture use should be minimal, however the population of the Southeastern United States is increasing rapidly and losses of stream discharge due to urban and rural development should be monitored prior to making management and restoration decisions (US Census Bureau, 2011).

V.3. ***Congeneric Spotted Bass Introduction***

Spotted Bass are generally found in every tributary of the Middle Chattahoochee River with often higher catch rates than Shoal Bass. Spotted Bass are habitat generalist, so habitat conditions appear to play no major role in their ability to persist in streams with high habitat heterogeneity. Thus, their introduction at any source in a watershed allows them to disperse into any connected habitat (Churchill and Bettoli 2015). When habitat becomes degraded for Shoal Bass and Chattahoochee Bass, Spotted Bass will be able to persist. Thus, any restoration aimed at promoting endemic black bass habitat will likely have no effect on reducing the persistence of Spotted Bass, so reductions in Spotted Bass populations will be necessary to promote endemic black bass survival.

Additionally, Spotted Bass are known to hybridize with other species of black bass and their introgression can swamp out the remaining genetics of native species of black bass (Avise et al. 1997). Taylor (2012) found that since introduction into the Chattahoochee River, Spotted Bass had caused at least 12% of the population of Shoal Bass hybrids in the Lower Flint River and that Shoal Bass males cross with Spotted Bass females and hybrids backcross with both Spotted Bass and Shoal Bass. Native stocking of Shoal Bass should be screened prior to stocking to ensure pure genetic makeup of offspring (Taylor 2012). Steps should be taken to reduce the overall increases in Spotted Bass populations in target streams before and after a stream is restored, such as sustained removal of Spotted Bass over the course of several years. Although populations of Spotted Bass are substantial in Middle Chattahoochee tributaries, analyses indicated no significant differences between mean mesohabitats for transects where Spotted Bass were present versus absent, so stream restoration targeted at increasing Shoal Bass and Chattahoochee Bass populations should have no net effect on increasing Spotted Bass populations. Also, Spotted Bass were associated with lower stream flows and stream widths, while both Chattahoochee Bass and Shoal Bass were associated with higher stream flows and there was no difference for stream width for either native species. Restorations should be targeted in run mesohabitats where predictive models indicated that they were less likely to be found.

V.4. ***Side-Scan Sonar Surveys of Small Streams***

Sonar surveys of shallow rivers and streams should be done in the winter months when depths are higher because there needs to be as few breaks as possible in scanning time in order to minimize the time spent rectifying imagery for a given stream. Surveys are typically conducted after a rain event when the peak discharge starts to decline or is expected to decline within the planned survey time (Kaeser and Litts 2010). Surveys are also better conducted after a few rain events have occurred because the first few rain events often expel leaf litter from the banks and exposed stream habitat, reducing overall clarity of images (Thom Litts, Georgia DNR-WRD, personal communication). In general compared to larger rivers, streams tend to have limited periods of higher mean discharge after rain events that are necessary for conducting sonar surveys. The shorter time of sustained high discharge is primarily due to less total runoff from the watershed, which can be exacerbated by high proportions of developed land cover (Hirpa, Gebremichael and Over 2010). During this study, I found that with a sustained rain event I had 3-4 days maximum of adequate discharge in 5th and large 4th order streams, and 1-2 days in smaller 3rd and 4th order streams. Elevation gradient of a given stream should also be considered prior to planning sonar surveys. Streams with high elevation gradients and rocky shoal complexes are often difficult to map continuously because shoal complexes are less likely to be inundated with water even after large rain events. Streams with high elevation gradients are also increasingly dangerous to navigate with turbulent shoals and safety should always be consider to avoid injury or equipment loss. The recommended method for mapping a stream safely is to start the survey downstream of where you plan to survey, navigate upstream, and then map downstream (Kaeser and Litts 2010). However, this option is often difficult in smaller streams because shoal complexes may not be navigable upstream, and the time required to navigate upstream often limits the amount of downstream sonar survey time allowed in safe daylight hours. Conducting sonar surveys with little or no prior knowledge of downstream conditions requires caution and identification of hazardous conditions ahead early enough that the survey can be safely stopped and the boat be navigated through the hazardous area. Communication with knowledgeable paddlers or anglers and prior identification of natural and anthropogenic structures using aerial imagery can help plan safe sonar surveys on these smaller systems.

Breaks in sonar scanning are to be expected in small rocky streams with a high elevation gradient; often because shoals are not inundated, even in high flow, and downed trees are more likely to obstruct navigation due to stream banks being closer. Each break in a sonar survey using the snapshot approach leads to considerably more time spent rectifying imagery in ArcGIS because each section has to be rectified separately (Kaeser and Litts 2010).

Two methods for conducting sonar surveys were used in this research and both approaches required the vessel to be moving at a relatively constant speed between 3-10 km-per-hour in order to maintain accurate image quality. The snapshot approach requires the person recording instream images from the unit to take pictures on the unit at a given interval of time based on scanning width, which is directly associated with the MSW of the mapped section (Kaeser and Litts 2010). This snapshot approach was used in all mapped streams with the exception of the lower section of Mulberry Creek. The smaller the MSW, the more often an image has to be captured in order to avoid missing data while minimizing the degree of overlap from one image to the next. Thus, taking the images in this approach becomes increasingly more difficult as MSW decreases. Time between image captures ranged from 10 seconds in Halawakee Creek (the smallest mapped stream) to 18 seconds in the largest mapped stream, Mulberry Creek. The video recording approach records a video of the imagery displayed on the side-scan sonar unit and only requires the user to start and end recording for each section, which makes focusing on navigating safely downstream easier.

Streams typically have to be mapped with a canoe using a small motor because boat ramps are typically not available on small streams, moving upstream and then scanning downstream is often impossible, and using a paddle makes navigating while recording snapshots difficult. Scanning in streams using the snapshot method should be limited to a MSW no less than 10 m wide to limit breaks in the sonar survey caused by unavoidable instream obstacles. Sonar surveys of small streams should always be conducted with 2 people with the person in the front of the canoe assisting the person driving the canoe by focusing on possible unseen obstacles. The transducer must be in the front of the canoe to avoid distortion of imagery, so the person in the front should also be mindful of submerged obstacles that are likely to damage the transducer.

Sonar survey breaks in mapped streams ranged from 3-20 for mapped streams, with fewer breaks on larger streams and more on smaller streams. The lower section of Mulberry

Creek was mapped using the recording approach and had 3 breaks. Sharp bends in the stream channel often occur in streams and can create severely warped imagery that often leads to problems with the control point network generated in image rectification (Kaeser and Litts 2010). Most of the images that become warped can be corrected, but each correction takes an extended amount of time to correct. To avoid warped imagery when performing a sonar survey attempt to navigate sharp bends with as wide of a turn as possible while maintaining instream bank habitat on the inner bend to avoid losing information. Overall the recording approach is recommended over the snapshot approach even if there are limited breaks in the sonar survey because effort processing the imagery is much quicker with the SonarTRX software, and image clarity is better. The imagery also loads much faster in ArcGIS when compared with the snapshot approach that must load each image individually after the rectification process ends and the habitat is being interpreted.

VI. *Conclusions and Management Implications*

Shoal Bass in the Middle Chattahoochee River are isolated primarily due to impoundments and distance between shoal habitat patches, so persistence of their populations in streams will be predicated on whether or not they can remain viable without having access to the remaining major shoal complexes within the mainstem of the Middle Chattahoochee River. Flat Shoals, Sweetwater, and Mulberry creeks all have major shoal complexes that appear to sustain a viable population of Shoal Bass. The Dog River and, Halawakee, Mountain Oak, Osanippa, and Wehadkee creeks all have large-major shoal complexes, however they all drain into reservoirs prior to reaching lotic sections of the Chattahoochee River, the most recent of which was the impoundment of the lower section of the Dog River in 1992. The middle section of Snake Creek was impounded in 2001 and I found a large population of Chattahoochee Bass directly downstream of the impoundment, indicating that the area of the impoundment likely heavily impacted the Chattahoochee Bass population. Centralhatchee, Little Uchee, and Hillabahatchee creeks also have large shoal complexes that are located ~8-40 km from the mainstem of the Chattahoochee River. Shoal Bass were found recently in Whooping Creek by Georgia DNR-WRD biologists and the Dog River during canoe electrofishing sampling for this research so small populations of Shoal Bass do persist in smaller watersheds. Isolated shoal complexes of other small tributary streams of the Chattahoochee River may also hold small populations of Shoal Bass, and further investigation into these shoals may increase understanding of Shoal Bass distribution and populations in smaller streams.

Restocking efforts should focus on the use of sub-adult individuals because initial stocking efforts in Alabama used advanced fingerlings and Sammons and Maceina (2009) suggested that sub-adult Shoal Bass would have higher survival. Shoal Bass habitat restoration should focus on boulder habitats in run mesohabitats of forested streams, especially in wider reaches. Spotted Bass microhabitat predictive model showed that they were associated with slower and narrower streams so initial restoration efforts should be directed away from these streams. Based on my research, the following are candidate streams for future restoration:

1) **<u>Centralhatchee, Hillabahatchee, and Snake creeks</u>** are located upstream of West Point Reservoir and flow into a lotic section of the Chattahoochee River. They are in high-gradient areas of Western Georgia in Heard County. The shoals in all of these streams are characterized by wide stream widths relative to the rest of the stream and are generally found in isolated deep valleys of upstream portions of the stream. All three streams have higher proportions of cobble and gravel riffles in stream sections near the shoal complex and both are in highly forested areas with low developed areas.

Snake Creek has a large shoal complex near the base of the recent (2001) impoundment of the creek and it had the highest catch rate of Chattahoochee Bass among streams sampled. The shoal complex is adjacent to a small suburb, but the streambanks appear to be well protected due to the elevation surrounding the stream and from a local park in Whitesburg, Carroll County, Georgia, called Historic Banning Mills. This area appears to be minimally impacted by anthropogenic sources, and efforts to promote future protection there are encouraged for the survival of the Chattahoochee Bass in Snake Creek. Shoal Bass were not sampled from Snake Creek even though there is a large shoal complex available for them and the stream connects directly to the Chattahoochee River without being impeded by an impoundment. Restocking may be an option for restoration in Snake Creek.

Shoals in Centralhatchee and Hillabahatchee creeks are remote and difficult to access, thus sampling during this research may have failed to detect Shoal Bass in these streams.However, Shoal Bass were sampled in the Hillabahatchee, and Centralhatchee creeks during community samples in summer 2015. Chattahoochee Bass were found in both streams during sampling of the streams in the last few years. Hillabahatchee Creek has an area adjacent to it with pasture land where livestock were witnessed using the stream. The area downstream of those locations was a large shoal complex in a high-gradient area of a deep valley.

2) **Wehadkee Creek** is located downstream of Centralhatchee Creek in Randolph County, Alabama, and drains into West Point Reservoir. There is a major shoal complex that is composed of large amounts of bedrock located ~12 km upstream of the reservoir. The shoal is approximately 350 m long and remains approximately 41

m wide for 200 m before narrowing. At the bottom of the wide section the shoal splits and there is a section that contains medium boulders prior to becoming run habitat and then a smaller shoal complex after the run habitat. Upstream of the shoal is a low-head dam that impedes migration of fish upstream of the complex. Removal of this dam may increase the amount of shoal habitat for Shoal Bass. However, the dam apparently functions as a barrier to upstream movement of Spotted Bass, as I collected none above the dam. There is livestock grazing land downstream of the shoal complex where livestock were witnessed using the stream, with associated eroding banks and likely nutrient input into the stream. There is a smaller shoal complex located just above West Point Reservoir that could support Shoal Bass, and there is a heavily forested area between the two shoals that may serve as a basis for future restoration. The stream narrows quickly above the impoundment and no Shoal Bass were found suggesting that it may be too small for their survival. No Chattahoochee Bass were sampled in this stream, but I collected bass that appear to be Tallapoosa Bass *Micropterus tallapoosae*. Any further restoration efforts for Shoal Bass will have to include restocking, as the species appears to have been extirpated from the stream, and West Point Reservoir blocks any upstream migration.

