AN ASSESSMENT OF FISH COMMUNITY STRUCTURE AND SEASONAL HABITAT USE OF HEADWATER CONFINED CHANNELS AND HEADWATER WETLANDS IN THE LOWER FLINT RIVER BASIN, SOUTHWEST GEORGIA

by

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Under the Direction of James T. Peterson

ABSTRACT

Headwater wetland streams comprise a significant proportion of aquatic habitats in the Southeast. Nonetheless, little is known about their fish communities. I examined seasonal fish community structure and habitat use in headwater wetland and confined channel streams during 2003-2004. Species richness and fish density were greater in wetland streams than in confined channel streams. Wetland fish communities, however, varied seasonally. Species richness and fish density in wetlands were positively related to dissolved oxygen concentrations, which were strongly influenced by stream discharge. During the winter, species richness and total fish density were positively related to stream temperature and negatively to current velocity, with the former influenced by groundwater inputs. Findings from this study suggest that wetland headwater streams were important stream fish habitats. The greater sensitivity of wetland stream habitats to low flows also suggests that streamflow regulations developed in confined channel streams may not be adequate for wetland headwater streams.

INDEX WORDS: Flint River Basin, Headwater Streams, Headwater Wetlands, Fish Community Structure, Seasonal Habitat Use, Groundwater, Akaike Information Criteria, Discriminant Analysis

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DEDICATION

I dedicate this thesis to the memory of my grandfather, Albert McPherson Jr., who passed away shortly after I began my college career. Daddy Mac knew the value of a hard day’s work, but he also had his share of fun. I most admired his love for people and his desire to help those in need.

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CHAPTER 1

INTRODUCTION

The aquatic systems of the Southeast U.S. contain some of the most diverse communities of temperate freshwater fish species in the world (Warren et al. 1997; Warren et al. 2000). With more than 500 species of fishes (Warren et al. 2000), the Southeast harbors nearly half the fish species found on the North American continent and approximately 60% of the native species present in the United States (Warren et al. 1997). The Southeast also contains the highest number of endemic fish species in North America, north of Mexico (Warren et al. 2000). Such high diversity and endemisism have been attributed to geologic history and habitat diversity (Warren and Burr 1994; Lydeard and Mayden 1995). Southeast streams were undisturbed by Pleistocene glaciation (Holman 1995), an environmental disturbance that led to the extinction of many of North America's flora and fauna (Lydeard and Mayden 1995). Southeast streams also collectively flow through six physiographic regions, resulting in the formation of a variety of complex aquatic habitat types (Dunne and Leopold 1978; Hodler and Schretter 1986). While the Southeast contains high diversity, it also has the highest proportion of fishes threatened with extinction (Warren et al. 2000). Approximately 28% of Southeast fishes were considered imperiled in 2000, a 125% increase from the number of imperiled fish species in 1979 (Warren et al. 2000). Efforts to conserve and enhance Southeastern fishes cannot be enacted without first understanding the life history requirements of these fishes.

The decline of fish populations in the Southeast U.S. has been attributed to anthropogenic impacts associated with the rapidly growing human population in the region (Warren et al.

2000). The human population in the Southeast grew 84% between 1950 and 1990, and the rate of growth continues to increase (Warren et al. 2000). Land use changes associated with increased human development have altered physical, chemical, and biological properties of stream systems. Examples of such alterations include habitat loss or fragmentation resulting from stream impoundment and channelization, urbanization, agriculture, deforestation, soil erosion, and water pollution (Etnier 1997; Richter et al. 1997; Warren et al. 2000). Stream impoundment alters the natural flow regime of a stream and limits fish movement, possibly preventing them from fulfilling their life history requirements (Warren et al. 2000). Increasing urbanization, agriculture, deforestation, pollution, and erosion alter hydrologic flow patterns and water quality (Richter et al. 1997; Warren et al. 2000). Because anthropogenic effects on streams negatively affects fish populations and these effects will likely increase, knowledge of Southeastern fishes' habitat requirements is vital for predicting fish population changes resulting from future habitat alterations.

Headwater wetland streams (WS) and headwater confined channel streams (CCS) represent a significant proportion of habitat available to fishes in the Coastal Plain. In the lower Flint River Basin (FRB) of southwest Georgia, WS account for over 10% of the total basin area (Kramer et al. 2003). Therefore, the goal of my study was to assess fish distribution and community structures in headwater CCS and headwater WS in the lower FRB.

Towards this end, I investigated fish communities in these systems with the following objectives:

1) Assess habitat types and availability in headwater CCS and headwater WS of the lower FBR.
2) Determine seasonal habitat use of fishes in headwater CCS and headwater WS of the lower FRB.
3) Compare the seasonal fish community structures and habitat use of headwater CCS and headwater WS in the lower FRB.

My study will provide managers with: 1) insight into spatial and temporal changes that occur within these systems, 2) information on the influence of headwater wetland habitat on fish distribution and community structure, and 3) WS fish and habitat sampling protocols.

CHAPTER 2

LITERATURE REVIEW

Fish Community Structure

Stream fish community structure is influenced by multiple, scale-specific factors (Frissel et al. 1986; Peterson and Rabeni 2001b). At a large scale, physiographic regions are characterized as having similar geologic and evolutionary histories (Robinson 1986) and are generally geographically fragmented, preventing dispersal (Gorman 1986). Physiographic regions also have characteristic climate patterns (Robinson 1986) that dictate which fish species can survive (Wehrly and Wiley 2003). As a result, physiographic regions have unique species pools. At a smaller scale, watershed characteristics, including local weather patterns, geology, and land use, largely determine stream physical habitat characteristics, such as substrate, depth, and current velocity (Robinson 1986; Peterson and Kwak 1999; Jackson et al. 2001). These, in turn influence stream fish distribution and community structure.

Within a watershed, the longitudinal position of stream reach can influence fish community structure (Schlosser 1987; Peterson and Rabeni 2001b). Headwater stream reaches, defined as first to third order streams (Vannote et al. 1980), are generally flashier than larger order streams (Schlosser 1987; Peterson and Rabeni 2001b). That is, the magnitude of flow within the stream is less predictable and changes rapidly with time (Poff et al. 1997). Thus, upstream reaches generally consist of species that are more tolerant to extreme fluctuations in flow, including flooding and drought, or species that have high dispersal capabilities (Larimore 1959; Schlosser 1987; Bayley and Osbourne 1993; Peterson and Rabeni 2001b).

Species richness increases with increasing habitat heterogeneity, which varies longitudinally within a watershed or stream system (Schlosser 1982a; Schlosser 1982b; Schlosser 1987; Peterson and Rabeni 2001b). Headwater stream reaches are generally narrower and shallower than downstream reaches and have little spatial variability in depth and current velocity (Schlosser 1982b; Schlosser 1991). As a result, headwater streams lack habitats such as deep pools (Schlosser 1987; Jackson and Sturm 2002), which are used by larger fishes, such as ictalurids, catostomids, and *Micropterus spp.* (Schlosser 1982a; Jenkins and Burkhead 1993). Headwater streams also tend to have lower substrate heterogeneity relative to downstream reaches (Schlosser 1982b). Many fish species have particular substrate, depth, and velocity preferences and some species require particular habitats to meet their life history requirements (Page 1983; Jenkins and Burkhead 1993). Thus, fish communities of headwater streams generally have lower species richness and smaller size individuals relative to communities of downstream reaches (Horwitz 1978; Schlosser 1987; Paller 1994; Peterson and Rabeni 2001b).

Habitat Use

Within a stream reach, fish distribution is influenced by habitat structure and biotic interactions (Bison et al. 1988; Harvey and Stewart 1991; Lobb and Orth 1991). Fishes may use structures such as logs as cover from predators, as a feeding substrate, and flow refugia (Angermeir and Karr 1984; Benke et al. 1985; Todd and Rabeni 1989; Peterson and Rabeni 2001b). For many fishes, maintaining position in habitats with high current velocity is energetically costly (Bison et al. 1988; Facey and Grossman 1990). Therefore these fishes, including catostomids, *Pomoxis spp.,* and *Micropterus spp*., use deep, slow-flowing pools (Aaland 1993). However, some fishes, such as percids, cottids, *Noturus spp*., and *Campostama* *spp.*, have a flattened or fusiform body shape that reduces current drag and allows these fishes to maintain position in fast-moving waters (e.g., races and riffles) with minimal energy expenditure (Facey and Grossman 1990; Peterson and Rabeni 2001b). As a result, these fishes are able to feed upon benthic invertebrates that occur in relatively high densities in these habitats (Roy et al. 2003). Fishes may use certain habitats, within a reach, in response to interspecific interactions (Schlosser 1995; Power and Matthews 1983). For example, to avoid predation by mammalian and avian predators, larger fish may use deeper habitats (Matthews et al. 1986; Schlosser 1987; Harvey and Stewart 1991), whereas small fishes may use shallow habitats to avoid predation by larger piscivores (Power and Matthews 1983; Schlosser 1987). In addition, intraspecific competition influences habitat use, because larger individuals can force smaller conspecifics out of preferred habitats (Schlosser 1987; Freeman and Stouder 1989). Furthermore, fish distribution also may be influenced by interspecific competition. For example, as smaller fishes aggregate in shallow habitats to avoid predation, these fishes may experience large overlap in resource use (Schlosser 1987).

Temporal Variation

Stream fish distribution and community structure can change seasonally (Peterson and Rabeni 2001b). Temperate streams exhibit seasonal variation in discharge, temperature, and DO. In addition, the biological requirements (i.e., growth, survival, and reproduction) of fishes change seasonally. Large-scale migration is one mechanism by which fishes can meet changing biological requirements despite environmental variation. For example, fishes may use groundwater-dominated reaches in the winter, which are warmer relative to surface-fed reaches (Peterson and Rabeni 1996), or fishes may migrate to spawn in the spring (Hall 1972; Todd and

Rabeni 1989; Schlosser 1982a). Thus, fish community structure within a reach can change seasonally as fish move to fulfill their life history requirements.

Within a reach, fish habitat use can change seasonally (Vadas 1992; Peterson and Rabeni 2001b). Changing mesohabitat use within a stream is another mechanism by which fishes can fulfill biological requirements. In the winter, the metabolism of warmwater fishes slows as stream temperatures decrease; the result is reduced food intake and growth (Raibley et al. 1997). To conserve energy, many fishes use deep, slow-moving pools containing large velocity reducing structures (Schlosser 1991; Todd and Rabeni 1989; Peterson and Rabeni 2001b). During the growing season, fishes may seek habitats with the most abundant food sources (e.g., woody debris or vegetation) that also offer cover from predators (Angermeir and Karr 1984; Peterson and Rabeni 2001b). Thus, stream fish community structure can change seasonally as fishes migrate to and from a stream reach, and habitat use can change seasonally as fishes alter position within a stream reach.

Wetland Headwater and Confined Channel Streams

Headwater streams in the Southeast U.S. can be broadly classified as CCS or WS. CCS are those in which, at baseflow (i.e., the portion of stream discharge usually maintained by groundwater and not associated with precipitation or melting snow; Rasmussen 2003), water is restricted to a clearly defined stream channel. Headwater WS are streams whose water is not restricted to a clearly defined channel regardless of baseflow condition (Welcomme 1979). In CCS, increased discharge results in increased depth and velocity. In contrast, increased discharge in WS causes a lateral expansion of water onto the floodplain and relatively little increase in depth and stream velocity. As a result, current velocity in the floodplain of a WS can be nearly zero, even after recent rainfall (personal observation).

Headwater CCS and headwater WS can be contrasted by their differences in stream depth and current velocity, factors that partly influence stream temperature and DO (Allan 1995; Arscott et al. 2001). Stream temperature increases and diel temperature fluctuations increase with decreasing depth because buffering capacity decreases with flow volume (Vannote 1980). Solar radiation generally has a greater influence on slower flowing streams compared to faster flowing streams (Arscott et al. 2001). Therefore, headwater WS can potentially exhibit higher temperatures and greater diel temperature fluctuations relative to CCS, especially in the floodplain habitats of a WS. Oxygen affinity decreases with increasing temperature (Allan 1995). Thus, headwater WS also may have lower DO and greater diel DO fluctuations relative to CCS, especially during the summer months. In addition, organic matter (e.g., detritus) accumulates in headwater WS because of their slow current velocities, and the respiration from detritus breakdown may further depress DO in these systems (Fisher and Willis 2000). To summarize, headwater WS potentially exhibit relatively higher temperatures, lower DO, and greater diel fluctuations in temperature and DO, whereas headwater CCS potentially exhibit relatively greater fluctuations in depth and current velocity.

Other factors, such as canopy cover and source of water inputs to a stream also influence headwater stream temperature and DO (Vannote 1980; Jackson et al. 2001). Headwater streams can be fed primarily by surface water or groundwater (Vannote et al. 1980; Wiley et al. 1990). Groundwater-fed headwaters maintain relatively constant temperatures and are usually both warmer in the winter and cooler in the summer relative to surface water fed headwaters (Allan 1995; Peterson and Rabeni 1996). Canopy cover can influence headwater stream temperature and DO by shading the stream from solar radiation (Peters et al. 1987; Angradi et al. 2001; Jackson et al. 2001).