3) **Osanippa Creek** is located in Chambers County, in Alabama, and has multiple large shoal complexes that stretch for several hundred meters each followed by shorter run and pool mesohabitats. The habitat appears to be in good condition for Shoal Bass survival, however there are a few factors which may be influencing the decline of the population. There is a large area upstream of the first shoal that has eroding stream banks and is heavily grazed by livestock. Large rain flood this area multiple times

each year likely causing a large nutrient load to flow downstream from these livestock pastures. Stream bank restoration and fencing livestock out of the stream will have to precede any Shoal Bass restoration efforts. Similar to Wehadkee Creek, the stream flows into the Bartlett's Ferry Reservoir so upstream migrations of Shoal Bass are unlikely and the population will need to be restocked. Osanippa Creek has an abundant Spotted Bass population, which may need to be reduced prior to restocking. Several past efforts to restock Shoal Bass in this stream have failed, possibly due to land use practices and competition with Spotted Bass. Thus, Spotted Bass removal and stream bank protections should be implemented prior to any restocking efforts.

4) **Dog River** is located upstream of Snake Creek in Carrol and Douglas counties in Georgia. It also has many long stretches of shoal complexes with equally as much run mesohabitat and relatively little pool mesohabitat. As mentioned above, there is an impoundment between the last shoal complex and the Chattahoochee River so upstream migration of Shoal Bass cannot occur. This stream has few spots with deep pools that could be used as refuge from drought conditions, thus Shoal Bass and Chattahoochee Bass may be more vulnerable to impacts from droughts, as found by Stormer and Maceina (2009) in Little Uchee Creek. In general, shoal habitats appear to have good-quality habitat, but lower velocity areas and eddies of rocky shoals appear to be heavily impacted by sedimentation. Few Shoal Bass were found here so after restoration work is completed Shoal Bass will need to be restocked. Chattahoochee Bass were found in Dog River in modest numbers so any effort to restore Shoal Bass habitat should also help Chattahoochee Bass survival.

5) **Mountain Oak Creek** is located in a heavily forested watershed with low developed areas, and low agricultural land use in Harris County, Georgia. It is located between both Flat Shoals and Mulberry creeks, which both support high populations of Shoal Bass. However it drains into the Bartlett's Ferry reservoir far from any riverine stretches of the river; whereas, Mulberry connects to the Chattahoochee at the upper end of Goat Rock Reservoir near the Bartlett's Ferry dam. Flat Shoals creeks connects to the Chattahoochee River at a major shoal complex (Sammons and Maceina 2009). The shoal habitats are found in areas of the stream with wide stream widths and are in a deep valley with a high stream gradient and are downstream of a heavily forested area, so land use in this watershed appears to be ideal. Prior to draining into the reservoir the stream flows through an area with adjacent wetlands, and the habitat consists primarily of deep runs with submerged cobble and gravel. The main restoration effort in this stream should be placed on Spotted Bass removal and subsequent Shoal Bass restocking.

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VIII. TABLES

Table 1. Sampling locations for black bass and habitat. Streams are listed from north to south as they entered the mainstem of the Chattahoochee River. *Asterisks denote streams where instream habitat was mapped using side-scan sonar.

Stream Name	Abbreviation	Stream Order	County	State
Sweetwater Creek	SWT	5	Douglas	GA
Dog Creek	DOG	4	Douglas	GA
Snake Creek	SNK	3	Carroll	GA
Whooping Creek	WPG	3	Carroll	GA
Centralhatchee Creek	CTH	3	Heard	GA
Hillabahatchee Creek	HLB	3	Heard	GA
New River	NEW	4	Heard/Coweta	GA
Wehadkee Creek	WHK	3	Randolph	AL
Flat Shoals Creek*	FSH	5	Harris	GA
Osanippa Creek*	OSA	4	Chambers/Lee	AL
Mountain Oak Creek*	MTN	4	Harris	GA
Halawakee Creek*	HAL	4	Lee	AL
Wacoochee Creek	WAC	3	Lee	AL
Mulberry Creek*	MUL	5	Harris	GA
Standing Boy Creek	STB	4	Harris/Muscogee	GA
Uchee Creek	UCH	5	Russell/Lee	AL
Little Uchee Creek	LUC	4	Lee	AL

Table 2. Modified Wentworth classification of instream microhabitat. Categories are based on particle size following methods described in Cummins (1962), with the addition of a bedrock category.

Category	Particle Size (mm)
Bedrock	N/A
Boulder	> 256
Cobble	< 256-64
Gravel	< 64-4
Sand	< 4-0.0625

Table 3. Total catch of four black bass species, number of mesohabitat sampled (N), mean black bass catch (CPE), and total effort using a backpack electrofishing unit in mesohabitats units of 16 Middle Chattahoochee River tributary streams in summer 2014. Species were Largemouth Bass (LMB), Spotted Bass (SPB), Shoal Bass (SHB), Chattahoochee Bass (CHB). Streams outside the range of Chattahoochee Bass are marked with a dash. All streams are listed alphabetically.

Stream	LMB	SPB	SHB	CHB	N	CPE (fish/hr)	Effort (hr)
Centralhatchee	0	0	0	4	8	0.58	1.66
Dog	0	3	0	0	4	0.84	1
Flat Shoals	0	6	99	-	9	2.4	10.55
Halawakee	7	3	2	-	9	2.19	1.74
Hillabahatchee	0	0	0	5	6	1.69	0.81
Little Uchee	19	0	34	-	6	5.65	2.74
Mountain Oak	1	1	1	-	10	0.66	1.56
Mulberry	0	0	8	-	9	0.49	2.49
New River	0	0	0	0	1	0	0.42
Osanippa	3	15	4	-	11	3.33	1.58
Snake	0	9	0	10	4	3	1.4
Standing Boy	3	9	0	-	1	3.37	1.19
Sweetwater	0	43	98	0	6	2.42	12.89
Wacoochee	7	2	3	-	10	2.43	1.38
Wehadkee	1	1	0	0	7	0.07	2.61
Whooping	0	0	0	3	7	0.54	1.11
TOTAL	41	92	249	22	108	.	45.12
MEAN CPE (hr)	1.25	1.92	1.77	3.39		1.85	.
Standard Deviation	4.38	5.2	3.98	5.21		1.54	.

Table 4. Percent of substrate types (defined in Table 2), and percent of rock and wood cover of each stream sampled using the point and transect method in 16 Middle Chattahoochee River tributaries in summer 2014. Streams were listed from North to South as they enter the Chattahoochee River.

Stream	Wood Cover	Rock Cover	Substrate %				
			Bedrock	Boulder	Cobble	Gravel	Sand
Sweetwater	8	89.8	75	25	0	0	0
Dog River	7	52.3	5	38	0	8	49
Snake	9	62.3	34	12	0	17	37
Whooping	7	54.5	8	14	7	36	35
Centralhatchee	10	75	1	3	17	48	31
Hillabahatchee	8	68.3	3	5	36	36	20
New River	35	0	0	0	0	0	100
Wehadkee	8	71.9	29.2	70.8	0	0	0
Flat Shoals	9	86.8	47	41	1	1	10
Osanippa	4	88.1	70.6	11.8	0	1.2	16.5
Mountain Oak	10	49.5	22	32	17	0	29
Halawakee	5	85.8	9	6	71	6	8
Wacoochee	4	88	93	3	0	0	4
Mulberry	14	36.4	23.8	20	1.9	1.9	52.4
Standing Boy	5	95	45	55	0	0	0
Little Uchee	2	92.5	73.3	15	5	1.7	5
MEAN	9.1	68.5	33.7	22	9.7	9.8	24.8
Standard Deviation	8.1	26.8	31.2	20.7	20.3	12.9	28.2

Table 5. Pearson correlation coefficients among microhabitat variables measured in mesohabitat units of 16 Middle Chattahoochee River tributaries using the point and transect method during the summer of 2014. Coefficients followed by a single asterisk were significant at P ≤ 0.10, those followed by a double asterisk were significant at P ≤ 0.01. Variables were percent bedrock (%BR), percent boulder (%BD), percent cobble (%COB), percent gravel (%GR), percent sand (%SD), percent rock cover (% RK), percent wood cover (%WD), depth (DEP), current stream width (CUR), and stream velocity (VEL).

	% BR	% BD	% COB	% GR	% SD	% RK	% WD	DEP	CUR	VEL
% BR	-	-0.4**	-0.34**	-0.31**	-0.5**	0.46**	-0.29**	-0.11	0.44**	0.04
% BD	-	-	-0.2*	-0.22*	-0.18*	0.03	0.04	0.12*	0.01	0.16
% COB	-	-	-	-0.03	-0.1	0.05	-0.07	-0.24*	-0.28**	-0.11
% GR	-	-	-	-	0.01	0	0.06	-0.24*	-0.37**	0.17*
% SD	-	-	-	-	-	-0.73**	0.4**	0.4**	-0.15*	-0.27**
% RK	-	-	-	-	-	-	-0.53**	-0.42**	0.2*	0.03
% WD	-	-	-	-	-	-	-	0.2	-0.12	0.07
DEP	-	-	-	-	-	-	-	-	0.2*	-0.19*
CUR	-	-	-	-	-	-	-	-	-	0.05

Table 6. Pearson correlation coefficients among black bass catch rates (fish/hr) and habitat variables measured in mesohabitat units of 16 River tributaries in summer 2014. Coefficients followed by a single asterisk were significant at P ≤ 0.10, those followed by a double asterisk were significant at P ≤ 0.01. Chattahoochee Bass (CHB) only included data for streams within their known distribution above West Point Reservoir. Variables were percent bedrock (%BR), percent boulder (%BD), percent cobble (%COB), percent gravel (%GR), percent sand (%SD), percent rock cover (% RK), percent wood cover (%WD), depth (DEP), current stream width (CUR), and stream velocity (VEL). Black bass species CPE included Shoal Bass (SHB), Spotted Bass (SPB), Largemouth Bass (LMB), and Chattahoochee Bass.

	% BR	% BD	% COB	% GR	% SD	% RK	% WD	DEP	WID	VEL
SHB	0.23*	0.07	-0.13	-0.17*	-0.19*	0.27**	-0.15	-0.15	0.31**	0.23*
SPB	0.22*	-0.06	-0.02	-0.10	-0.17*	0.26**	-0.21*	-0.12	0.07	-0.05
LMB	0.25**	-0.1	-0.07	-0.12	-0.10	0.155	-0.14	-0.17*	0.01	0.06
CHB	0.25	-0.19	0.07	-0.17	0.11	0.19	0.16	0.07	0.37*	-0.13

Table 7. Best microhabitat predictive model of Shoal Bass catch rate (fish/hr) as it relates to habitat variables measured in mesohabitat units of 16 Middle Chattahoochee River tributaries in summer 2014. The model used a Poisson distribution with a random effect for stream. Models are based on model selection with no interactions. Model selection used Akaike's Information Criterion (AIC) and -log likelihood to determine the best model. Bayes Information Criterion (BIC) is another model selection criterion, and deviance is a quality of fit statistic for a model.

Fixed effects:	Estimate	Standard Error	z value	Pr(>|z|)
(Intercept)	-1.221	0.927	-1.317	0.188
Depth (m)	-1.984	0.852	-2.329	0.020
Stream Width (m)	-0.015	0.015	-0.952	0.341
% Wood Cover	-10.046	1.891	-5.312	< 0.001
% Boulder	1.712	0.493	3.475	< 0.001
% Cobble	-3.304	1.357	-2.434	< 0.001
AIC	BIC	log Likelihood	Deviance	df residual
213.8	232.4	-99.9	199.8	99

Table 8. Best microhabitat predictive model of Spotted Bass catch rates (fish/hr) and habitat variables measured in mesohabitat units of 16 Middle Chattahoochee River tributaries in summer 2014. The model used a Poisson distribution with a random effect for stream. Models are based on model selection with no interactions. Model selection used Akaike's Information Criterion (AIC) and -log likelihood to determine the best model. Bayes Information Criterion (BIC) is another model selection criterion, and deviance is a quality of fit statistic for a model.

Fixed Effects	Estimate	Standard Error	z value	Pr(>|z|)
(Intercept)	3.376	1.145	2.948	< 0.01
Depth (m)	-5.129	1.210	-4.24	< 0.001
Velocity (m/s)	-14.859	2.774	-5.357	< 0.001
Stream width (m)	-0.051	0.019	-2.765	< 0.01
% Wood Cover	-47.986	5.590	-8.584	< 0.001
% Boulder	3.115	0.670	4.65	< 0.001

AIC	BIC	log Likelihood	Deviance	df residual
235.9	254.5	-110.9	221.9	99

Table 9. Best microhabitat predictive model of Largemouth Bass catch rate (fish/hr) as it relates to habitat variables measured in mesohabitat units of 16 Middle Chattahoochee River tributaries in summer 2014. The model used a negative binomial distribution, due to overdispersion, with a random effect for stream. Models are based on model selection with no interactions. Model selection used Akaike's Information Criterion (AIC) and -log likelihood to determine the best model. Bayes Information Criterion (BIC) is another model selection criterion, dispersion is a parameter measuring the spread of a distribution, deviance is a quality of fit statistic for a model.

Fixed effects:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.873	1.070	0.82	0.415
% Bedrock	1.604	0.640	2.51	0.0121
% Sand	2.442	2.123	1.15	0.252
% Gravel	-22.807	22.930	-0.99	0.324
% Wood Cover	-18.907	6.115	-3.09	< 0.01
Depth (m)	-5.78	2.447	-2.36	0.018
AIC	dispersion	log Likelihood	Deviance	df residual
121.2	403.43	-51.6217	41.9	99

Table 10. Best microhabitat predictive model of Chattahoochee Bass catch rate (fish/hr) as it relates to habitat variables measured in mesohabitat units of 16 Middle Chattahoochee River tributaries in summer 2014, based on model selection with no interactions. The model used a Poisson distribution with a random effect for stream. Model selection used Akaike's Information Criterion (AIC) and -log likelihood to determine the best model. Bayes Information Criterion (BIC) is another model selection criterion, and deviance is a quality of fit statistic for a model.

Fixed effects:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.585	1.645	-2.788	< 0.01
% Sand	2.691	0.992	2.713	< 0.01
% Rock	2.843	1.477	1.925	0.054
Stream Width (m)	10.479	6.641	1.578	0.115
AIC	BIC	-log Likelihood	Deviance	df residual
76.1	83.9	-33.1	66.1	30

Table 11. Total catch of four black bass species, number of transects sampled (N), mean black bass catch (CPE), mean estimated mesohabitats (Run, Pool, and Shoal), and total effort from canoe electrofishing (15-minute transects) of 16 Middle Chattahoochee River tributaries in summer 2013. Species were Largemouth Bass (LMB), Spotted Bass (SPB), Shoal Bass (SHB), Chattahoochee Bass (CHB). Streams outside the range of Chattahoochee Bass are marked with a dash. All streams are listed alphabetically.

Stream	LMB	SPB	SHB	CHB	Run	Pool	Shoal	N	Effort (hr)
Centralhatchee	1	6	0	2	0.4	0.37	0.24	10	2.5
Dog	2	20	3	9	0.48	0.06	0.46	16	4
Flat Shoals	0	12	17	-	0.7	0.04	0.26	20	5
Halawakee	17	10	0	-	0.74	0.09	0.18	10	2.5
Hillabahatchee	0	8	0	-	0.15	0.35	0.5	12	3
Little Uchee	13	3	0	-	0.59	0.17	0.25	13	3.25
Mountain Oak	1	12	0	-	0.73	0.1	0.17	10	2.5
Mulberry	13	26	38	-	0.44	0.34	0.22	19	4.75
New River	4	7	0	0	0.86	0.14	0	6	1.5
Osanippa	4	21	1	-	0.22	0.21	0.57	22	5.5
Snake	7	19	0	29	0.3	0.14	0.57	17	4.25
Standing Boy	9	31	0	-	0.42	0.23	0.35	13	3.25
Sweetwater	4	13	3	0	0.36	0.43	0.22	9	2.25
Uchee	7	8	0	-	0.84	0.08	0.08	18	4.5
Wehadkee	13	2	0	0	0.38	0.41	0.21	10	2.5
Whooping	2	9	0	21	0.47	0.08	0.45	13	3.25
TOTAL	97	207	62	61	.	.	.	218	54.5
MEAN CPE(fish/hr)	1.78	3.8	1.14	3.01	.	.	.	.	3.41
Standard Dev.	3.52	4.77	3.74	5.19	.	.	.	.	1.1

Table 12. Pearson correlation coefficients among black bass catch rates in canoe electrofishing samples (fish/hr) and percent mesohabitats estimated in 16 Middle Chattahoochee River tributaries. Coefficients followed by a single asterisk were significant at $P \leq 0.10$, those followed by a double asterisk were significant at $P \leq 0.01$. Chattahoochee Bass only included data for streams within their known distribution above West Point Reservoir.

MESO	Shoal Bass CPE	Spotted Bass CPE	Largemouth Bass CPE	Chattahoochee Bass CPE
Run	-0.03	0.13*	-0.16*	-0.18**
Pool	0.02	-0.13*	0.19**	-0.12*
Shoal	0.02	-0.04	0.02	0.29**

Table 13. Black Bass mesohabitat predictive models used to determine the probability of catching a black bass species in each mesohabitat. Models used black bass presence/absence and estimated mesohabitat data from canoe electrofishing (15-minute transects) of 16 Middle Chattahoochee River tributaries surveyed in the summer of 2013. Predictive models using a Binomial distribution of species presence/absence with a random effect of stream. Only significant effects of mesohabitat were shown for each species. Akaike's Information Criterion (AIC) is a model selection criterion, corrected Akaike's Information Criterion (AICc) is a model selection criterion with a correction for the number of parameters, Bayes Information Criterion (BIC) is another model selection criterion, and deviance is a quality of fit statistic for a model. No significant models were found for Spotted Bass.

Species	Fixed Effects	Estimate	Std. Error	z value	Pr(>|z|)	AIC	AICc	BIC	-nll	deviance	df
Shoal Bass	% Shoal	3.397	1.406	2.417	P< 0.05	107.7	107.8	117.9	-50.9	101.7	215
	% Run	-1.601	0.957	-1.673	P< 0.10	112.7	112.9	122.9	-53.4	106.7	215
Largemouth Bass	% Run	-1.085	0.548	-1.979	P< 0.05	244.8	244.9	254.9	-119.4	238.8	215
	% Pool	2.287	0.67	3.412	P< 0.001	236.5	236.7	246.7	-115.3	230.5	215
Chattahoochee Bass	% Shoal	5.562	1.432	3.885	P< 0.001	72.9	73.3	79.9	-33.5	66.9	92
	% Run	-4.11	1.348	-3.049	P< 0.01	82.4	82.7	89.3	-38.2	76.4	92
	% Pool	-9.481	4.484	-2.114	P< 0.05	86	86.4	93	-40	80	92

Table 14. Land use areas (km²) for each stream sampled in the Middle Chattahoochee River. Land cover data were collected from NLCD imagery and analyzed in ArcGIS 10. Areas (km²) of each land cover type are measured for each watershed. Streams were listed alphabetically and stream abbreviations are listed in Table 1. Forested cover was divided into deciduous (Decid), evergreen (Everg), and mixed. Wetlands were divided into wooded and herbaceous wetlands (Herba), and herbaceous plants are different from wetland herbaceous plants.

		Developed					Forested					Agriculture		Wetlands	
Stream	Area	Open	Low	Med	High	Barren	Decid	Everg	Mixed	Shrub	Herba	Pasture	Crop	Wooded	Herba
CTH	219.9	9.1	2.7	0.7	0.1	0.6	73.3	51.4	0.8	15.2	10.3	53.3	0	1.9	0
DOG	293.5	29.2	15.5	3.1	1.1	1.8	106.7	67.7	0.8	10.7	13.4	36.2	0	2.5	0.1
FSH	811.8	30.3	7.7	0.8	0.3	1.8	207.1	251.2	6.3	74.2	52.6	138.2	0.5	32.4	2.8
HLB	298.1	8.1	1.4	0.1	0	1.1	107	84.3	0.9	33.4	23.8	31	0	5.5	0.3
HWK	284.5	12.6	9.9	2.9	1.5	1	89.9	63	1.9	23.4	20	48.9	0.4	6.7	0.6
LUC	497.9	37.3	18.4	2.3	0.5	1.9	151	91.2	22.9	69.3	15.1	50.2	11.5	19.1	1.5
MTN	253.3	13.9	1.7	0.3	0	0.2	91.7	84.7	1.6	16.5	12.5	13.1	0	12.4	0.2
MUL	836	43.6	8.5	0.9	0.3	1.4	327.6	219	4	66	54.5	72.2	0.1	27.7	1.8
NWR	545	25.4	12	2	1.6	0.8	132.2	192.8	3.8	31	30.5	75.2	0.1	29.3	0.3
OSA	448.1	19.1	5.7	1.2	0.5	1.1	143.8	113.2	4.6	46	27.7	62.1	0.1	19.7	1.1
SNK	184.3	9	4.3	0.4	0.1	0.5	66.1	50.2	0.4	12.8	12.6	20.2	0	2.6	0
STB	256.2	18	9.7	1.5	0.4	2.7	99.9	68	1.7	11.6	14.1	17.4	0.1	6.9	0.2
SWT	991.1	192	158	38.3	16.5	3.1	225.1	171.4	3.7	18.8	29.7	87.4	0	34.8	2.2
UCH	715.7	35.9	10.6	1.2	0.1	0.9	161.2	121.5	59.5	135.5	11.7	86.8	38.9	40.6	2.2
WAC	119.5	3.8	1.7	0.1	0	0.8	35.7	37.7	0.5	10.8	13.3	13.2	0	1.4	0
WHK	315.6	11.2	4.3	0.7	0.2	0.5	99.8	63.2	1.8	36	27.8	59.8	0.1	7.8	1.1
WPG	117.2	5.7	2.7	0.3	0.1	0.1	41	28.4	0.6	6.4	6.2	23.8	0	1	0.1
TOTAL	7187.7	504.2	275	56.8	23.3	20.3	2159.1	1759	115.8	617.6	375.8	889	51.8	252.3	14.5
MEAN	417.2	28.7	15.4	3.2	1.3	1.2	125.7	103.6	6.6	35.8	22.2	51	2.9	14.8	0.8

Table 15. Mean land-cover (km²) of streams with a high Shoal Bass population, low Shoal Bass (SHB) population, absent, comparison of high versus absent, comparison of low versus absent, and comparison of high versus low. Mean land-cover of streams where Chattahoochee Bass (CHB) are present and absent, and present versus absent. Forested cover was divided into deciduous (Decid), evergreen (Everg), and mixed. Wetlands were divided into wooded and herbaceous wetlands (Herba), and herbaceous plants are different from wetland herbaceous areas.

	Area	Developed					Forested					Agriculture		Wetlands	
	(km²)	Open	Low	Med	High	Barren	Decid.	Everg	Mixed	Shrub	Herba	Pasture	Crop	Wooded	Herba
SHB Present	483.2	39.2	23	5	2.1	1.35	149.1	117.4	4.7	36.5	25.6	56.3	1.3	16.2	1.1
SHB Absent	336.6	16.1	6.5	0.9	0.4	1	95.5	83.5	9.8	36.1	17.2	46.6	5.6	12.9	0.5
SHB High	879.6	88.6	58.1	13.3	5.7	2.1	253.3	213.9	4.7	53	45.6	99.3	0.2	31.6	2.3
SHB Low	313.2	18	7.9	1.5	0.5	1	104.4	76.1	4.8	29.4	17	37.9	1.7	9.6	0.6
CHB Present	222.6	12.2	5.3	0.9	0.3	0.8	78.8	56.4	0.7	15.7	13.3	32.9	0	2.7	0.1
CHB Absent	617.2	76.2	58.1	13.7	6.1	1.5	152.4	142.5	3.1	28.6	29.3	74.1	0.1	24	1.2

Table 16. Streams were assigned into abundance categories for Shoal Bass (SHB) and Chattahoochee Bass (CHB) based upon total catch of each species throughout the study. Streams where > 25 fish were collected were considered high abundance, whereas, those where <25 fish were collected were considered low abundance. If no fish were collected, the species was considered absent.