Flint River Basin Stream Fishes

Currently, little is known about fishes in headwater WS of the Coastal Plain in the Southeast U.S. A variety of factors in the region could influence the suitability of these systems for stream fishes. Growing water demands in Georgia, Florida, and Alabama have created significant concerns about water allocation in the region, resulting in the Tri-State Water War. The primary land use in the lower FRB is row-crop agriculture, and the local economy is sustained by significant ground and surface water withdrawals. The Flint River Drought Protection Act (FRDPA) was initiated during a recent 5-year drought to protect stream flow levels within the lower FRB. Currently, the DPA applies only to surface water withdrawals and does not specifically target potentially important stream fish habitats, such as headwater WS. With increased understanding of FRB fishes, the FRDPA could concentrate efforts on preserving the most important habitats. Similarly, minimum flow standards in the lower FRB may not adequately protect streamflows in headwater WS. The purpose of this study, therefore, was to examine habitat characteristics, fish community structure, and fish habitat use in headwater WS and headwater CCS. This study will provide information about the function of these systems and their importance as habitat for stream fishes.

CHAPTER 3

METHODS

Site Description

I investigated fish community structure and seasonal habitat use of fishes in headwater CCS and headwater WS in the lower FRB, located in Randolph, Terrell, Lee, and Calhoun Counties, Georgia (Figure 1). The lower FRB is in the Doherty Plain district of the Coastal Plain Physiographic Region, an area characterized by karst topography resulting in limestone outcrops, sinkholes, and shallow aquifers (GA DNR 1997). Streams in the region are typically low gradient with substrate primarily composed of silt and sand. Land use in the lower FRB is primarily row-crop agriculture (Albertson and Torak 2002). However, WS account for more than 10% of the total area of the lower FRB, including 124.94 km^2 of emergent herbaceous WS and 1957.157 km^2 of wooded WS (Kramer et al. 2003).

I studied fish habitat use and community structure in six first-order and second-order headwater stream reaches in the lower FRB, in southwest Georgia (Table 1). I chose sites within the same physiographic region, watershed, and longitudinal position within the watershed to allow comparison of fish communities between sites with minimal confounding influence. Two CCS sites and one WS site were fed primarily by groundwater from the Floridian aquifer (mean conductivity > 100 µS/cm), whereas the remaining sites were residuum (superficial aquifer) dominated (mean conductivity <100 µS/cm). My WS sites consisted of a wooded WS (Spring Creek), an emergent herbaceous WS (Mossy Creek), and a WS with emergent herbaceous vegetation and some trees (Pachitla Creek). The wooded WS had extensive wooded floodplain habitat, was heavily shaded, and received greater amounts of organic inputs in the form of leaf litter relative to the other WS study sites. The emergent herbaceous WS had very little canopy cover in the form of trees but it had extensive emergent aquatic vegetation. In contrast, the emergent herbaceous wetland with some trees was intermediate between the other two WS study sites with regard to canopy cover and aquatic vegetation.

To assess seasonal changes in fish community structure and seasonal habitat use, I sampled each site once seasonally (with the exception of Mossy Creek explained below) during 2003-2004. Spring sampling was conducted during April – June, summer sampling during July – August, and winter sampling during December – January. I sampled fishes and habitat ½ hour after sunrise and ½ hour before sunset. I used a Smith-Root LR 24 pulsed DC backpack electrofisher operating at approximately 0.25 A pulsed DC to sample fishes at all sites. All CCS sites were long enough to include all representative habitats of each stream sampled and WS site area was large enough to encompass all available habitats.

Wetland Stream Habitat Classification and Composition

To ensure representative sample coverage of all available habitat types and to allow extrapolation or estimation of fish community metrics, I stratified WS for fish and habitat sampling. I stratified WS into main channel, side channel, and floodplain habitat types (Figure 2). Each habitat was sampled separately. I defined main channel habitat as the thalwig of the WS. Under very low flow conditions, only the main channel would be present and this habitat would resemble a CCS. Side channel habitats likely were once the thalwig of the WS, and are therefore deeper than floodplain. Under low and falling stream flow conditions, the side channel habitat will persist longer than floodplain. Floodplain habitat is the relatively shallower, slower flowing habitat that can occur anywhere between the thalwig and the water's edge. Floodplain habitat in Pachitla Creek and Mossy Creek were not present during this study as this habitat does not occur during normal base flows.

To determine the dimensions and habitat composition of each WS, I used a line-transect method during a normal base flow period (McMahon et al. 1996). I determined the relative abundance of each habitat type along each transect tape line by dividing the width of a habitat type by the total width of the WS. For example, if the width of a WS along one transect was 100 m and 10 m of the WS width was side channel habitat, then percent side channel habitat along the transect is: 10/100 = 0.10 = 10%.

Fish Sampling

Confined channel streams. -- Prior to fish sampling, upstream and downstream ends of each site were blocked-off with 7-mm mesh nets that were secured to the streambed. Fishes were sampled using a three-pass procedure: the first upstream, the second downstream, and the third upstream. Fishes were collected with a 2-person sampling crew. One crewmember carried the backpack electrofisher while a second crewmember used a dip net to collect stunned fishes. Fishes trapped in the downstream block net were also included in the sample.

Wetland streams. -- I sampled fishes in WS by collecting habitat-specific samples. Using preliminary fish and habitat data, I determined the optimal number of sample units in Spring Creek was 55 per season including: 15 from main channel habitat, 15 from side channel habitat, and 25 from floodplain habitat (McPherson and Peterson 2004). In Pachitla Creek, the optimal number of samples per season was 30, including: 15 from main channel habitat and 15 from side channel habitat. The small size of Mossy Creek permitted collection of only 16 sample units per sampling occasion including: 8 from main channel habitat and 8 from side channel habitat. I sampled each Mossy Creek habitat twice per season. However, I averaged the location specific repeated measurements prior to analysis to avoid pseudo replication.

To sample fishes, habitat-specific sample units were enclosed by placing 7-mm mesh block nets over poles. To avoid frightening fishes in or out of these enclosures, each net was suspended above the water with fasteners attached to nylon line (Peterson and Rabeni 2001b). The nets then were dropped remotely by pulling the nylon line after a period of 20 minutes, a time period long enough for warmwater fishes to recolonize an area disturbed by the installation of sampling equipment (Peterson 1996). Each net was inspected to ensure it dropped securely to the streambed. Fishes were sampled using a four-pass procedure: the first upstream, the second downstream, the third upstream, and the fourth downstream. Fishes were collected with a 2-person sampling crew. One crewmember carried the electrofisher and both crewmembers carried a dip net to collect stunned fishes. Fishes that had drifted into the downstream net also were included in the sample.

All fishes collected were identified to species, measured for total length to the nearest millimeter (mm), and weighed to the nearest gram (g). Smaller fishes (e.g., cyprinids and percids) were preserved in 10% formalin solution for identification in the lab, whereas larger or easily identifiable fishes were identified, measured, weighed, and released at the site.

Habitat Measurements

<u>Chemical measurements and temperature</u>. – I measured habitat at each site using the following calibrated handheld meters: a YSI 55 for dissolved oxygen, water temperature, and air temperature, a Hanna HI 93703 for turbidity, and an Oakton CON 400 Series for specific

conductivity. All measurements were taken prior to fish sampling. At CCS sites, these measurements were taken once. At WS sites, I took numerous habitat-specific measurements. When I simultaneously sampled multiple enclosures within a single habitat type, I took habitat measurements once within close proximity of each enclosure. When I simultaneously sampled multiple enclosures covering more than one habitat type, I took measurements once per habitat type.

Confined channel streams. -- Following fish sampling, a line-transect method (McMahon et al. 1996) was used to make physical habitat measurements at CCS sites. Previous research in the lower FRB indicated that taking physical measurements at eight points along 10 transects are sufficient for estimating mean width, mean depth, and mean current velocity with 20% precision (McCargo 2004). Wetted width measurements were taken along each of the 10 transects. Mean current velocity and depth were measured at each point along a transect (80 total measurements). At points less than 0.65 m depth, mean velocity was measured at 0.6 depth at each point along a transect. When depth was greater than 0.65 m depth, velocity was measured at 0.8 and 0.2 depth and averaged. Depth was recorded to the nearest 0.01 m; mean velocity was recorded to the nearest 0.01 m/sec. Mesohabitat composition was classified as pool, riffle, run, glide, forewater, or backwater (Hawkins et al. 1993; Peterson and Rabeni 2001a) and estimated by examining the stream ½ m in front and ½ m behind each transect along its entire length. Substrate composition was estimated visually by examining the stream bottom ½ m in front and ½ m behind each transect along its entire length. Substrate was classified by particle size by using a Modified Wentworth particle size classification (McMahon et al. 1996) as follows: clay/silt (0-0.0625 mm), sand, (0.0625-2 mm), gravel/pebble (2-64 mm), cobble (64-256 mm), boulder (>256 mm), and bedrock (no particles). Substrate composition was recorded as a percentage. The density of large wood, defined as wood pieces > 1 m long and > 5 cm in diameter, was determined by counting wood pieces within the wetted channel. In addition, root wads and small wood aggregates were counted as a single piece of wood.

Wetland streams. -- Following fish sampling, physical habitat measurements were taken within each sample unit. The area of each unit was determined by taking one length and one width measurement for rectangular or square shaped units and averaging two length and width measurements for irregular shaped units. Preliminary sampling data suggested that the optimal sampling protocol was to take depth and mean velocity measurements at 5 random points within each sample unit (Figure 3). Substrate composition was visually estimated within the entire area of each sample unit by using the modified Wentworth particle size classification (described above). Vegetation type, percent vegetation, and percent large wood within each sample unit was estimated visually. Vegetation was classified as emergent, submergent, floating. Percent shade, which is the percentage of each sample unit shaded from solar radiation during sampling also was measured. In addition, the habitat types adjacent to each sample unit were estimated visually and recorded as a percentage of the total perimeter.

Definitions and Statistical Analyses

Species richness is the total number of species found in a defined area (Meffe and Carrol 1997). Low species richness values generally indicate a degraded ecological system, whereas high values usually indicate a better quality system (Meffe and Carrol 1997; Pullin 2002). When sampling with backpack electrofishing gear, species detection generally is not 100% (i.e., some species are missed; Bayley and Dowling 1990). Therefore, I adjusted species richness estimates for each WS sample and each CCS sample by using a backpack electrofisher gear efficiency model (Bayley and Dowling 1990). When species richness is calculated for a sample, species identity is not considered. Thus, habitat-specific sample richness estimates cannot be used to estimate site-level species richness. One approach to estimating species richness for an area of interest, given multiple samples, is to use a capture-recapture jackknife procedure (Heltshe and Forrester 1983; Williams et al. 2002). Sampling occasions should be concluded within a time period short enough to assume changes in species composition has not occurred (Williams et al. 2002). Habitat-specific WS samples were treated as capture occasions and estimated species richness per WS site and season by using a jackknife procedure in program CAPTURE (Williams et al. 2002; Rexstad and Burnham 1991).

I calculated total fish density for each WS sample and for each CCS sample. Backpack electrofishing gear efficiency (i.e., the proportion of fishes captured) is generally not 100% and varies depending upon a variety of factors (e.g., size of fishes, depth of water column, and water clarity). To account for the efficiency of my sampling gear, I adjusted length frequency data using a backpack electrofisher gear efficiency model (Bayley and Dowling 1990) and used adjusted length frequency data for all calculations that required fish abundance estimates. I extrapolated total fish density per WS site and season by multiplying habitat-specific mean density estimates by the relative proportion of the site that habitat represented, summing the results and multiplying by the total area of each WS site.

Species evenness is an index used for measuring the distribution of individuals among species (Kwak and Peterson *in press*). I calculated species evenness for each WS enclosure as:

$$J' = H'/\log_e s$$

where $\log_e$ is the natural logarithm, s is the number of species collected, and H' is Shannon-Weaver's Diversity Index calculated as:

$$H' = -\sum_{i=1}^{s} (p_i)(\log_e p_i)$$

where s is the number species collected, $\log_e$ is the natural logarithm, and p_i is the proportion of the total sample represented by the ith species (Kwak and Peterson *in press)*.