	Abundance Classification		Land Use Categories			
Stream	SHB	CHB	Developed	Nat.	Ag.	Forested
Centralhatchee	Absent	Present	5.7	69.5	24.2	57.1
Dog	Low	Present	16.7	68.8	12.3	59.7
Flat Shoals	High	-	4.8	77.2	17.1	57.2
Hillabahatchee	Low	Present	3.2	85.6	10.4	64.5
Halawakee	Absent	-	9.5	72.2	17.3	54.4
Little Uchee	Low	-	11.7	74.3	12.4	53.2
Mountain Oak	Low	-	6.3	86.7	5.2	70.3
Mulberry	High	-	6.4	83.8	8.6	65.9
New River	Absent	Absent	7.5	77	13.8	60.3
Osanippa	Low	-	5.9	79.5	13.9	58.4
Snake	Absent	Present	7.5	78.5	11	63.3
Standing Boy	Absent	-	11.6	79	6.8	66.2
Sweetwater	High	Absent	40.9	49	8.8	40.4
Uchee	Absent	-	6.7	74.4	17.6	47.8
Wacoochee	Absent	-	4.7	83.2	11	61.8
Wehadkee	Absent	Absent	5.2	75.3	19	52.2
Whooping	Low	Present	7.5	71.4	20.3	59.7
MEAN	.	.	9.5	75.6	13.5	58.4

Table 17. Total substrate types (km²) within each mesohabitat of each mapped stream from side-scan sonar surveys performed during the spring of 2015. Streams are listed from north to south as they enter the Chattahoochee River.

Stream	Substrate	Mesohabitat				
		Pool	Riffle	Run	Shoal	Total
Flat Shoals Creek	Bedrock	0.626	0.074	0.682	3.802	5.184
	Boulder	0.398	0.401	1.624	3.764	6.187
	Cobble	0.261	0.504	0.494	0.110	1.370
	Sand/Gravel	2.945	0.334	36.037	0.064	39.379
	Shadow	0.009	0.073	0.521	0.000	0.603
	Unsure	0.140	0.000	0.040	0.000	0.179
Mountain Oak Creek	Bedrock	0.233	0.027	0.280	0.424	0.965
	Boulder	0.124	0.068	0.262	0.635	1.088
	Cobble	0.153	0.158	0.604	0.099	1.014
	Sand/Gravel	0.890	0.015	4.972	0.221	6.098
	Shadow	0.008	0.012	0.032	0.003	0.055
	Unsure	0.000	0.000	0.000	0.160	0.160
Osanippa Creek	Bedrock	1.298	0.319	2.031	1.491	5.140
	Boulder	0.453	0.645	1.899	2.742	5.739
	Cobble	0.220	0.257	0.895	0.364	1.736
	Sand/Gravel	1.989	0.336	8.240	0.170	10.736
	Shadow	0.000	0.000	0.073	0.000	0.073
	Unsure	0.000	0.000	0.000	0.000	0.000
Halawakee Creek	Bedrock	0.647	0.017	0.348	1.127	2.138
	Boulder	0.266	1.104	0.796	2.946	5.112
	Cobble	0.485	0.907	0.973	0.697	3.063
	Sand/Gravel	1.302	0.314	6.057	0.170	7.843
	Shadow	0.001	0.129	0.033	0.030	0.194
	Unsure	0.000	0.000	0.000	0.053	0.053
Mulberry Creek	Bedrock	1.322	0.093	0.882	4.543	6.839
	Boulder	2.330	0.485	2.645	2.459	7.919
	Cobble	0.399	0.191	0.805	0.161	1.556
	Sand/Gravel	9.239	0.585	39.408	0.977	50.209
	Shadow	0.107	0.172	0.468	0.269	1.016
	Unsure	0.196	0.102	0.009	0.063	0.370
	TOTAL	26.041	7.321	111.112	27.545	172.019

Table 18. Percent substrate within each mesohabitat of each mapped stream from side-scan sonar surveys performed during the spring of 2015. Streams are listed from north to south as they enter the Chattahoochee River.

Stream	Substrate	Mesohabitat				
		Pool	Riffle	Run	Shoal	Total
Flat Shoals Creek	Bedrock	14.3	5.4	1.7	49.1	9.8
	Boulder	9.1	28.9	4.1	48.6	11.7
	Cobble	6.0	36.4	1.3	1.4	2.6
	Sand/Gravel	67.3	24.1	91.5	0.8	74.4
	Shadow	0.2	5.2	1.3	0.0	1.1
	Unsure	3.2	0.0	0.1	0.0	0.3
Mountain Oak Creek	Bedrock	16.6	9.8	4.6	27.5	10.3
	Boulder	8.8	24.3	4.3	41.1	11.6
	Cobble	10.8	56.5	9.8	6.4	10.8
	Sand/Gravel	63.2	5.3	80.8	14.4	65.0
	Shadow	0.6	4.1	0.5	0.2	0.6
	Unsure	0.0	0.0	0.0	10.4	1.7
Osanippa Creek	Bedrock	32.8	20.5	15.5	31.3	21.9
	Boulder	11.4	41.4	14.5	57.5	24.5
	Cobble	5.6	16.5	6.8	7.6	7.4
	Sand/Gravel	50.2	21.6	62.7	3.6	45.8
	Shadow	0.0	0.0	0.6	0.0	0.3
	Unsure	0.0	0.0	0.0	0.0	0.0
Halawakee Creek	Bedrock	23.9	0.7	4.2	22.4	11.6
	Boulder	9.8	44.7	9.7	58.6	27.8
	Cobble	18.0	36.7	11.9	13.9	16.6
	Sand/Gravel	48.2	12.7	73.8	3.4	42.6
	Shadow	0.0	5.2	0.4	0.6	1.1
	Unsure	0.0	0.0	0.0	1.1	0.3
Mulberry Creek	Bedrock	9.7	5.7	2.0	53.6	10.1
	Boulder	17.1	29.8	6.0	29.0	11.7
	Cobble	2.9	11.7	1.8	1.9	2.3
	Sand/Gravel	68.0	35.9	89.1	11.5	73.9
	Shadow	0.8	10.6	1.1	3.2	1.5
	Unsure	1.4	6.3	0.0	0.7	0.5

IX. FIGURES

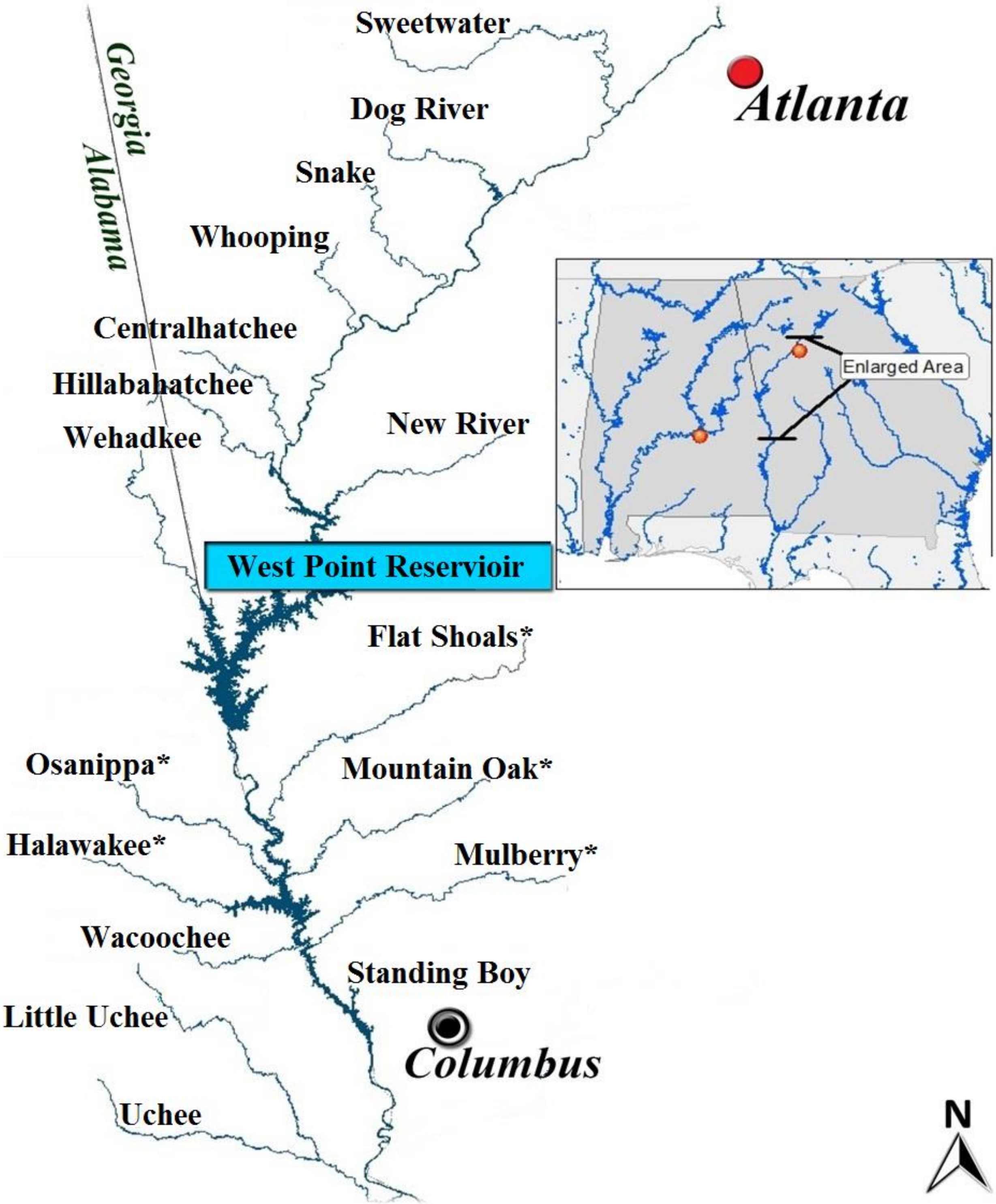

Figure 1. Study area of the Middle Chattahoochee River of Alabama and Georgia. All streams shown were sampled for habitat at multiple scales and with electrofishing. *Streams where side-scan sonar surveys were conducted are denoted by an asterisk.

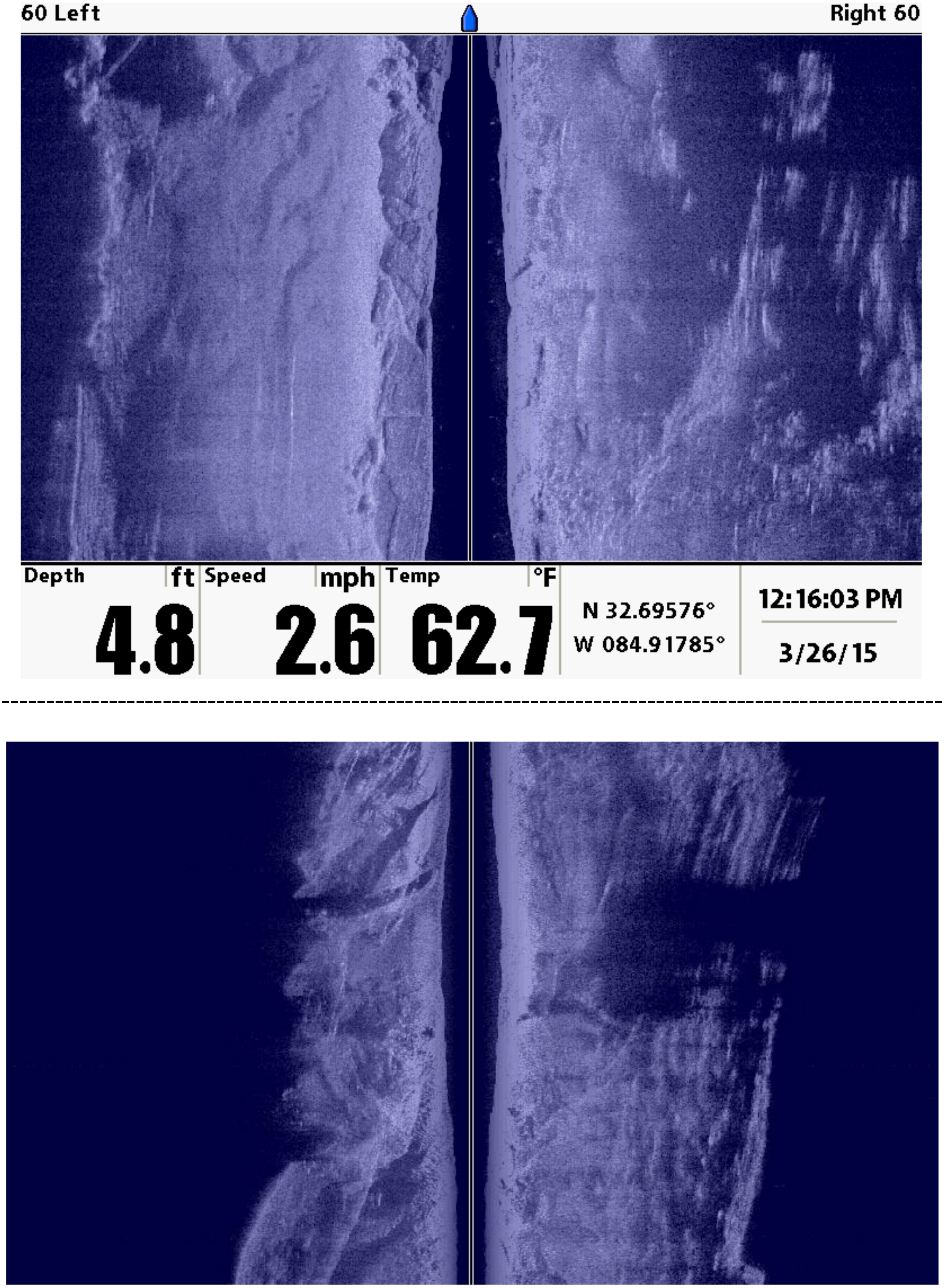

Figure 2. (TOP) Example image output from side-scan sonar mapping. Picture shows scanning width at the top left and right in feet, depth in feet, boat speed in miles-per-hour, temperature in Fahrenheit, latitude and longitude in decimal degrees, time, and date. (BOTTOM) Example imagery with the 'collar' of information removed for later rectification in ArcGIS.

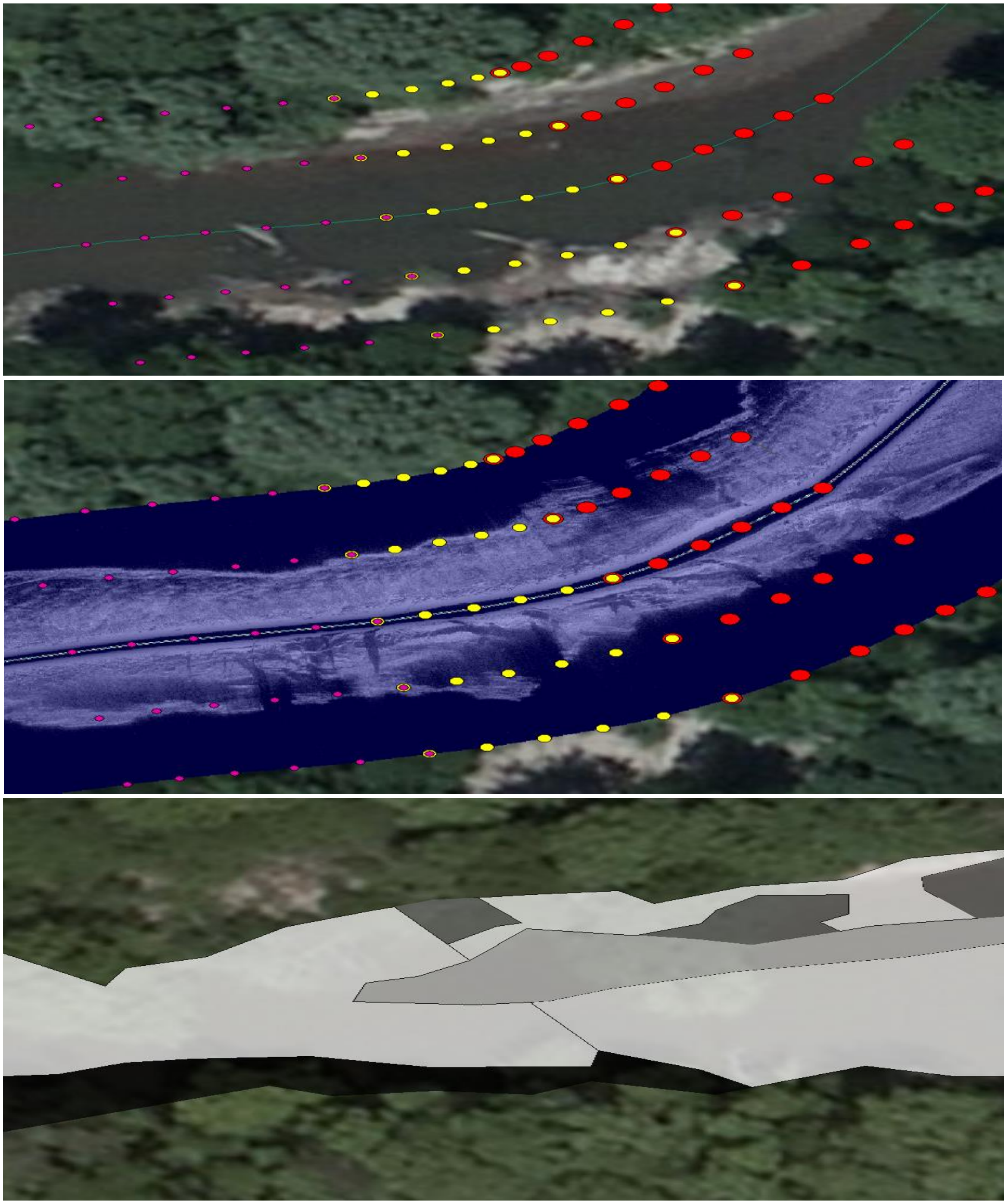

Figure 3. (TOP) Image of a control point network for 3 images using side-scan sonar. Points represent the 30-point networks of 3 images that determine how the images will be warped or rectified to fit the stream GPS path and connect to adjacent imagery. (MIDDLE) Image of a control point network with merged images of instream habitats, showing how images are merged together and follow the stream banks. (BOTTOM) Image of habitat delineation and the final step in procedure for quantifying instream habitat. Bedrock substrates are black, boulder substrates are dark grey, cobble substrates are grey, and sand substrates are light grey.

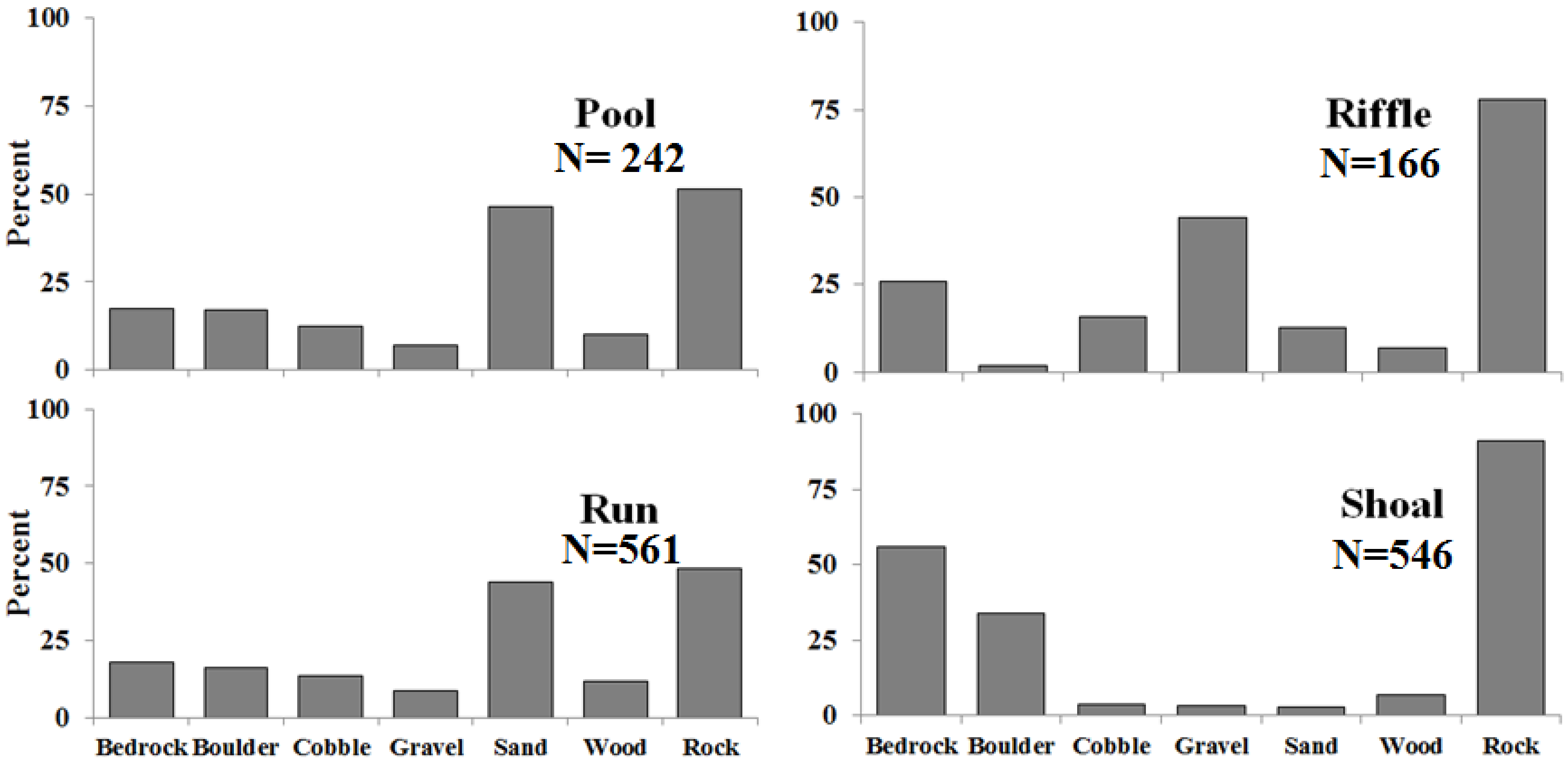

Figure 4. Percent of substrate types (defined in Table 2), and percent of rock and wood cover of four mesohabitats sampled using the point and transect method in 16 Middle Chattahoochee River tributaries in summer 2014. The number of points sampled in each mesohabitat is defined by N.