Analysis of Variance (ANOVA) is statistical test used for comparing differences among groups or treatments as well as interactions between these groups (Bhattacharrya and Johnson 1977). Thus, I used ANOVA to test for statistical differences in species richness, fish density, and species evenness among WS sites, WS habitats, seasons, and all interactions. Goodness-of-fit of each ANOVA was determined by examining residual plots and normal probability plots. If the data were non-normal, I performed natural log transformation and refit the ANOVAs. Because floodplain habitat occurred only in Spring Creek, I conducted ANOVAs of all WS sites excluding floodplain habitat data from Spring Creek. I also used ANOVA to examine differences in species richness and fish density among stream types (WS versus CCS), seasons, and all interactions. Because there is generally a relationship between species richness and area (Connor and McCoy 1979), I used the area sampled (area of each CCS reach, WS, and/or WS enclosure) as a covariate in all ANOVAs of species richness and species evenness. I considered differences statistically significant at the $\alpha = 0.05$ level for all ANOVA tests.

If statistically significant differences were detected using an ANOVA, Tukey least squares mean multiple comparison tests can be used to further eluciate these differences (Milliken and Johnson 2002). I used Tukey mean multiple comparisons to examine statistically significant differences of all ANOVAs. I considered differences statistically significant at the $\alpha = 0.05$ level for all Tukey tests.

Repeated measures linear regression is a statistical technique used to assess the influence of numerous predictor variables on a response variable, particularly when samples are not independent (Sokal and Rohlf 1995). My samples were not independent because I sampled the same sites seasonally. Thus, I used repeated measures linear regression models to examine the effects of WS characteristics on species richness, total fish density, and dissolved oxygen concentration.

I used an information-theoretic approach (Burnham and Anderson 1998) to evaluate the fit of my repeated measures linear regression models. I first constructed a global model consisting of all main and two-way interaction effects that I hypothesized to influence predictor variables (Table 2). I subsequently created additional candidate models that were biologically meaningful subsets of the global model. I used Akaike's Information Criteria (AIC; Akaike 1973) with the small sample size adjustment (AIC_c: Hurvich and Tsai 1989) to evaluate the fit of each model. I interpreted the best fitting candidate model to be the model with the greatest Akaike weight relative to the other candidate models (Burnham and Anderson 1998). I also constructed a confidence set of models, comparable to a conference interval, which included candidate models with Akaike weights within 10% of the best fitting model, which is similar to Royall's (1997) cutoff of 12.5% for evaluating strength of evidence. Goodness-of-fit was determined by examining each global model (i.e., species richness, total fish density, and dissolved oxygen). If the data were non-normal, I performed natural log transformation and refit the model.

I used discriminant analysis, a multivariate statistical technique, to examine differences among WS habitat types with regard to fish species composition (Peterson and Rabeni 2001b). Prior to analysis, I excluded rare species that occurred in less than 5% of my sample collection because rare species and can distort statistical relationships (Gauch 1982). Discriminant analysis reduces fish species abundances into uncorrelated discriminant functions that maximize the differences among habitat types. To interpret individual discriminant functions, I examined discriminant function variable correlations and considered high correlations (absolute value) to have the largest influence on the discriminant function. I interpreted the characteristics of WS habitat types by examining bi-plots of discriminant function scores. I also examined the physical habitat characteristics of WS by using discriminant analysis and the same procedures that I used to examine fish species composition as detailed above.

Discriminant analysis also can be used assess predictability of fish species composition and physical characteristics in particular habitat types (Peterson and Rabeni 2001a; 2001b). To assess predictability of WS habitat type species composition and physical habitat characteristics, I used discriminant analysis and a leave-one-out cross-validation procedure (Lachenbruch 1975). During leave-one-out cross validation, a sample is removed from the data, the discriminant analysis model is fit, and the left out observation is classified using the discriminant analysis model. The process is then repeated for each observation.

CHAPTER 4

RESULTS

I sampled all study sites during summer 2003, winter 2004, and spring 2004. I was unable to sample tributary to Muckalee during summer 2004 due to lack of streamflow. Additionally, I was unable to collect all WS samples during summer 2004 because of low flows (Table 3). I also completed summer 2003 sampling at one WS study site on October 5th because of inclement weather. On two occasions, I also had to resample CCS that became flooded by rain events prior to completion of sampling.

A total of 2752 fishes, representing 35 species were collected during this study (Table 4; Appendix A). Most fishes were collected during winter (45%), and the fewest fishes were collected during summer 2004 (12%) (Tables 4 and 5). Of the 35 species collected, 27 were collected from both WS and CCS (Table 4). Additionally, five species collected were unique to WS samples and three species were unique to CCS samples. CCS site length differed slightly during the study and averaged 102 m (range 96 - 120 m). Habitat composition of WS site was determined during November 20th and 21st, 2004. Habitat composition varied between WS sites (Tables 6 and 7). Floodplain habitat area was 5324.92 m^2 and composed 88% of the surface area in Spring Creek, whereas floodplain habitat did not occur at Mossy or Pachitla creeks. Side channel habitats represented the greatest relative surface area in Pachitla Creek (75%) and Mossy Creek (74%), whereas this habitat represented 3% of the total surface area in Spring Creek. Side channel habitat area was 1040.75 m^2 at Mossy Creek, 1476.92 m^2 at Spring Creek, and 2677.67

m^2 at Pachitla Creek. Main channel habitats represented 34% of the relative surface area in Mossy Creek, 25% in Pachitla Creek, and 9% in Spring Creek. Main channel habitat area was greatest in Spring Creek (5324.92 m^2), followed by Pachitla Creek (903.83 m^2) and Mossy Creek (358.8 m^2).

Wetland Stream Physical Habitat Characteristics

Physical habitat characteristics including mean depth, mean current velocity, large woody debris, silt, and vegetation differed by site and by habitat type (Table 6). Discriminant analysis of the physical habitat characteristics of WS habitat types indicated two discriminant functions that accounted for 100% of the variance among WS habitat types. The first discriminant function explained 97.64% of variation among WS habitat types and was negatively loaded by the amount of silt substrate and positively loaded by mean depth and mean current velocity (Table 8). The second discriminant function was positively loaded by large wood and accounted for the remaining 2.36% of variation among WS habitat types. The discriminant analysis bi-plot indicated that Spring Creek floodplain habitat contained the greatest amount of silt and lowest current velocity and depth, whereas Spring Creek and Pachitla Creek main channel habitats contained the lowest amount silt and the greatest current velocity and depth (Figure 4). Spring Creek habitats also contained greater amounts of large wood relative to habitats within other study sites (Figure 4).

Overall WS habitat classification accuracy, determined via a leave-one-out cross validation procedure, averaged 61% and had a variance of 522 (Table 9). Classification accuracies for floodplain, main channel, and side channel habitats were 78.8%, 70.9% (average) and 45.5% (average) respectively. Associated variances for main channel and side channel habitats were 200.2 and 15.7 respectively. Main channel habitats were, on average, most often misclassified as side channels (25.8%, variance 125.4), and floodplain was most often misclassified as side channel (18.8%). Side channel habitats were nearly equally misclassified as main channel (27.8%, variance 623.3) or floodplain (26.7%, variance 590.8).

The best fitting model for predicting dissolved oxygen included temperature, average current velocity, wooded, and an average current velocity by average current velocity interaction and was 2.4 times better than the next best fitting model that contained temperature, average current velocity, and 2 two-way interactions: average current velocity by average current velocity and temperature by wooded (Table 10). Parameter estimates for the best fitting model indicated dissolved oxygen was negatively related to temperature and wooded and positively related to stream current velocity (Table 11; Figure 5).

Wetland Stream Fish Communities

<u>Site comparisons</u>. -- There were significant ($P<0.05$) differences in species richness across sites, seasons, and two two-way interactions: site by season and site by habitat type (Table 12). The covariate, size of area sampled also accounted for a significant ($P<0.05$) amount of variation in species richness. Multiple comparisons of the site by season interaction indicated that species richness was greatest in Spring Creek during winter and lowest in Spring Creek during spring and summer (Table 13). Multiple comparisons of the site by habitat type interaction indicated that species richness was lowest in Spring Creek side channel habitat types (Table 13). The remaining species richness values were not statistically significant.

The best-fitting model for predicting species richness included area, dissolved oxygen, temperature, vegetation, large wood, winter, current velocity, and a current velocity by winter interaction, and was 2.8 times better than the next best-fitting model that contained area, dissolved oxygen, temperature, vegetation, large wood, spring, winter, a winter by current velocity two-way interaction (Table 14). Parameter estimates for the best-fitting model indicated area, dissolved oxygen, temperature, vegetation, large, and winter were positively related to species richness, whereas current velocity was negatively related to species richness (Table 15; Figure 6).

There were significant ($P<0.05$) differences in total fish density across seasons, habitat types, and 2 two-way interactions: site by season and site by habitat type (Table 16). Multiple comparisons of the site by season interaction indicated that total fish density was greatest in Spring Creek during the winter and in Mossy Creek during the summer, whereas total fish density did not differ significantly ($P>0.05$) among sites during other seasons (Table 17). In contrast, multiple comparisons of the site by habitat type interaction indicated that total fish density was greatest in Spring Creek main channel habitat and lowest in Spring Creek side channel habitat (Table 17). The remaining differences were not statistically different.

The best-fitting model for predicting total fish density included, dissolved oxygen, temperature, vegetation, large wood, winter, current velocity, and a current velocity by winter interaction and was 2.7 times better than the next best fitting model that contained dissolved oxygen, temperature, vegetation, large wood, spring, winter, current velocity, and a winter by current velocity interaction (Table 18). Parameter estimates for the best-fitting model indicated dissolved oxygen, temperature, vegetation, large wood, and winter were positively related to species richness, whereas current velocity was negatively related to total fish density (Table 19; Figure 7). The negative velocity by winter interaction indicated that total fish density was more strongly and negatively related to current velocity during winter.

There were significant ($P<0.05$) differences in species evenness across sites, seasons, and two two-way interactions: site by season and site by habitat type (Table 20). The covariate, size of area sampled, also accounted for a significant ($P<0.05$) amount of variation in species evenness. Multiple comparisons of the site by season interaction indicated that species evenness was greatest at Spring Creek during winter and lowest in Spring Creek during summer and spring (Table 21). In contrast, multiple comparisons of site by habitat type interactions indicated that species evenness was lowest in Spring Creek side channel habitat while the remaining species evenness values were not significantly different (Table 21).

Discriminant analysis of WS habitat type fish assemblages during spring indicated two discriminant functions that accounted for 100% of the variance among habitat types. The first discriminant function was positively loaded by the densities of bluegill, banded pygmy sunfish, pirate perch, redbreast sunfish, spotted sunfish, and weed shiners and accounted for 83.6% of variation among habitat types (Table 22). The second discriminant function positively was loaded by the densities of brook silverside and golden shiner and accounted for 16.4% of the variance among WS habitat types. The discriminant analysis bi-plot indicated that Mossy Creek and Spring Creek main channel habitats contained greater densities of bluegill, banded pygmy sunfish, pirate perch, red-breast sunfish, spotted sunfish, and weed shiner, whereas Spring Creek side channel and floodplain habitats contained lower densities of these species (Figure 8). Mossy Creek main channel habitat contained greater densities of brook silverside and golden shiner relative to all other habitats and sites.

Overall WS habitat type fish assemblage classification accuracy during spring, determined via the leave-one-out cross validation procedure, was relatively low and averaged 34.0% and had a variance of 936 (Table 23). Classification accuracies for floodplain, side channel, and main channel habitats were 88.0%, 10.8% (average), and 39.2% (average) respectively. Associated variances for main channel and side channel habitats were 402.0 and 102.0 respectively. Main channel habitats were, on average, most often misclassified as floodplain habitats (32.5%, variance 118.8) as were side channel habitats (52.8%, variance 979.6). Floodplain habitat was misclassified similarly as main channel (4.0%) and side channel (8.0%).

Discriminant analysis of WS habitat type fish assemblages during summer indicated two discriminant functions that accounted for 100% of the variance among habitat types. The first discriminant function accounted for 65.7% of the variance and was positively loaded by the densities of brook silverside, mosquitofish, and golden shiner, negatively loaded by pirate perch densities (Table 22). The second discriminant function was negatively loaded by the densities of banded pygmy sunfish, positively loaded warmouth densities, and accounted for 34.3% of the variance among habitat types. The discriminant analysis bi-plot indicated that Mossy Creek side channel habitat contained greater densities of brook silverside, mosquitofish, and golden shiner and lower densities pirate perch (Figure 9). Pachitla Creek side channel habitat contained greater densities of warmouth and lower densities of banded pygmy sunfish.

Overall WS habitat type fish assemblage classification accuracy during summer, determined via the leave-one-out cross validation procedure, was relatively low and averaged 33.7% and had a variance of 271.1(Table 24). Classification accuracies for floodplain, side channel, and main channel habitats were 23.3%, 18.8% (average), and 52.2% (average), respectively. Associated variances for main channel and side channel habitats were 3.61 and 92.4 respectively. Main channel habitats were, on average, most often misclassified as side channel habitats (30.0%, variance 344.9), while side channel habitats were most often misclassified as main channel habitat (53.5%, variance 1171.0). Floodplain habitat was more often misclassified as main channel habitat (60.0%).