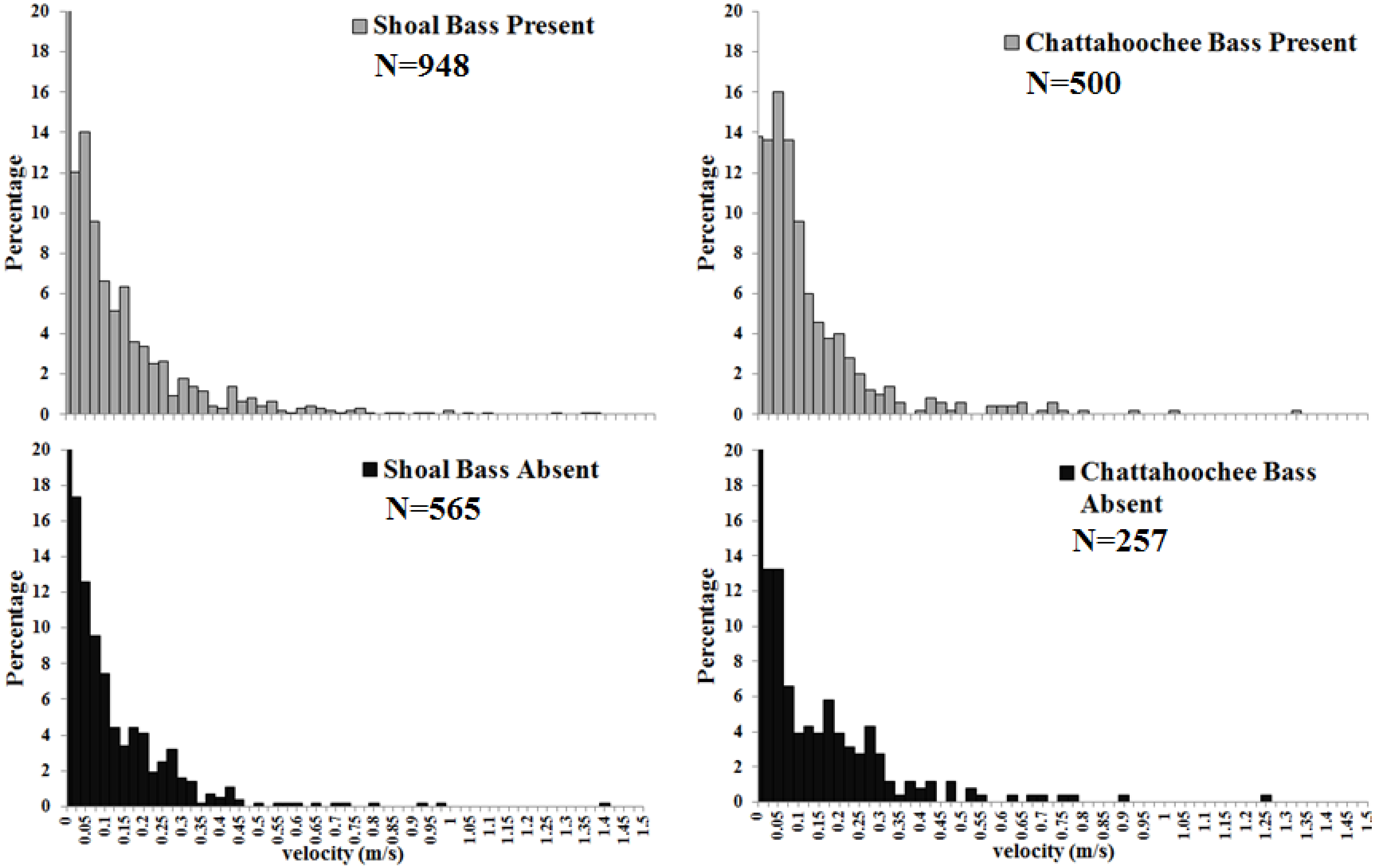

Figure 5. Stream velocity (m/s) frequency distributions between Shoal Bass and Chattahoochee Bass presence/absence. Distributions were compared using a K-S test ($P < 0.05$). Chattahoochee Bass data are from streams within their known range.

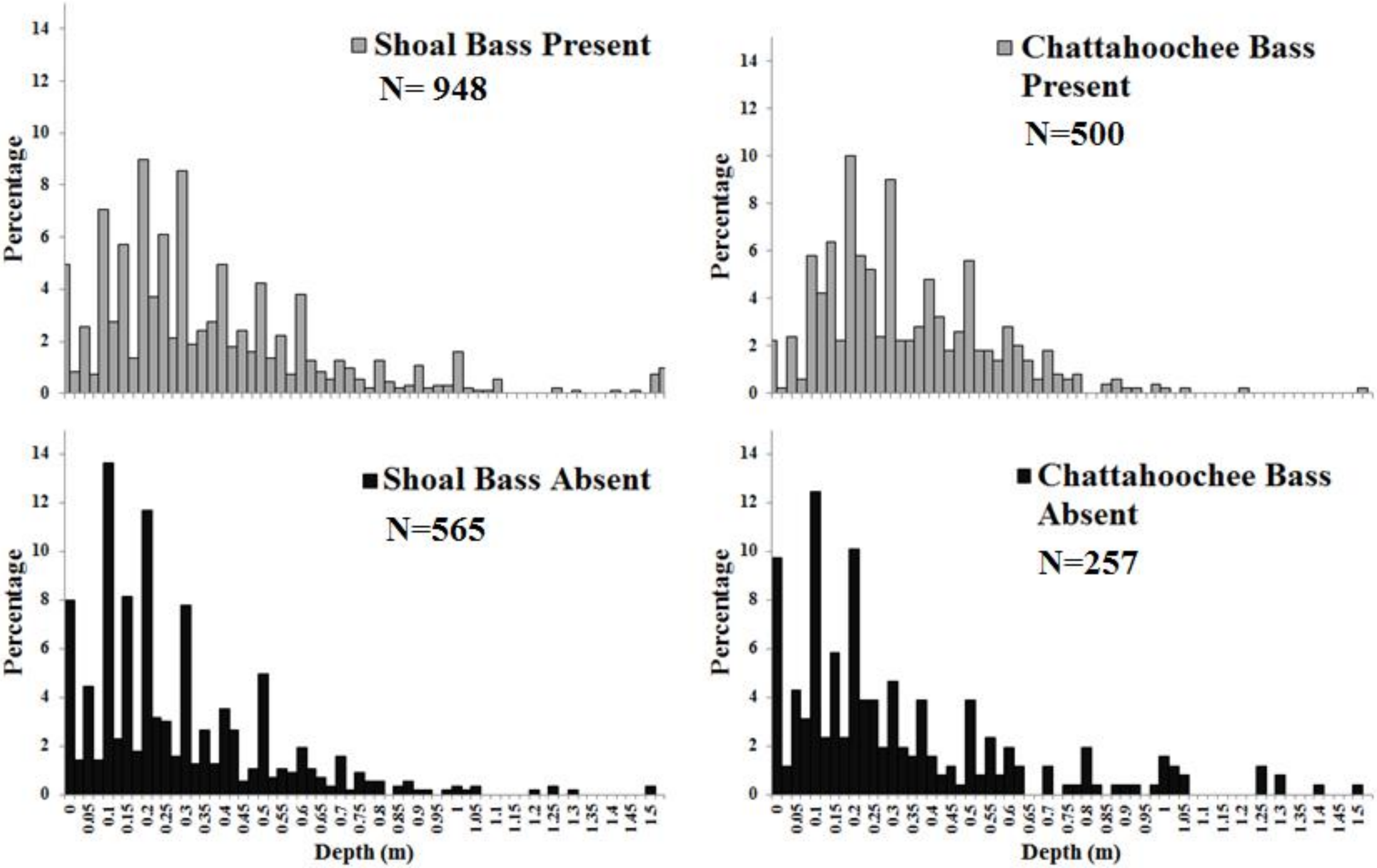

Figure 6. Stream depth (m) frequency distributions between Shoal Bass and Chattahoochee Bass presence/absence. Distributions were compared using a K-S test ($P < 0.05$). Chattahoochee Bass data are from streams within their known range.

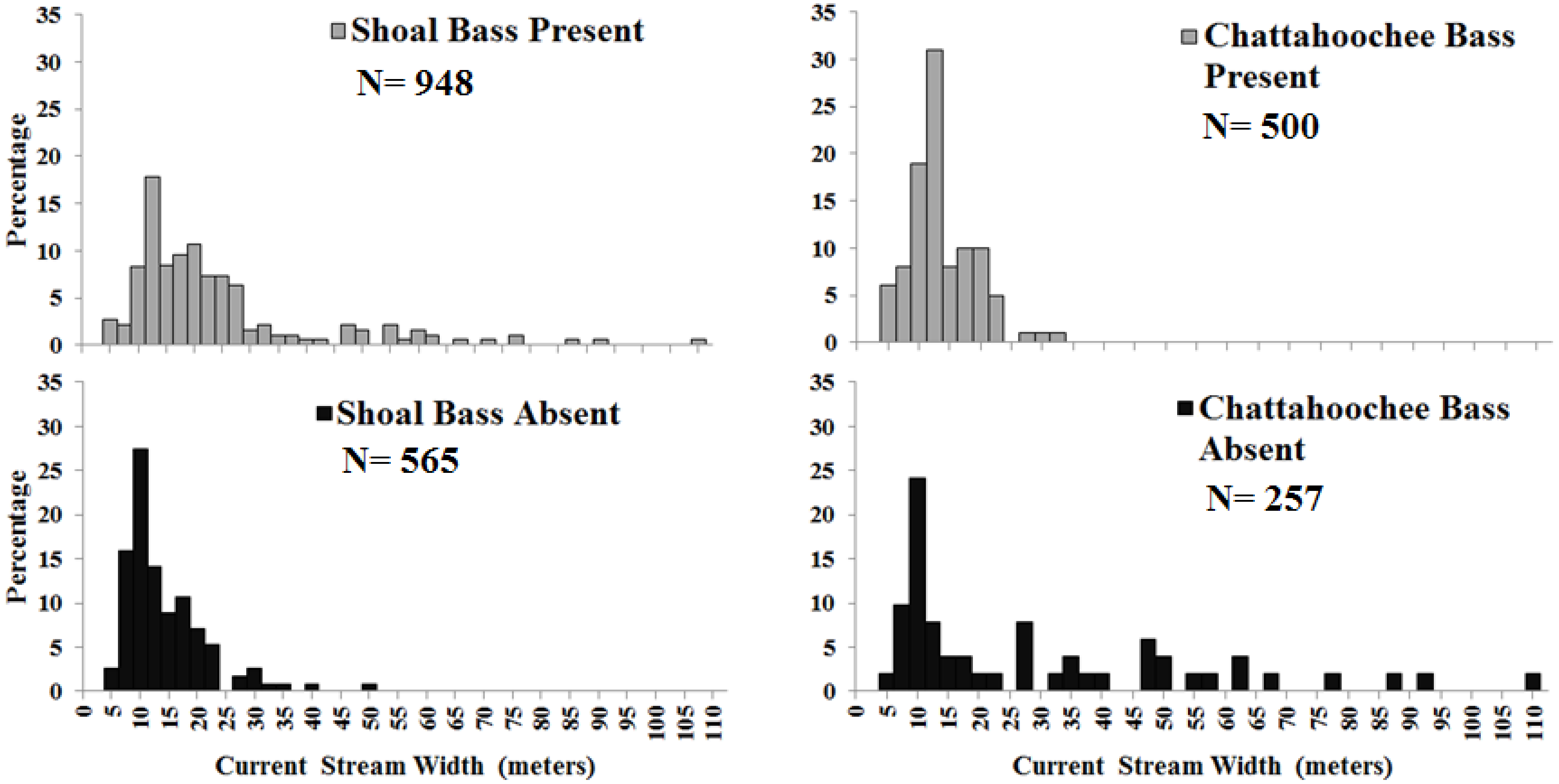

Figure 7. Stream width (m) frequency distributions between Shoal Bass and Chattahoochee Bass presence/absence. Distributions were compared using a K-S test ($P< 0.05$). Chattahoochee Bass data are from streams within their known range.

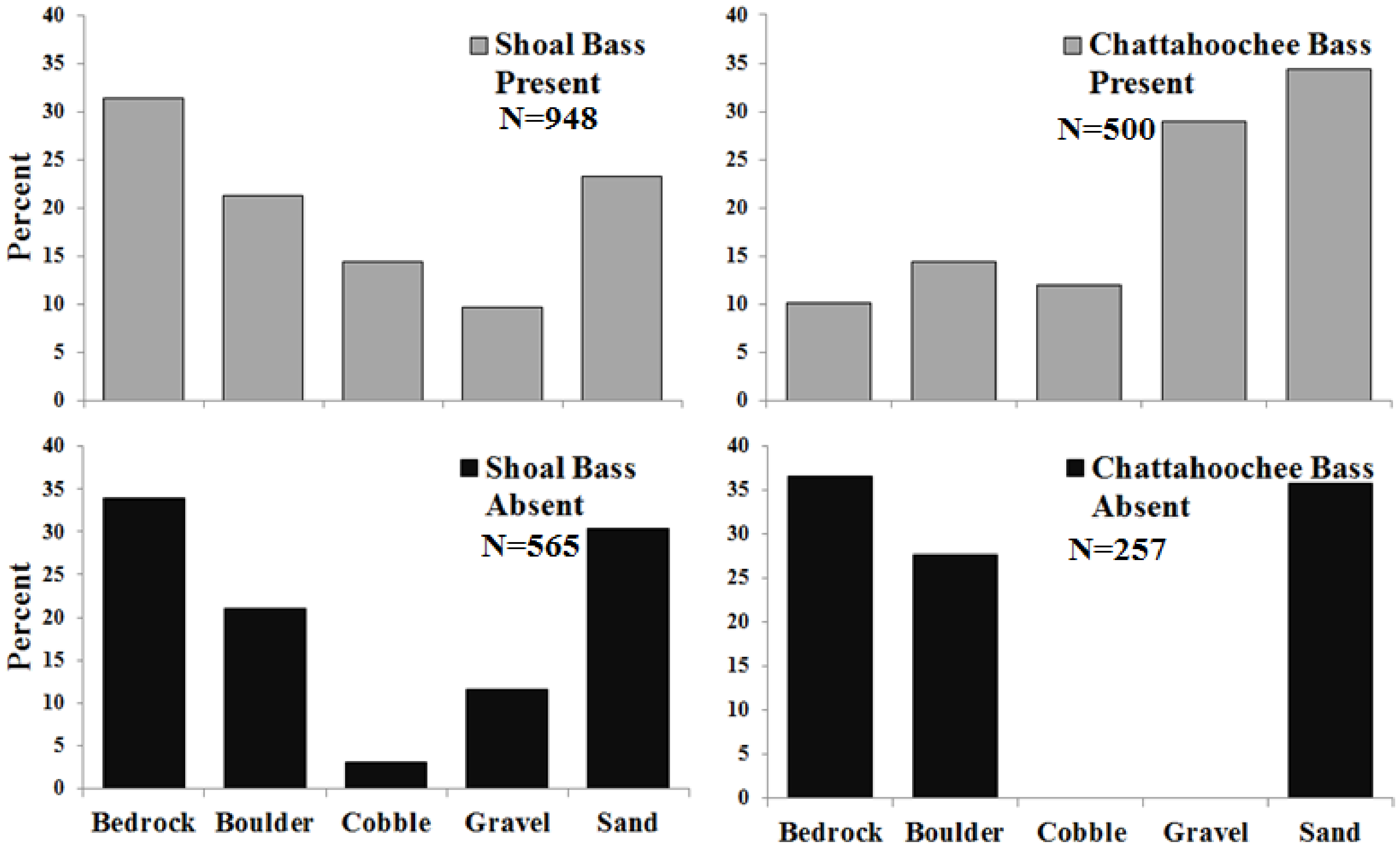

Figure 8. Percent substrate types (defined in Table 2) of Shoal Bass and Chattahoochee Bass presence/absence from backpack electrofishing surveys of mesohabitats in 16 Middle Chattahoochee River tributaries in summer 2014 ($P< 0.10$). Chattahoochee Bass data only from streams within their known range.