Discriminant analysis of WS habitat type fish assemblages during winter indicated two discriminant functions that accounted for 100% of the variance among habitat types. The first discriminant function accounted for 77.8% of the variance and was positively loaded by the densities of bluegill and swamp darter, negatively loaded by banded pygmy sunfish and pirate perch (Table 22). The second discriminant function was positively loaded by the densities of redeye chub and mosquitofish and accounted for 22.2% of the variance among habitat types. The discriminant analysis bi-plot indicated that Mossy Creek main channel habitat contained greater densities of bluegill and swamp darters and lower densities of banded pygmy sunfish and pirate perch (Figure 10). Spring Creek main channel habitat contained greater densities of redeye chub and mosquitofish.

Overall habitat type fish assemblage classification accuracy during winter, determined via the leave-one-out cross validation procedure, averaged 56.5% and had a variance of 308.8 (Table 25). Classification accuracies for floodplain, side channel, and main channel habitats were 64.0%, 60.8% (average), and 49.7% (average) respectively. Associated variances for main channel and side channel habitats were 767.8 and 402.0 respectively. Main channel habitats were, on average, most often misclassified as side channel habitats (39.2%, variance 1109.7), while side channel habitats were most often misclassified as main channel habitat (36.9%, variance 545.5). Floodplain habitat was more often misclassified as main channel (24.0%).

Comparison of Wetland Stream and Confined Channel Stream Fish Communities

There were significant ($P<0.05$) differences in species richness across stream types (Table 4.26). Multiple comparisons of stream type indicated that species richness was significantly greater in WS (16.61) than in CCS (11.25). There also were significant ($P<0.05$) differences in total fish density across stream types (Table 4.27). Multiple comparisons of stream type indicated that total fish density was significantly greater in WS (8.00 no./m^2) than in CCS (4.35 no./m^2).

CHAPTER 5

DISCUSSION

I found statistically significant ($P<0.05$) differences in species richness and total fish density between WS and CCS. Additionally, I found statistically significant ($P<0.05$) differences in species richness, evenness, and total fish density between WS site and season interactions and WS habitat interactions. Previous studies have shown that fish community structure varies geographically (Marsh-Matthews and Matthews 2000) and by stream size (Schlosser 1987; Peterson 2001b). By choosing sites within the same physiographic region, watershed, and longitudinal position within a watershed, I was able to minimize the influence of larger scale factors (Frissel et al. 1986) that determined the available fish species pool. Therefore, I believe the observed differences in fish distribution and community structure were related to seasonal fish movement and reach scale factors including physical habitat complexity and environmental stability.

Habitat Complexity

Headwater streams are generally shallower and the habitats within these reaches are more homogenous (i.e. less variation in depth, current velocity, and substrate size) relative to downstream or larger reaches (Schlosser 1982b; Schlosser 1991). Large-bodied species generally require deeper habitats to avoid avian and terrestrial predators (Matthews et al. 1986; Schlosser 1987). I found few large-bodied species within the CCS study sites; Schlosser (1987) reported similar results. Additionally, few of the individuals I collected within large-bodied species groups were adult fishes, and less than 1.0% of my total CCS fish collection included individuals greater than 175 mm total length. Thus, I believe the absence of large-bodied fishes in the CCS sites was probably related to the lack of deep habitats in these stream reaches.

Although the absence of large-bodied fishes in headwater streams has been attributed to lack of deepwater habitats required by these fishes (Schlosser 1987), headwater WS streams are not typical streams (Welcomme 1979). For example, my WS main channel habitats were, on average 0.5 m deep, more than twice as deep as my CCS study reaches (0.19 m average). While these habitats might offer habitat for larger-bodied fishes, I collected very few large-bodied individuals in my WS study sites. For example, fishes greater than 150 mm total length comprised less than 1.0% of my total WS fish collection. In this study, Headwater CCS reaches bounded the headwater WS. That is, a CCS flowed into (formed) a WS and a CCS flowed from a WS. Thus, fishes must travel through relatively shallow Headwater CCS streams when migrating to fulfill life history requirements (Hall 1972: Todd and Rabeni 1989) or because environmental disturbance has rendered the WS unsuitable. Therefore, I believe the lack of large body species in the headwater WS was partly the result of a lack of deeper migratory paths to larger stream reaches.

Lower species richness in headwater streams, relative to larger downstream reaches, also has been attributed to the availability of other habitats types and habitat complexity (Peterson and Rabeni 2001b). Many species have particular habitat preferences and some species require particular habitats to fulfill their life history requirements (Page 1983; Jenkins and Burkhead 1993). For example, swamp darters, taillight shiners, and fliers prefer habitats with low current velocities and heavy vegetation, whereas creek chubsuckers and lake chubsuckers prefer relatively deep vegetated habitats (Pfliger 1997). I found that species richness in WS habitats was positively related to vegetation and large wood and the confidence set of models also indicated that there was some evidence that richness was related to depth. The presence of large woody debris within a stream increases habitat complexity by altering depth, velocity, and substrate of a stream (Angermeier and Karr 1984). Similarly, aquatic vegetation increases habitat complexity and offers fishes refuge from predators (Pelicice et al. 2005) and areas for spawning (Bayley 1995). The CCS reaches contained less large wood than the WS habitats, and vegetation within CCS is uncharacteristic and was therefore not assessed. Thus, I believe the higher species richness in WS was related, in part, to greater habitat complexity of headwater WS habitats.

Environmental Stability

Temperature can influence fish distribution and community structure (Wehrly and Wiley 2003). Streams that exhibit extreme temperature fluctuations are generally are dominated by species tolerant of these conditions (Smale and Rabeni 1995; Wehrly and Wiley 2003). I detected few temperature-sensitive species in my headwater WS. However, the redeye chub is a temperature sensitive species that requires groundwater-dominated streams presumably for thermal refugia (Mettee et al. 1996). Of my WS fish collection, redeye chubs were only collected in my WS site with significant inputs from the Floridian aquifer during winter, whereas this species was absent or rare in other sites during all months and in the Floridian aquifer-influenced WS during spring and summer. Although temperature was potentially responsible for regulating the density and distribution of redeye chub, other factors such as stream current velocity and dissolved oxygen were likely more important in regulating the presence or density of more tolerant species.

Stream current velocity can influence fish distribution and community structure (Grossman et al. 1998). Headwater streams are characterized by intense and frequent disturbance (Resh et al. 1988), including flashiness, flooding, and high stream current velocities (Schlosser 1985). Consequently, these systems are typically dominated by flow tolerant and colonizing species (Adams et al. 2004). Although I observed flashiness at my CCS study sites, flashiness is not characteristic of WS (Welcomme 1979). For example, I observed minimal increase in current velocity at my WS study streams following intense rain events. I found flow-intolerant species including tail light shiners, swamp darters, and fliers (Pflieger 1997) within my WS, but not within my CCS. Thus, I believe the higher species richness I observed within my WS compared to my CCS also was related to the lower variation in current velocity in these systems relative to my CCS.

Dissolved oxygen concentration can influence fish distribution and community structure (Smale and Rabeni 1995). Streams that exhibit low dissolved concentrations may contain fewer, more tolerant species relative to streams with higher dissolved oxygen levels (Smale and Rabeni 1995). For example, larger-bodied stream fishes may avoid areas of low oxygen because their oxygen needs are greater relative to small-bodied fishes (Burleson et al. 2001). Additionally, dissolved oxygen concentrations between 1.0 and 2.0 mg/L can be lethal for many stream fishes (Smale and Rabeni 1995). Slow flowing streams are more susceptible to higher temperatures than faster flowing streams (Arscott et. Al 2001), and higher temperatures reduce stream oxygen affinity (Allan 1995). WS are susceptible to low dissolved oxygen levels because of their characteristically slow current velocities and dense accumulation of organic debris, which consumes oxygen during decomposition (Fisher and Willis 2000). I found that WS dissolved oxygen concentration increased with increasing stream current velocity, but decreased with increasing temperature and organic material. This finding is consistent with previous research. For example, dissolved oxygen in Pachitla Creek during spring and summer averaged 8.07 mg/L, whereas Spring Creek dissolved oxygen during this period averaged 2.89 mg/L and a minimum value of 0.57 mg/L was observed. Similarly, species richness, evenness, and total fish density were lowest in Spring Creek, the wooded WS, during the warmer seasons compared to other WS sites. Therefore, I believe the relatively low dissolved oxygen concentrations observed in the wooded WS during spring and summer contributed to the relatively low species richness, evenness, and total fish density observed at this site.

Seasonal Differences

Fish habitat use and community structure can change seasonally as fishes migrate to fulfill life history requirements (Peterson and Rabeni 2001b; Peterson and Rabeni 1996). For example, many fishes migrate to areas suitable for spawning during spring (Schlosser 1991; Hall 1972), including WS (Poff et al. 1997; Bayley 1995). During my study, I did not detect significant increases in species richness or total fish density during spring relative to other seasons, nor did I observe spawning fishes. Though I could not determine whether fishes were using WS areas for spawning, I did detect sexually mature fishes during spring and young-of year fishes during summer in these systems. Therefore, fishes potentially could have been spawning within my WS sites during this study.

During winter, the metabolism of fishes is generally low (Schlosser 1991; Peterson and Rabeni 1996). Therefore, fishes may seek out deep, slowing moving habitats that are suitable for conserving energy (Schlosser 1991) or relatively warmer habitats (Peterson and Rabeni 1996). I found WS species richness and total fish density increased during winter, but fishes used relatively low current velocity habitats. This finding is consistent with previous research. Additionally, WS were, on average, deeper and had lower current velocities relative to my CCS. Further, the WS dominated by groundwater from the Floridian aquifer exhibited higher temperatures and had higher species richness and total fish density, during winter, relative to the residuum dominated WS sites. Therefore, my WS sites, particularly the site influenced by groundwater from the Floridian aquifer, were likely used by fishes as seasonal refugia during winter.

Management Implications

This and other studies suggest that WS are important to fish communities. Although other studies suggest that WS are important for spawning (Poff et al. 1997; Bayley 1995) and nursery areas (Kwak 1988), my study suggests that WS may also be harsh environments during warmer seasons. WS characteristically exhibit relatively low stream current velocities and heavy accumulations of detritus, which can lower dissolved oxygen concentration to levels of concern for stream fishes. WS dissolved oxygen may even reach lethal levels under low flow conditions or during the spring in wooded WS, when leaf litter decomposes. Conversely, WS influenced by groundwater may be important as a seasonal refuge for fishes during winter. The relatively high species richness and total fish density observed during winter in my WS influenced by groundwater from the Floridian aquifer suggests that this system is relatively more important in structuring fish communities relative to other site by season comparisons. However, the potential importance of this and similar WS would not be recognized if they were examined only during warmer seasons. Therefore, I believe that managers should consider the functionality of WS during all seasons when assessing the importance of these systems for stream fishes.

Minimum stream flow requirements are generally established on CCS to protect fishes from environmental extremes associated with low flows. Observed dissolved oxygen levels in my CCS sites were never within the lethal range for stream fishes. However, the Headwater WS streams were characteristically different from CCS. WS maintain relatively low stream current velocities as they laterally expand onto floodplains often containing large amounts of organic debris. Consequently, the consumption of oxygen during the decomposition of organic matter, combined with low current velocities and limited potential for stream mixing, can result in dissolved oxygen levels that are lethal for WS fishes. Additionally, low stream flows, such as those observed during drought, increase the potential for lethal dissolved oxygen concentrations within WS. Therefore, the minimum stream flows required to sustain WS fish communities probably differ from CCS. Therefore, I believe that managers also should consider WS when establishing minimum flow standards.

LITERATURE CITED

Aaland, L. P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13: 790-806.

Adams, S. B., M. L. Warren, and W. R. Hagg. 2004. Spatial and temporal patterns in fish assemblages of upper coastal plain streams, Mississippi, USA. Hydrobiologia 528: 45-61.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 in Second International Symposium on Information Theory. B.N. Petrov and F. Csaki, editors. Akademiai Kiado, Budapest, Hungary.

Albertson, P. N. and L. J. Torak. 2002. Simulated effects of ground-water pumpage on stream-aquifer flow in the vicinity of federally protected species of freshwater mussels in the lower Apalachicola-Chattahoochee-Flint River Basin (subarea 4) southeastern Alabama, northwestern Florida, and southwestern Georgia. Water Resources Investigations Report 02-4016. Atlanta, GA.

Allan, J. D. 1995. Stream ecology: structure and function of running waters. Kluwer Academic Publishers. Boston, MA.

Angermeir, P. L., and J. R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. Transactions of the American Fisheries Society 113: 716-726.

Angradi, T., H. Hood, and D. Tarter. 2001. Vertical, longitudinal, and temporal variation in the macrobenthos of an Appalachian headwater stream system. The American Midland Naturalist 146: 223-242.

Arscott, D. B., K. Tockner, and J. V. Ward. 2001. Thermal heterogeneity along a braided floodplain river (Tagliamento River, northeastern Italy). Canadian Journal of Aquatic Sciences 58: 2359-2373.

Bayley, P. B., and D. C. Dowling. 1990. Gear efficiency calibrations for stream and river sampling. Illinois Natural History Survey. Aquatic Ecology Technical Report 90/8. Champaign, IL.

Bayley, P. B., and L. L. Osborne. 1993. Natural rehabilitation of stream fish populations in an Illinois catchment. Freshwater Biology 29: 295-300.

Bayley, P. B. 1995. Understanding large river-floodplain ecosystems: significant economic advantages and increased biodiversity and stability would result from restoration of impaired systems. Bioscience 45: 153-158.

Benke, A. C, Henry, R. L. Gillespie, and R. J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. Fisheries 10: 8-13.

Bhattacharrya, G. K., and R. A. Johnson. 1977. Statistical concepts and methods: Wiley series in probability and mathematical statistics. John Wiley and Sons, Inc. New York, New York.

Bison, P. A., K. Sullivan, and J. L. Nielson. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117: 262-273.

Burleson M. L., D. R. Wilhelm, and N. J. Smatresk. 2001. The influence of fish size on the avoidance of hypoxia and oxygen selection by largemouth bass. Journal of Fish Biology 59: 1336-1349.

Burnham, K. P. and D. R. Anderson. 1998. Model selection and inference: an information-theoretic approach. Springer-Verlag, New York.

Connor, E. F., and E. D. McCoy. 1979. The statistics and biology of the species area relationship. American Naturalist 113: 791-833.

Dunne, T. D., and L. B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company. New York, NY.

Etnier, D. A. 1997. Jeopardized Southeastern freshwater fishes: a search for causes. Pages 87-104 in G.W. Benz and D.E. Collins, eds. Aquatic fauna in peril: the southeastern prospective. Special Publication 1, Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, GA.

Facey, D. E., and G. D. Grossman. 1990. The metabolic cost of maintaining position for four North American stream fishes: effects of season and velocity. Physiological Zoology 63: 757-776.

Fisher, S. J., and D. W. Willis. 2000. Seasonal dynamics of aquatic fauna and habitat parameters in a perched upper Missouri River WS. WS 20: 470-478.

Frisell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10: 199-214.

Freeman, M. C., and D. J. Stouder. 1989. Intraspecific interactions influence size specific depth distribution in *Cottus bairdi*. Environmental Biology of Fishes 24: 231-236.

Gauch, H. G. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge, New York.

Georgia Department of Natural Resources (GA DNR). 1997. Flint River Basin management plan. Available online at: http://www.state.ga.us/dnr/environ/plans_files/plans/flint-pdf/flint.pdf

Gorman, O. T. 1986. Evolutionary ecology and historical ecology: assembly, structure, and organization of stream fish communities. Pages 659-688. In Systematics, Historical Ecology, and North American Freshwater Fishes. R.L. Mayden, editor. Stanford University Press, Stanford, California.

Grossman, G. D, R. E. Ratajczak, Jr., M. Crawford, and M. C. Freeman. 1998. Assemblage organization in stream fishes: effects of environmental variation and interspecific interactions. Ecological Monographs 68: 395:420.

Hall, A. S. 1972. Migration and metabolism in a temperate stream ecosystem. Ecology 53: 586-604.

Harvey, B. C., and A. J. Stewart. 1991. Fish size and habitat depth relationships in headwater streams. Oecologia 87: 336-342.

Hawkins, C. P., J. L. Kershner, P. A. Bison, M. D. Bryant, L. M. Decker, S. V. Gregory, D. A. McCullough, C. K. Overton, G. H. Reeves, R. J. Steedman, and M. K. Young. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 8: 3-12.

Heltshe, J. F., and N. E. Forester. 1983. Estimating species richness using the jackknife procedure. Biometerics 39: 1-11.

Hodler T. W., and H. A. Shretter. 1986. Atlas of Georgia. University of Georgia Press, Athens, GA.

Holman, J. A. 1995. Pleistocene amphibians and reptiles in North American. Oxford University Press. New York, NY. p. 5.

Horwitz, R. L. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecological Monographs 48: 307-321.

Hurvich, C. M. and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76: 297-307.

Jackson, C. R., C. A. Sturm, J. M. Ward. 2001. Timber harvest impacts on small headwater stream channels in the coast ranges of Washington. Journal of the American Water Resources Association 37: 1553-1549.

Jackson, C. R. and C. A. Sturm. 2002. Woody debris and channel morphology in first- and second-order forested channels in Washington's coast ranges. Water Resources Research 38 (9), 1177.

Jenkins, R. E., and N. M. Burkhead. 1993. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, Maryland.

Kwak, T.J. 1988. Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois. American Midland Naturalist 120: 241-249.

Kwak, T. J., and J. T. Peterson. Community Indices, Parameters, and Comparisons. In M. Brown and C. Guy, editors. Analysis and interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, Maryland. *in press.*

Kramer, E. A., M. J. Conroy, M. J. Elliott, E. A. Anderson, W. R. Bumback, and J. Epstein. 2003. A GAP analysis of Georgia. Final Report and Data. US Department of Interior, U.S. Geological Survey. Biological Resource Division, GAP Analysis Program. 4 CD's.

Lachenbruch, P. A. 1975. Discriminant analysis. Collier Macmillan, New York.

Larimore, R. W., W. F. Childers, and C. Heckrotte. 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. Transactions of the American Fisheries Society 88: 261-285.

Lobb, M. D., and D. J. Orth. 1991. Habitat use by an assemblage of fish in a large warmwater stream. Transactions of the American Fisheries Society 1: 65-78.

Lydeard, C., and R. L. Mayden. 1995. A diverse and endangered aquatic ecosystem of the Southeast United States. Conservation Biology 9: 800-805.

Marsh-Matthews, E., and W. J. Matthews. 2000. Geographic, terrestrial and aquatic factors: which most influence the structure of stream fish assemblages in the Midwestern United States? Ecology of Freshwater 9: 9-21.

Matthews, W. J., M. E. Power, and A. J. Stewart. 1986. Depth distribution of *Campostoma* grazing scars in an Ozark stream. Environmental Biology of Fishes 17: 291-297.

McCargo, J. W. 2004. Influence of drought on seasonal fish assemblages and habitat in the lower Flint River Basin, Georgia. MS Thesis, University of Georgia, Athens.

McManhon, T. E, A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83-120. In Fisheries Techniques, 2nd ed. B.R. Murphy and D.W. Willis, eds. American Fisheries Society, Bethesda Maryland.

McPherson, Jr., R. D., and J. T. Peterson. 2004. The development of sampling protocols for measuring habitat characteristics and fish community attributes of headwater wetland streams in southwest Georgia. The Annual Meeting of the Georgia Chapter of the American Fisheries Society. Athens.

Meffe, G. K., and C. R. Carrol. 1997. Principles of conservation biology, 2nd edition. Sinauer Associates, Inc. Sunderland, Massachusetts.

Mettee, M. F., P. E. O'Neil, and J. M. Pierson. 1996. Fishes of Alabama and the Mobile Basin. Oxmoor House, Birmingham, Alabama.

Milliken, G. A., and D. E. Johnson. 2002. Analysis of messy data. Volume III: analysis of covariance. Chapman and Hall/CRC. New York, New York.

Page, L. M. 1983. Handbook of Darters. T.F.H. Publications, Neptune City, New Jersey.

Paller, M. H. 1994. Relationships between fish assemblage structure and stream order in South Carolina Coastal Plain streams. Transactions of the American Fisheries Society 123: 150-161.

Pelicice, F. M., A. A. Agostinho, and S. M. Thomaz. 2005. Fish assemblages associated with Egeria in a tropical reservoir: investigating the effects of plant biomass and diel period. ACTA Oecologica-International Journal of Ecology 27: 9-16.

Peters, G. T., J. R. Webster, and E. F. Benefield. 1987. Microbial activity associated with seston in headwater streams: effects of nitrogen, phosphorous, and temperature. Freshwater Biology 18: 405-413.

Peterson, J. T. 1996. The evaluation of hydraulic unit based habitat classification system. Ph.D. Dissertation, University of Missouri, Columbia, Missouri.

Peterson, J. T., and C. F. Rabeni. 1996. Natural thermal refugia for temperate warmwater stream fishes. North American Journal of Fisheries Management 16: 738-746.

Peterson, J. T., and T. J. Kwak. 1999. Modeling effects of land use and climate change on riverine smallmouth bass. Ecological Applications 9: 1391-1404.

Peterson, J. T., and C. F. Rabeni. 2001a. Evaluating the physical characteristics of channel units in an Ozark stream. Transactions of the American Fisheries Society 130: 898-910.

Peterson, J. T., and C.F. Rabeni. 2001b. The relation of fish assemblages to channel units in an Ozark stream. Transactions of the American Fisheries Society 130: 991-926.

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

Poff, N. R., D. J. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47: 769-784.

Power, M. E., and W.J. Matthews. 1983. Algae grazing minnows (*Campostoma anomalum*), piscivourous bass (*Micropterus spp*.) and the distribution of attached algae in a small prairie-margin stream. Oecologia 60: 328-332.

Pullin, A. S. 2002. Conservation biology. Cambridge University Press. New York, New York.

Raibley, P. T., K. S. Irons, T. M. O'Hara, K. D. Blodgett, and R. E. Sparks. 1997. Winter habitats used by largemouth bass in the Illinois River, a large river-floodplain ecosystem. North American Journal of Fisheries Management 17: 401-412.

Rasmussen, T. C. 2003. CRSS 3060 Hydrologic Glossary. Available online at: http://www.hydrology.uga.edu/rasmussen/class/3060/glossary.pdf

Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, and R. C. Wissmar. 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7: 433-455.

Rexstad, E., and K. P. Burnham. 1991. User's guide for interactive Program CAPTURE Colorado Cooperative Fish & Wildlife Research Unit, Colorado State University, Fort Collins, Colorado.

Richter, B. D., D. P. Braun, M.A. Mendelson, and L.L. Master. 1997. Threats to imperiled freshwater fauna. Conservation Biology 11: 1081-1093.

Robinson, H. W. 1986. Zoogeographic implications of the Mississippi River basin. Pages 267-285 in the Zoogeography of North American Freshwater Fishes. C. Hocutt and E. Wiley, editors, New York, New York.

Roy, A. H., A. D. Rosemond, D. S. Leigh, M. J. Paul, and J. B. Wallace. 2003. Habitat-specific responses of stream insects to land cover disturbance: biological consequences and monitoring implications. Journal of the North American Benthological Society 22:292-307.

Royall, R. M. 1997. Statistical evidence: likelihood paradigm. Chapman and Hall, New York.

Sargent, J. C. and D. L. Galat. 2002. Fish mortality and physiochemistry in a managed floodplain WS. WS Ecology and Management 10: 115-121.

Schlosser, I. J. 1982a. Trophic structure, reproductive success, and growth rate of fishes in a natural and modified headwater stream. Canadian Journal of Aquatic Science 39: 968-978.

Schlosser, I. J. 1982b. Fish community structure an function along two habitat gradients in a headwater stream. Ecological Monographs 52: 395-414.

Schlosser, I. J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. Ecology 66: 1484-1490.

Schlosser, I. J. 1987. A conceptual framework for fish communities in small warmwater streams. Pages 194-212 in W.S. Matthews and D.C. Heins, editors. Community and evolutionary ecology of North American stream fishes. Okalahoma University Press, Norman.

Schlosser, I. J. 1991. Stream fish ecology: a landscape perspective. Bioscience 41: 704-712.

Schlosser, I. J. 1995. Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia 303: 71-81.

Smale, M. A., and C. F. Rabeni. 1995. Influences of hypoxia and hypothermia on fish species composition in headwater streams. Transactions of the American Fisheries Society 124: 711-725.

Sokal, R. R., and F.J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. Freeman, New York.

Todd B. L., and C.F. Rabeni. 1989. Movement and habitat use by stream dwelling smallmouth bass. Transactions of the American Fisheries Society 118: 229-242.

Vadas, Jr., R. L. 1992. Seasonal habitat use, species associations, and assemblage structure of forage fishes in Goose Creek, Northern Virginia. Journal of Freshwater Ecology 7: 149-164.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Aquatic Sciences 37: 130-139.

Warren, M. L., and B. M. Burr. 1994. Status of freshwater fishes of the United States: overview of an imperiled fauna. Fisheries 19:6-18.

Warren, M. L., P. L. Angermeier, B. M. Burr, and W. R. Hagg. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the Southeastern United States. Pages 105-164 in G.W. Benz and D.E. Collins, eds. Aquatic fauna in peril: the southeastern prospective. Special Publication 1, Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, GA.

Warren, Jr., M. L., B. M. Burr, S. J. Walsh, H. L. Bart Jr., R. C. Cashner, D. A. Etnier, B. J. Freeman, B. R. Kuhajda, R. L. Mayden, H. W. Robison, S. T. Ross, W. C. Starnes. 2000. Diversity, distribution, and conservation status the native freshwater fishes of the Southeastern United States. Fisheries 25: 7-29.