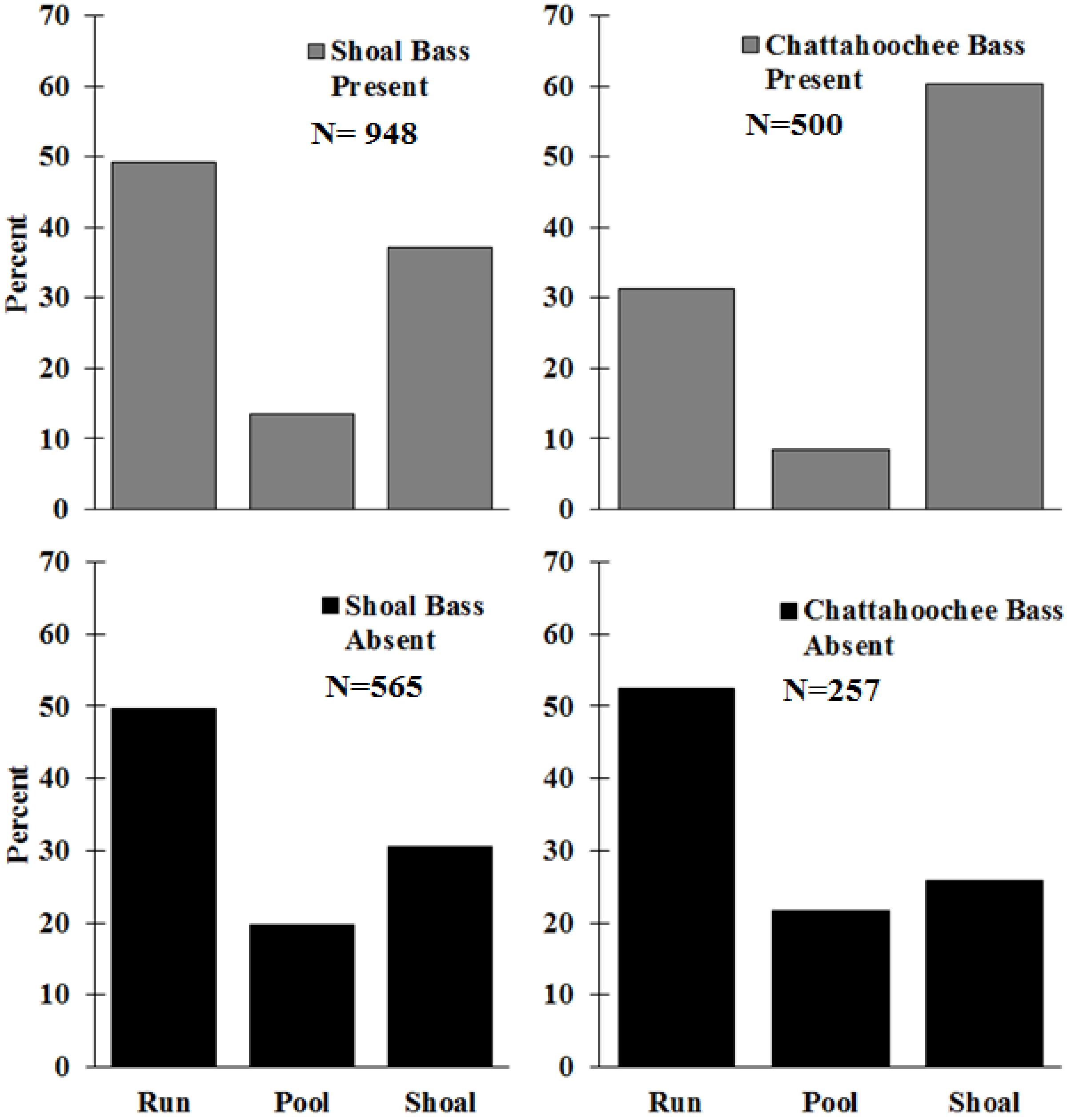

Figure 9. Percent mesohabitat types (defined in Table 2) of Shoal Bass and Chattahoochee Bass presence/absence from canoe electrofishing 15-minute transects of stream reaches in 16 Middle Chattahoochee River tributaries in summer 2013 (P< 0.10). Chattahoochee Bass data only from streams within their known range.

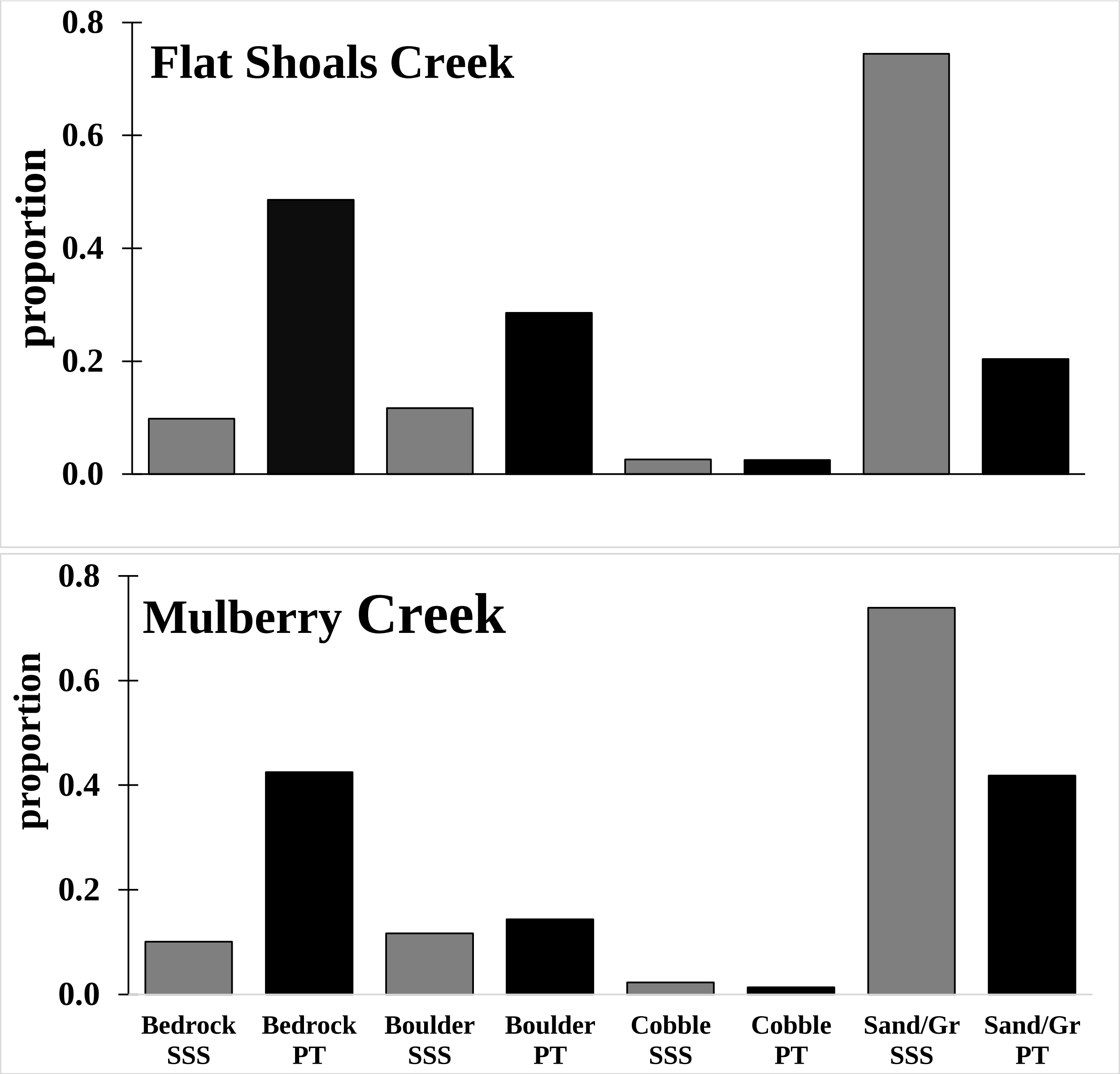

Figure 10. Comparison of mean substrates between point/transect data and side-scan sonar data from Flat Shoals and Mulberry Creeks, which both have similar-sized watershed areas (811.8-836 km²). Data were collected for point/transect (PT) surveys in summer 2014 and side-scan sonar (SSS)surveys in spring 2015.