Wehrly, K. E., and M. J. Wiley. 2003. Classifying regional variation in thermal regime based on stream fish community patterns. Transactions of the American Fisheries Society 132:18-38.

Welcomme, R. L. 1979. Fisheries ecology of floodplain rivers. Longman Group Limited. New York, New York.

Wiley, M. J., L. L. Osbourne, and R. W. Larimore. 1990. Longitudinal structure of an agricultural prairie river system and its relationship to current stream ecosystem theory. Canadian Journal of Aquatic Science 47: 373-384.

Willams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and Management of Animal Populations. Academic Press. San Diego, California.

Table 1. Name, stream order, stream type, location (UTM coordinates), and dominant water source of sample sites in the lower FRB that were sampled during spring, summer, and winter 2003-2004.

Site Name	Stream Order	Stream type	X Coordinate	Y Coordinate	Dominant Water Source
Kiokee Creek	2nd	Confined	751367.5312	3505286.465	Floridian aquifer
Mossy Creek	2nd	Wetland	743303.3642	3526347.873	Residuum
Pachitla Creek	2nd	Wetland	715890.2129	3518020.382	Residuum
Spring Creek	2nd	Wetland	742486.7691	3484052.092	Floridian aquifer
Un-named tributary to Muckalee Creek	2nd	Confined	775567.5203	3519642.690	Floridian aquifer
Wolf Creek	2nd	Confined	734651.4574	3520980.960	Residuum

Table 2. Description of sample-specific model parameters used to evaluate fish assemblages and dissolved oxygen at the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004.

Parameter	Description of Model Parameter
Area	Area (m^2) of sample units
DO	Dissolved oxygen concentration (mg/L)
Temp	Temperature (^oC)
Veg	Summation of percent emergent, submergent, and floating vegetation
LWD	Large wood expressed as percentage of sample unit area
Spring	Spring season, binary coded as 1 for spring, 0 for summer and winter
Winter	Winter season, binary coded as 1 for winter, 0 for spring and summer
Dep	Average depth (m) within sample unit
Wooded	Wooded WS, binary coded as 1 for Spring Creek 0 for Pachitla and Mossy Creeks
Vel	Average velocity (m/sec) within sample unit
Winter*Vel	Winter*average velocity interaction
Spring*Veg	Spring*summation percent vegetation interaction
Dep*LWD	Average depth*large wood interaction
Vel*Temp	Average velocity*temperature interaction
Vel*Vel	Average velocity*average velocity interaction, quadratic term
Temp*Wooded	Temperature*wooded interaction

Table 3. Summary of samples collected by site and season in the lower FRB during spring, summer, and winter 2003-2004.

Site	Habitat type	Summer 2003	Winter 2003	Spring 2003	Summer 2004
Confined channel					
Kiokee	All	1	1	1	1
Un-named tributary					
To Muckalee	All	1	1	1	0
Wolf	All	1	1	1	1
Wetland					
Mossy					
	Floodplain	*	*	*	*
	Main channel	8	8	8	8
	Side channel	7	8	8	8
Pachitla					
	Floodplain	*	*	*	*
	Main channel	15	15	15	15
	Side channel	15	15	15	7
Spring					
	Floodplain	24	25	25	6
	Main channel	15	15	15	15
	Side channel	15	15	15	16

*Habitat not available.

Table 4. Species collected from each of the six study sites in the lower FRB during spring, summer, and winter 2003-2004.

			Confined channel			Wetland		
Species Code	Common Name	Scientific Name	KIO	MUCK	WOLF	MOSS	PACH	SPG
BBD	Blackbanded Darter	*Percina nigrofasciata*			X		X	
BLG	Bluegill	*Lepomis macrochirus*	X		X	X	X	X
BOF	Bowfin	*Amia calva*		X				X
BPS	Banded Pigmy Sunfish	*Elassoma zonatum*			X	X	X	X
BRD	Brown Darter	*Etheostoma edwini*	X		X	X	X	X
BRS	Brook Silverside	*Labidesthes sicculus*			X	X	X	X
BTS	Blacktail Shiner	*Cyprinella venusta*		X		X	X	
BUS	Bluenose Shiner	*Pteronotropis welaka*						
CCS	Creek Chubsucker	*Erimyzon oblongus*			X	X		X
CLC	Clear Chub	*Hybopsis winchelli*				X		
DOS	Dollar Sunfish	*Lepomis marginatus*			X	X	X	
FLI	Flier	*Centrarchus macropterus*						X
GAM	Mosquitofish	*Gambusia holbrooki*	X	X	X	X	X	X
GOS	Golden Shiner	*Notemigonus crysoleucas*			X	X	X	X
GSF	Green Sunfish	*Lepomis cyanellus*		X				
LCS	Lake Chubsucker	*Erimyzon sucetta*			X	X		
LMB	Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X	X
LNS	Longnose Shiner	*Notropis longirostris*					X	
PIP	Pirate Perch	*Aphredoderus sayanus*	X	X	X	X	X	X
RBS	Redbreast Sunfish	*Lepomis auritus*		X	X	X	X	X
REC	Redeye Chub	*Notropis harperi*	X	X			X	X
RES	Redear Sunfish	*Lepomis microlophus*			X	X	X	
RFP	Redfin/Grass Pickerel	*Esox americanus x vermiculatus*	X	X	X	X	X	X
SBL	Southern Brook Lamprey	*Ichthyomyzon gagei*			X		X	
SFS	Sailfin Shiner	*Pteronotropis hypselopterus*		X	X		X	X

Table 4. Continued

Species Code	Common Name	Scientific Name	Confined channel			Wetland		
			KIO	MUCK	WOLF	MOSS	PACH	SPG
SMT	Speckled Madtom	*Noturus leptacanthus*		X	X		X	X
SPB	Spotted Bass	*Micropterus Punctulatus (Rafinesque)*	X					
SPG	Spotted Gar	*Lepiosteus oculatus*				X		
SPS	Spotted Sucker	*Minytrema melanops*		X	X	X		
SPT	Spotted Sunfish	*Lepomis punctatus*	X		X	X	X	X
SWD	Swamp Darter	*Etheostoma fusiforme*				X		X
TLS	Taillight Shiner	*Notropis maculatus*				X	X	X
WAR	Warmouth	*Lepomis Gulosus (Cuvier)*		X	X	X	X	X
WES	Weed Shiner	*Notropis texanus*			X	X	X	X
YBH	Yellow Bullhead	*Ameirurus natalis*	X	X	X		X	

Table 5. Mean species richness and total fish density and their associated standard deviations by wetland habitat type and season from the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Also shown, extrapolated species richness and total fish density for each wetland study site. * = Habitat not present.

Wetland	Season	Species richness main channel	Species richness side channel	Species richness floodplain	Species richness total	Fish density main channel	Fish density side channel	Fish density floodplain	Fish density total
Mossy									
	Summer 2003	2.1(1.0)	1.9(1.8)	*	16	2.4(1.5)	3.8(4.9)	*	3.4(5.1)
	Winter 2004	2.6(2.4)	1.1(0.9)	*	23	11.2(10.5)	4.4(5.8)	*	6.1(12.0)
	Spring 2004	2.2(2.0)	1.3(1.0)	*	23	7(7.8)	4.2(5.6)	*	4.9(9.6)
	Summer 2004	2.3(2.0)	2.3(2.0)	*	16	16.5(18.6)	17.8(22.3)	*	17.5(29.0)
Pachitla									
	Summer 2003	3.7(1.9)	3.8(2.8)	*	20	5.7(5.5)	7.8(7.5)	*	7.3(9.3)
	Winter 2004	2.1(2.5)	2.9(2.2)	*	20	5.6(10.0)	9.8(13.3)	*	8.8(16.6)
	Spring 2004	2.3(2.2)	2.6(1.8)	*	25	7.3(6.9)	8.8(10.9)	*	8.4(12.9)
	Summer 2004	1.5(1.8)	2.6(1.6)	*	17	5.5(9.6)	2.9(2.5)	*	3.6(9.9)
Spring									
	Summer 2003	0.6(0.8)	1.2(1.6)	1.4(1.6)	10	3.8(5.3)	7.3(13.4)	7.7(14.7)	7.4(20.6)
	Winter 2004	4.6(0.9)	2.9(1.9)	3.0(1.5)	16	48(48.2)	39.8(43.0)	22.1(15.4)	25.0(66.4)
	Spring 2004	2.1(1.6)	0.2(0.4)	0.4(0.7)	12	24.8(21.7)	3.4(7.3)	1.3(3.9)	3.5(23.2)
	Summer 2004	1.8(1.5)	0.4(0.8)	0.5(1.2)	10	29.4(35.7)	1.5(3.6)	2.4(6.0)	4.8(36.4)

Table 6. Means and 95% confidence intervals (in parentheses) of physical habitat characteristics at all study sites in the lower FRB during spring, summer, and winter 2003-2004.

Site	Habitat	Area (m^2)	Depth (m)	Velocity (m/sec)	LWD (%)	Silt (%)	Vegetation (%)
Confined Channel							
Kiokee	All	329.5	0.13	0.06	5.85	58.19	0
		(301.36-357.64)	(0.11-0.15)	(0.02-0.09)	(2.07-9.63)	(15.36-100)	
Un-named tributary to Muckalee	All	206.67	0.11	0.03	5.88	86.33	0
		(171.49-241.84)	(0.09-0.13)	(0.01-0.04)	(1.34-10.43)	(59.55-100)	
Wolf	All	546.93	0.33	0.11	9.61	18.69	0
		(427.19-666.67)	(0.24-0.43)	(0.04-0.17)	(3.28-15.94)	(14.75-22.62)	
Wetland							
Mossy	Main channel	358.8	0.58	0.03	4.11	57.63	11.56
			(0.55 - 0.61)	(0.02 - 0.03)	(0.97 - 7.26)	(47.35 - 67.92)	(4.92 - 18.20)
	Side channel	1040.75	0.52	0.02	2.34	67.93	5.46
			(0.48 - 0.56)	(0.02 - 0.03)	(0.21 - 4.47)	(58.55- 77.30)	(2.46 - 8.47)
Pachitla	Main channel	903.83	0.45	0.09	4.67	62.75	1.08
			(0.41 - 0.49)	(0.08 - 0.11)	(2.64 - 6.70)	(55.37 - 70.13)	(0 - 2.20)
	Side channel	2677.67	0.32	0.06	2.31	83.08	2.98
			(0.29 - 0.35)	(0.04 - 0.07)	(0.60 - 4.02)	(76.36 - 89.79)	(1.25 - 4.71)
Spring	Main channel	5324.92	0.48	0.02	20.08	82.16	0
			(0.44 - .52)	(0.02 - 0.03)	(14.88 - 25.28)	(77.33 - 86.99)	
	Side channel	1476.92	0.36	0.02	11.07	98.68	0.16
			(0.34 - 0.38)	(0.02 - 0.02)	(8.25 - 13.88)	(97.75 - 99.61)	(0 - .49)
	Floodplain	51066.2	0.26	0.02	10.13	100	0.75
			(0.24 - 0.28)	(0.01 - 0.02)	(7.59 - 12.66)	(100 - 100)	(0.07 - 1.43)

Table 7. Habitat composition, expressed as a proportion, of each of the three wetland study sites in the lower FRB. Estimates based on line-transects completed November 20th and 21st 2004.

Habitat type	Mossy	Pachitla	Spring
Main channel	0.34	0.25	0.09
Side channel	0.66	0.75	0.03
Floodplain	0.00	0.00	0.88

Table 8. Standardized canonical discriminant function coefficients and correlations of the discriminant analysis of habitat characteristics of the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. High correlations (in bold) were interpreted as having the largest the influence on the function.

Habitat variable	Coefficient 1	Correlation 1	Coefficient 2	Correlation 2
Mean Depth	6.5093	**0.73798**	-1.2278	-0.3361
Mean Current Velocity	14.0888	**0.47031**	-1.56	-0.1418
Percent Large Wood	0.0347	0.07924	0.07067	**0.96635**
Percent Vegetation	0.0111	0.13108	-0.0154	-0.2616
Percent Silt	-0.0226	**-0.6429**	-0.007	-0.0098

Table 9. Correct classification rates, expressed as percentages, of habitats by wetland study site in the lower FRB during spring, summer, and winter 2003-2004.

		Percent classified as:		
Wetland	Habitat type	Main channel	Side channel	Floodplain
Mossy	Main channel	71.0	29.0	0.0
	Side channel	56.3	43.8	0.0
Pachitla	Main channel	85.0	13.3	1.7
	Side channel	17.3	50.0	32.7
Spring	Main channel	56.7	35.0	8.3
	Side channel	9.8	42.6	47.5
	Floodplain	2.5	18.8	78.8

Table 10. Predictor variables, number of models (K), AIC_c, ΔAIC_c, Akaike weights (w), and percent of maximum Akaike weight for the confidence set of candidate models predicting dissolved oxygen at the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Model parameters defined in Table 2.