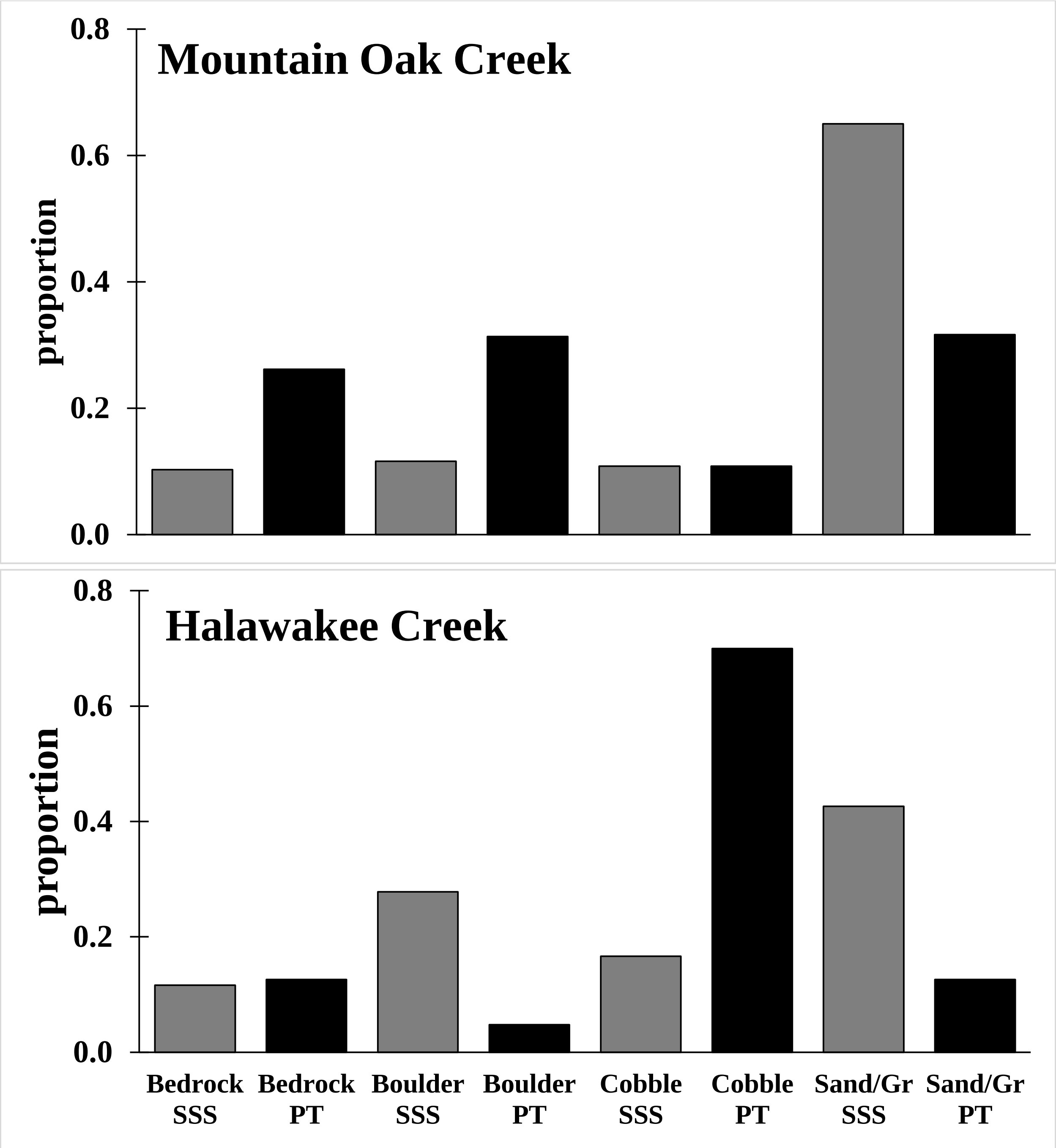

Figure 11. Comparison of mean substrates between point/transect data and side-scan sonar data from Mountain Oak and Halawakee Creeks, which both have similar-sized watershed areas (253.3-284.5 km²). Data were collected for point/transect (PT) surveys in summer 2014 and side-scan sonar surveys (SSS) in spring 2015.

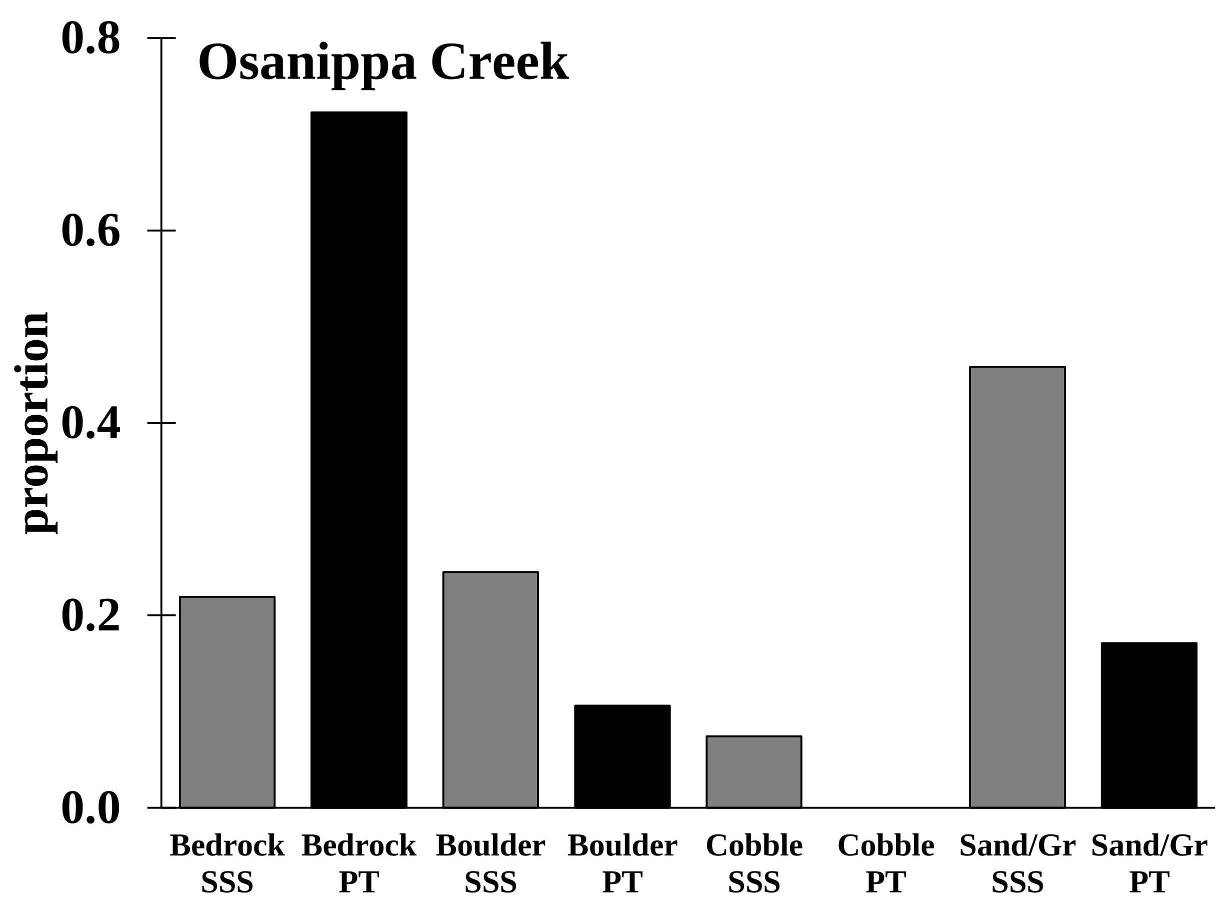

Figure 12. Comparison of mean substrates between point/transect data and side-scan sonar data from Osanippa Creek, which has a watershed area that is intermediate to other mapped streams (448.1 km²). Data were collected for point/transect (PT) surveys in summer 2014 and side-scan sonar surveys (SSS) in spring 2015.

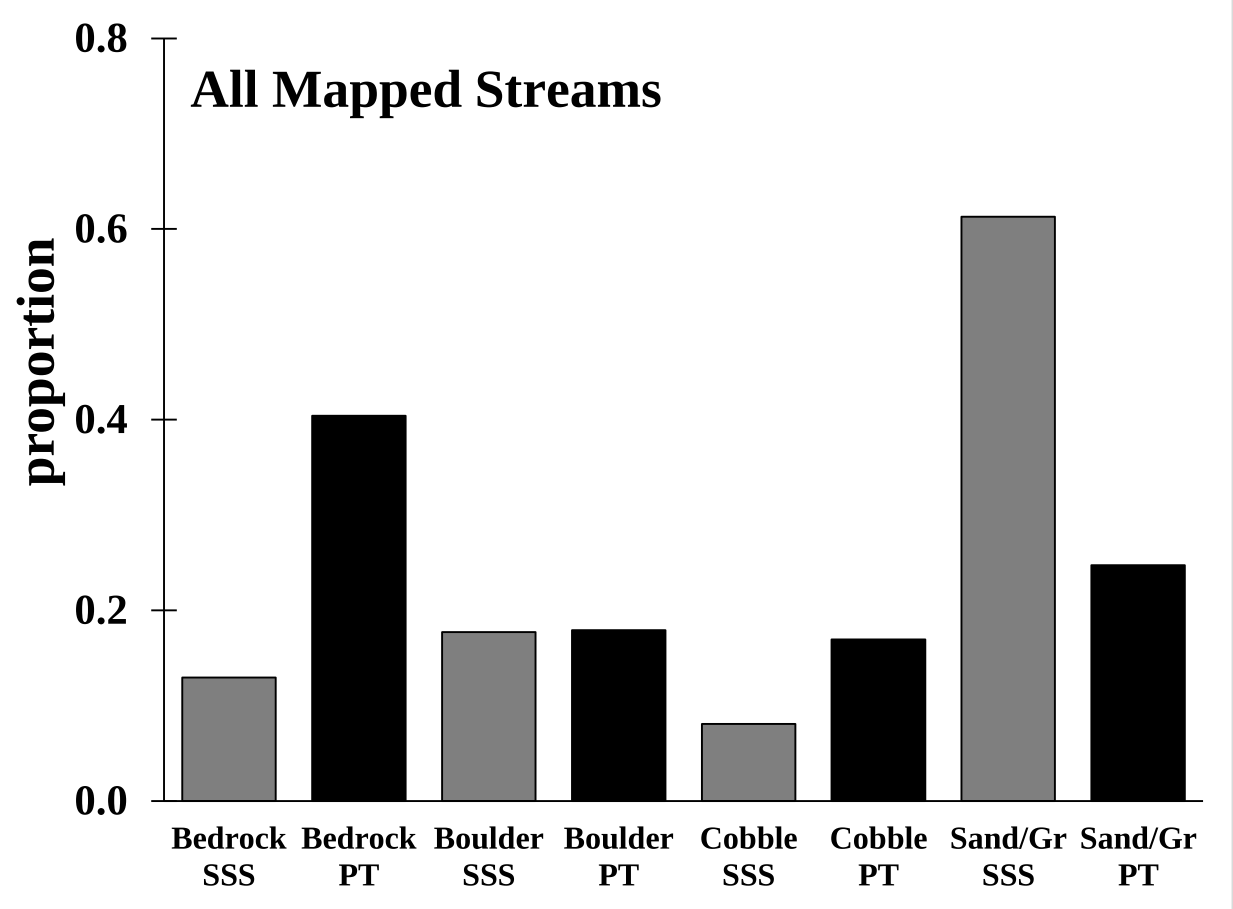

Figure 13. Comparison of mean substrates between point/transect data and side-scan sonar data from mapped streams overall Data were collected for point/transect (PT) surveys in summer 2014 and side-scan sonar surveys (SSS) in spring 2015.

X**. APPENDICES**

X.1. Side-Scan Sonar Start and End GPS Points.

Appendix 1. Side-scan sonar Middle Chattahoochee River tributary start and end latitude and longitude in decimal degrees.

Stream	Start Lat	Start Long	End Lat	End Long
Flat Shoals	32.881358	-85.077806	32.794239	-85.137466
Mountain Oak	32.741173	-85.068769	32.726271	-85.095011
Osanippa	32.784802	-85.193542	32.831511	-85.147502
Halawakee	32.69751	-85.266742	32.686139	-85.204418
Mulberry	32.695939	-84.913133	32.640596	-85.065272

X.2. Point/Transect Sampling Form

SHOAL BASS HABITAT SAMPLING

DATE:____________________ STREAM:__________________

REACH:__________ MSW:___________ MESOHABITAT:____________

% WOODY COVER:______________% ROCK/BOULDER:________/_________

START : WPT:______LAT:________________LONG:___________________
STOP : WPT:______LAT:________________LONG:__________________

		WIDTH					MEASUREMENTS (mm)						
TR	PT	BF	CUR	DEP	VEL	SUB	1	2	3	4	5	6	7

X.3. Point/Transect Electrofishing Form

SHOAL BASS ELECTROFISHING

Date:___________________ **Stream**:_________________________ **Reach**:

MESO UNIT	EFF	SPP	TL	WT	PIT tag	Fin Clip

X.4. Canoe Hand-held Electrofishing Sampling Form

Chattahoochee Tribs - HH Electrofishing Forms

Date:________________ **Creek:__________________________________**

Transect:__________
WPT: ____/____
LAT: ________________/___________________
LONG:________________/___________________
HAB: _____%RN _____%PL ______%SH

Spp	TL	WT	CLIP

Transect:__________
WPT: ____/____
LAT: _________________/_________________
LONG:_________________/_________________
HAB: _____%RN _____%PL ______%SH

Spp	TL	WT	CLIP

X.5. Land Cover Classifications

Class\ Value	Classification Description
Water	
11	**Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil.
12	**Perennial Ice/Snow** - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	**Developed, Open Space** - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity** -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	**Deciduous Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	**Evergreen Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	**Mixed Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
51	**Dwarf Scrub** - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	**Shrub/Scrub** - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
71	**Grassland/Herbaceous** - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
72	**Sedge/Herbaceous** - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	**Lichens** - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	**Moss** - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	
81	**Pasture/Hay** – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	**Cultivated Crops** – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	**Woody Wetlands** - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	**Emergent Herbaceous Wetlands** - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

A Revision of : A Land Use And Land Cover Classification System For Use With Remote Sensor Data (Anderson, et al. 1976)