Candidate Model	K	AIC_c	ΔAIC_c	w_i	Percent of maximum w_i
Temp Vel Vel*Vel Wooded	4	1579.45	0	0.68494	100
Temp Vel Vel*Vel Wooded Temp*Wooded	5	1581.20	1.747	0.28593	41.75

Table 11. Estimates of fixed effects for the best-fitting repeated measures linear model predicting dissolved oxygen in habitats types of my three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Model parameters defined in Table 2.

			95% Confidence Interval	
Parameter	Parameter Estimate	Standard Error	Lower	Upper
Intercept	11.182	0.4544	10.2884	12.0756
Temp	-0.2732	0.01742	-0.3074	-0.2389
Vel	39.5107	7.4071	24.9456	54.0759
Vel*Vel	-111.17	36.8115	-183.55	-38.784
Wooded	-2.506	0.2379	-2.9739	-2.0381

Table 12. Analysis of variance of habitat type and seasonal species richness at all three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004.

Source	Degrees of freedom	Sum of squares	Mean square	F-value	P-value
Site	2	3.765	1.882	5.97	0.0029
Season	3	3.044	1.015	3.22	0.0233
Site*Season	6	16.305	2.718	8.62	<0.0001
Habitat	1	0.920	0.920	2.92	0.0887
Site*Habitat	2	4.543	2.271	7.21	0.0009
Season*Habitat	3	1.307	0.436	1.38	0.2487
Site*Season*Habitat	6	4.001	0.667	2.12	0.0518
Area	1	4.407	4.407	13.98	0.0002

Table 13. Tukey-Kramer multiple comparison of seasonal mean species richness and habitat mean species richness at all three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Data have been natural log-transformed. Non-significant (P>0.05) means are underlined.

Seasonal comparisons

Spring	Pachitla	Mossy	Pachitla	Mossy	Pachitla	Pachitla	Mossy	Mossy	Spring	Spring	Spring
Winter 2004	Summer 2003	Summer 2004	Spring 2004	Summer 2003	Winter 2004	Summer 2004	Winter 2004	Spring 2004	Spring 2004	Summer 2004	Summer 2003
1.47	1.32	1.05	1	0.97	0.96	0.95	0.91	0.9	0.63	0.59	0.48

Habitat comparisons

Pachitla	Mossy	Spring	Pachitla	Mossy	Spring
Side channel	Main channel	Main channel	Main channel	Side channel	Side channel
1.14	1.02	0.99	0.97	0.9	0.59

Table 14. Predictor variables, number of models (K), AIC_c, ΔAIC_c, Akaike weights (w), and percent of maximum Akaike weight for the confidence set of candidate models (*i*) predicting natural log-transformed species richness in habitat types of the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Model parameters defined in Table 2.

Candidate Model	K	AIC_c	ΔAIC_c	w_i	Percent of maximum w_i
Area DO Temp Veg LWD Winter Vel Winter*Vel	8	690.278	0.000	0.547	100.00
Area DO Temp Veg LWD Spring Winter Vel Winter*Vel	9	692.317	2.039	0.197	36.07
Area DO Temp Veg LWD Spring Winter Vel Dep Winter*Vel	10	694.051	3.773	0.083	15.15

Table 15. Estimates of fixed effects for the best-fitting repeated measures linear model predicting natural log-transformed species richness in my three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Model parameters defined in Table 2.

			95% Confidence Interval	
Parameter	Parameter Estimate	Standard Error	Lower	Upper
Intercept	-0.7857	0.2936	-1.3631	-0.2083
Area	0.0410	0.0087	0.0240	0.0580
DO	0.0817	0.0145	0.0531	0.1103
Temp	0.0356	0.0113	0.0133	0.0578
Veg	0.0088	0.0046	-0.0002	0.0178
LWD	0.0061	0.0025	0.0011	0.0111
Winter	0.8147	0.1434	0.5327	1.0967
Vel	-0.9806	0.9774	-2.9026	0.9414
Winter*Vel	-6.2100	1.8737	-9.8946	-2.5254

Table 16. Analysis of variance of habitat type and seasonal total fish density at all three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004.

Source	Degrees of freedom	Sum of squares	Mean square	F -Value	P-Value
Site	2	6.092	3.046	2.11	0.1230
Season	3	27.978	9.326	6.46	0.0003
Site*Season	6	57.421	9.570	6.63	<0.0001
Habitat	1	7.962	7.962	5.52	0.0195
Site*Habitat	2	25.988	12.994	9.01	0.0002
Season*Habitat	3	8.297	2.766	1.92	0.1271
Site*Season*Habitat	6	17.656	2.943	2.04	0.0607

Table 17. Tukey-Kramer multiple comparison test of habitat type and seasonal mean total fish density at all three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Data have been natural log-transformed. Non-significant ($P>0.05$) means are underlined.

Seasonal comparisons

Spring	Mossy	Pachitla	Mossy	Pachitla	Spring	Pachitla	Spring	Mossy	Mossy	Pachitla	Spring
Winter 2004	Summer 2004	Summer 2003	Winter 2004	Spring 2004	Spring 2004	Winter 2004	Summer 2004	Spring 2004	Summer 2003	Summer 2004	Summer 2003
3.23	1.99	1.73	1.66	1.64	1.62	1.59	1.36	1.32	1.16	1.13	1.07

Habitat comparisons

Spring	Pachitla	Mossy	Mossy	Pachitla	Spring
Main channel	Side channel	Main channel	Side channel	Main channel	Side channel
2.35	1.66	1.65	1.41	1.38	1.29

Table 18. Predictor variables, number of models (K), AIC_c, ΔAIC_c, Akaike weights (w), and percent of maximum Akaike weight for the confidence set of candidate models (*i*) predicting natural log-transformed total fish density in habitat types of the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Model parameters defined in Table 2.

Candidate Model	K	AICc	AICc	w_i	Percent of maxium w_i
DO Temp Veg LWD Winter Vel Winter*Vel	7	1278.88	0.000	0.466	100.00
DO Temp Veg LWD Spring Winter Vel Winter*Vel	8	1280.88	1.996	0.172	36.85
DO Temp Veg LWD Spring Winter Vel Dep Winter*Vel	9	1281.96	3.077	0.100	21.47
DO Temp LWD Spring Winter Vel Dep Winter*Vel	8	1281.96	3.080	0.100	21.44

Table 19. Estimates of fixed effects for the best-fitting repeated measures linear model predicting natural log-transformed total fish density in habitat types of my three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Model parameters defined in Table 2.

Parameter	Parameter Estimate	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Intercept	-0.1924	0.6399	-1.4507	1.0660
DO	0.0792	0.0310	0.0183	0.1401
Temp	0.0427	0.0248	-0.0061	0.0914
Veg	0.0164	0.0100	-0.0034	0.0361
LWD	0.0259	0.0056	0.0150	0.0368
Winter	1.8178	0.3144	1.1995	2.4361
Vel	-1.5333	2.1325	-5.7267	2.6601
Winter*Vel	-11.8984	4.1061	-19.9728	-3.8240

Table 20. Analysis of variance of habitat type and seasonal mean species evenness at all three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004.

Source	Degrees of freedom	Sum of squares	Mean square	F-Value	P-Value
Site	2	0.448	0.224	5.53	0.0044
Season	3	0.328	0.109	2.70	0.0461
Site*Season	6	1.706	0.284	7.02	<0.0001
Habitat	1	0.058	0.058	1.44	0.2313
Site*Habitat	2	0.481	0.240	5.94	0.0030
Season*Habitat	3	0.111	0.037	0.91	0.4349
Site*Season*Habitat	6	0.398	0.066	1.64	0.1369
Area	1	0.266	0.266	6.57	0.0109

Table 21. Tukey-Kramer multiple comparison of habitat type and seasonal mean species evenness at all three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Data have been natural log-transformed. Non-significant (P>0.05) means are underlined.

Seasonal comparisons

Spring Winter 2004	Mossy Spring 2004	Mossy Summer 2004	Mossy Summer 2003	Pachitla Summer 2003	Mossy Winter 2004	Pachitla Spring 2004	Pachitla Summer 2004	Pachitla Winter 2004	Spring Spring 2004	Spring Summer 2004	Spring Summer 2003
0.402	0.329	0.274	0.26	0.257	0.255	0.217	0.216	0.185	0.131	0.111	0.059

Habitat comparisons

Mossy Main channel	Mossy Side channel	Pachitla Main channel	Spring Main channel	Pachitla Side channel	Spring Side channel
0.296	0.263	0.252	0.236	0.186	0.115

Table 22. Standardized canonical discriminant function coefficients and correlations of the discriminant analysis of wetland fish communities within the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Higher correlations (in bold) were interpreted as having the largest the influence on the function.

Species code	Coefficient 1	Correlation 1	Coefficient 2	Correlation 2
Spring				
BLG	0.48519	**0.4327**	0.5255	0.15539
BPS	0.4398	**0.49745**	0.03509	-0.1771
BRD	0.22501	0.1651	0.28313	0.08726
BRS	-0.1115	0.05909	4.36829	**0.73601**
GOS	0.3611	0.22468	0.86785	**0.46379**
PIP	0.62669	**0.59734**	-0.4904	-0.3351
RBS	0.53485	**0.42448**	-1.3078	-0.1729
SPT	0.29476	**0.46124**	0.58748	0.21674
WES	1.00618	**0.46157**	0.08772	0.25197
Summer				
BLG	0.26172	0.32317	0.02618	-0.1624
BPS	0.12024	-0.1334	-0.4604	**-0.3538**
BRD	0.68823	0.23363	0.073	0.06663
BRS	0.75695	**0.4308**	0.19533	-0.1289
GAM	2.38076	**0.48835**	3.19806	0.33501
GOS	0.57576	**0.44213**	0.14552	0.04377
LMB	-0.1997	0.1595	0.71275	0.18683
PIP	-1.0077	**-0.7086**	0.24571	0.12967
RBS	-0.0688	0.23967	-0.8065	-0.4867
REC	-0.0164	-0.2076	0.44495	0.31748
SPT	0.0285	0.3739	0.02755	-0.1037
TLS	0.24681	0.15913	-0.0007	-0.1205
WAR	0.57687	0.00257	2.48683	**0.4086**
WES	0.26691	0.27501	-0.6464	-0.2667

Table 22. Continued.

Species code	Coefficient 1	Correlation 1	Coefficient 2	Correlation 2
<u>Winter</u>				
BLG	0.99346	**0.33453**	-0.3428	-0.2563
BPS	-0.3196	**-0.2666**	-0.2296	0.00165
BRD	-0.2208	-0.0872	-0.4074	-0.1504
BRS	-1.3007	0.13738	-2.4118	-0.2051
GAM	-2.6052	-0.2841	1.91016	**0.42729**
PIP	-0.3477	**-0.4153**	0.54907	0.39633
RBS	-0.0504	0.12844	0.31114	-0.0172
REC	0.42094	0.1331	0.46859	**0.70126**
SFS	0.50124	0.41269	0.37684	0.2733
SPT	0.06183	0.17147	-0.1091	0.01782
SWD	0.77907	**0.4698**	0.40108	0.11293
WES	0.82603	0.25375	0.67928	-0.0578

Table 23. Correct classification rates, expressed as percentages and based on discriminant analysis of fish communities during spring, of habitats by wetland study site in the lower FRB.

		Percent classified as:		
Site	Habitat type	Main channel	Side channel	Floodplain
Moss	Main channel	37.5	25.0	37.5
	Side channel	62.5	12.5	25.0
Pachitla	Main channel	20.0	40.0	40.0
	Side channel	33.3	20.0	46.7
Spring Creek	Main channel	60.0	20.0	20.0
	Side channel	13.3	0.0	86.7
	Floodplain	4.0	8.0	88.0

Table 24. Correct classification rates, expressed as percentages and based on discriminant analysis of fish communities during summer, of habitats by wetland study site in the lower FRB.

		Percent classified as:		
Site	Habitat type	Main channel	Side channel	Floodplain
Moss	Main channel	53.3	46.7	0.0
	Side channel	68.8	18.8	12.5
Pachitla	Main channel	53.3	33.3	13.3
	Side channel	14.3	34.3	54.4
Spring Creek	Main channel	50.0	10.0	40.0
	Side channel	77.4	3.2	19.4
	Floodplain	60.0	16.7	23.3

Table 25. Correct classification rates, expressed as percentages and based on discriminant analysis of fish communities during winter, of habitats by wetland study site in the lower FRB.

		Percent classified as:		
Site	Habitat type	Main channel	Side channel	Floodplain
Moss	Main channel	62.5	37.5	0.0
	Side channel	37.5	62.5	0.0
Pachitla	Main channel	26.7	73.3	0.0
	Side channel	13.3	80.0	6.7
Spring Creek	Main channel	60.0	6.7	33.3
	Side channel	60.0	40.0	33.3
	Floodplain	12.0	24.0	64.0

Table 26. Analysis of variance of stream type and seasonal species richness at three wetland and three confined channel study sites in the lower FRB during spring, summer, and winter 2003-2004.

Source	*Degrees* of freedom	Sum of squares	Mean square	F value	P-value
Type	1	0.7236	0.7236	5.57	0.0334
Season	3	0.3205	0.1068	0.82	0.5034
Type*Season	3	0.5591	0.1864	1.43	0.2750
Area	1	0.0002	0.0002	0.00	0.9732

Table 27. Analysis of variance of stream type and seasonal total fish density at three wetland and three confined channel study sites in the lower FRB during spring, summer, and winter 2003-2004. Data have been natural log-transformed.

Source	Degrees of freedom	Sum of squares	Mean square	F-Value	P-Value
Type	1	2.10516	2.10516	5.29	0.0362
Season	3	1.09661	0.36554	0.92	0.4555
Type*Season	3	0.23960	0.07987	0.20	0.8942

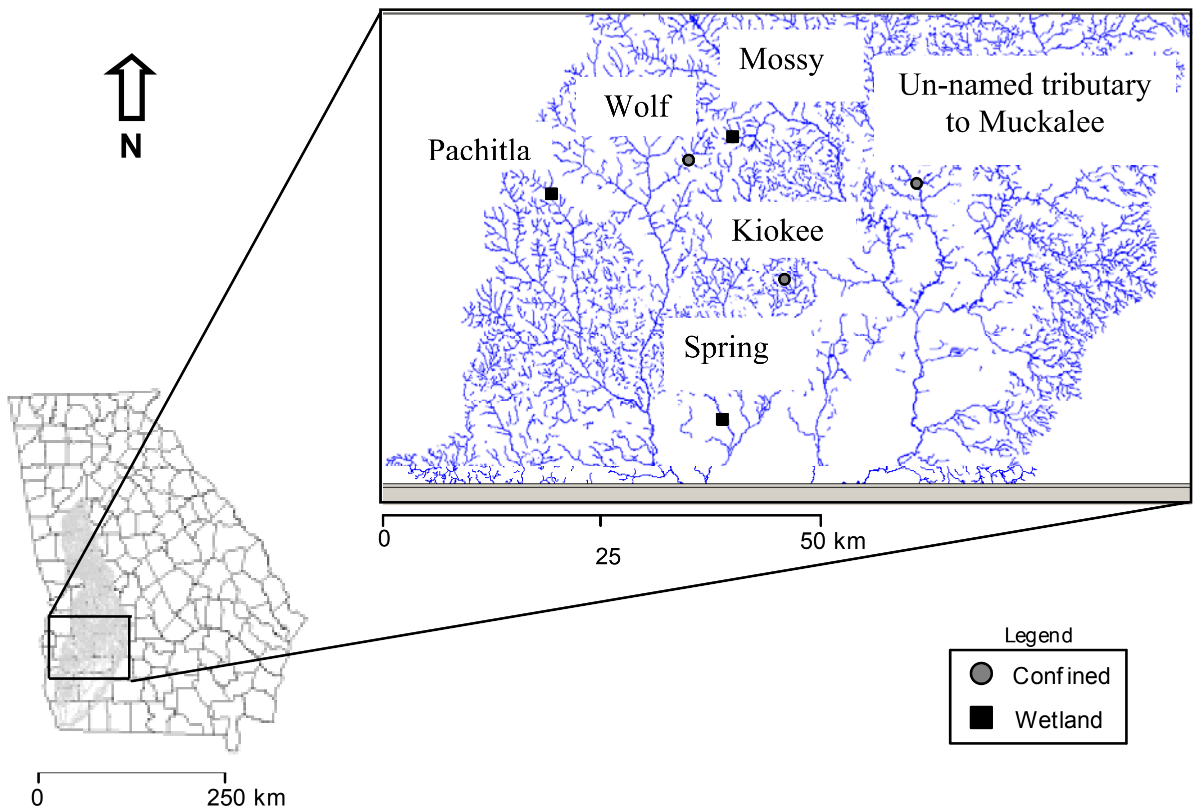

Figure 1. Locations of six study sites in the lower FRB of southwest Georgia that were sampled spring, summer, and winter 2003-2004.

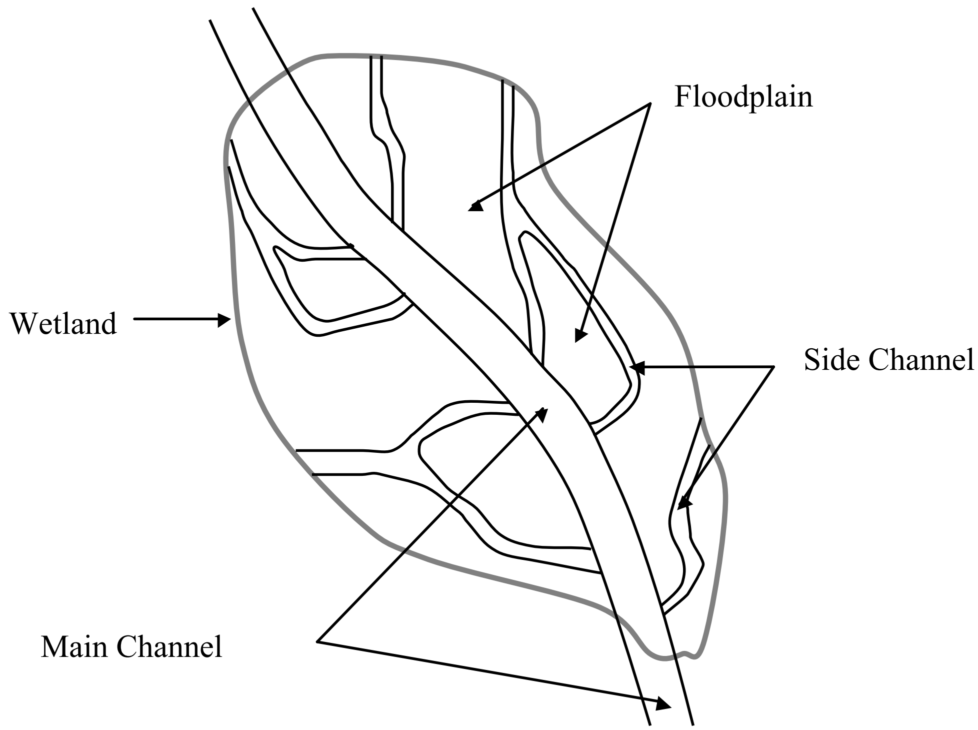

Figure 2. Wetland stream habitat classification including main channel, side channel, and floodplain habitats for wetland streams in the lower FRB sampled during spring, summer, and winter 2003-2004.

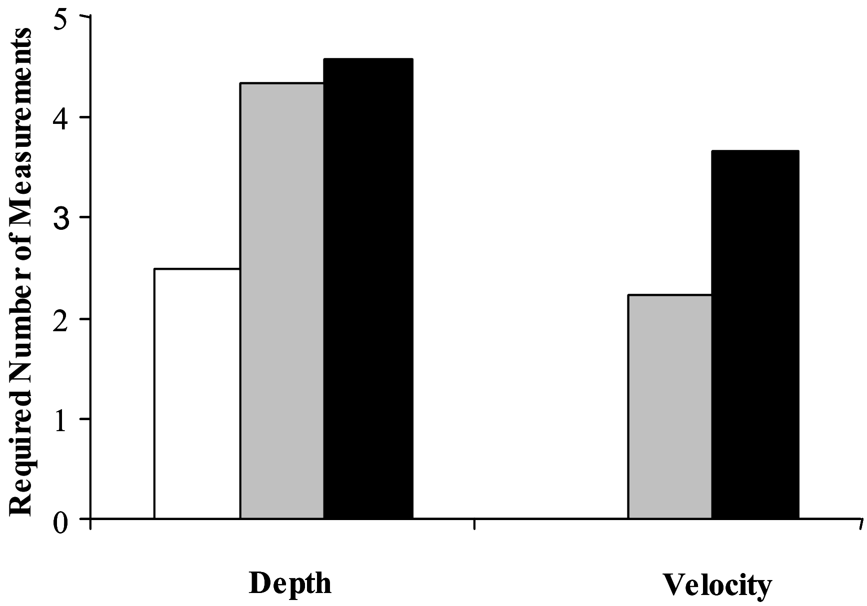

Figure 3. Total number of depth and velocity measurements required to capture biologically significant changes in depth (0.05 m) and current velocity (0.02 m/sec) within wetland study sites of the lower FRB. Based on preliminary sample data collected spring 2003. □ = Floodplain habitat, ▩ = Main channel habitat, and ■ = Side channel habitat.

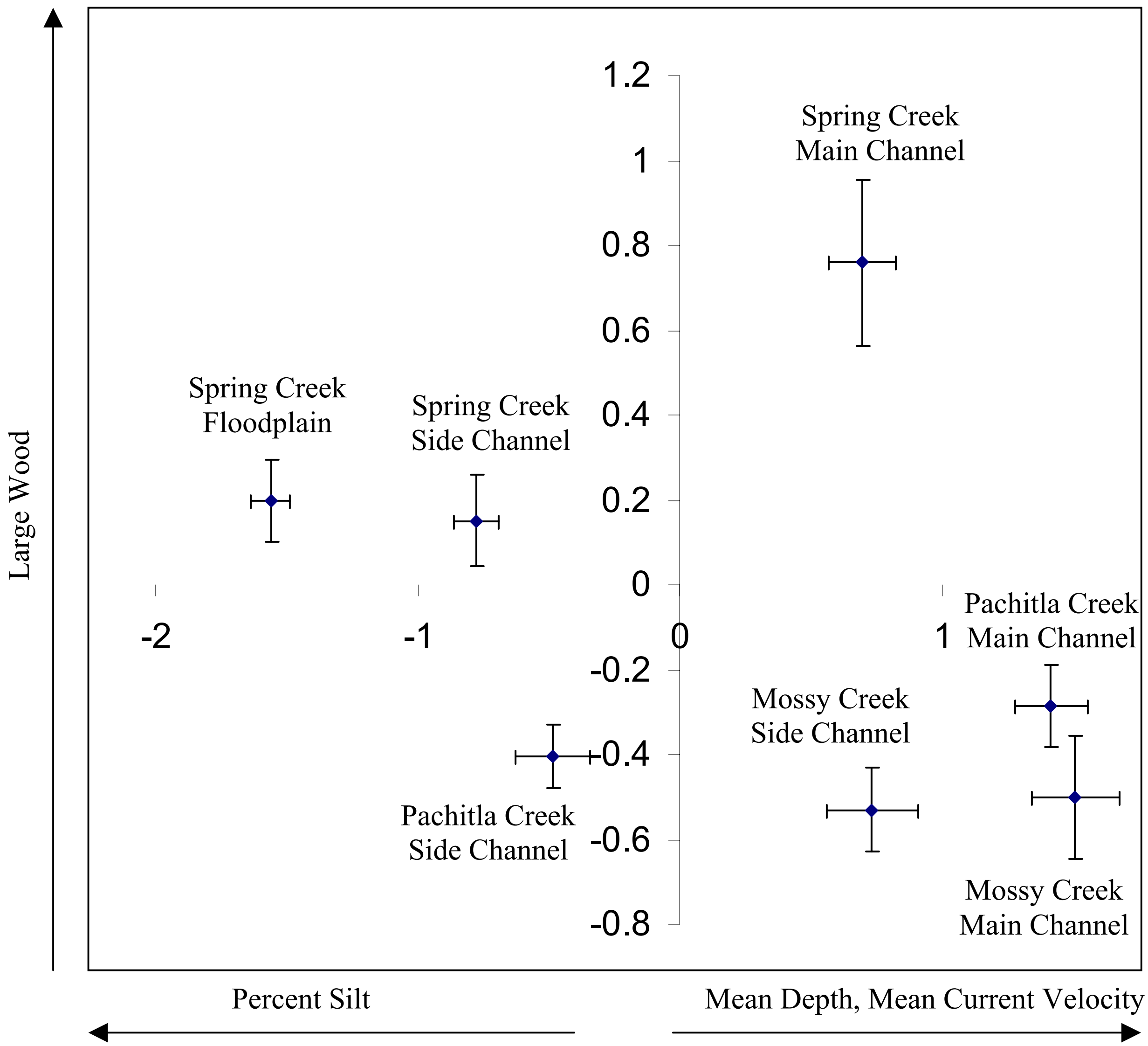

Figure 4. Discriminant function bi-plots for two functions from the analysis of physical habitat characteristics of wetland stream habitats in the three wetland study sites in the lower FRB during spring, summer, and winter 2003-2004. Brackets are standard errors of discriminant function scores.

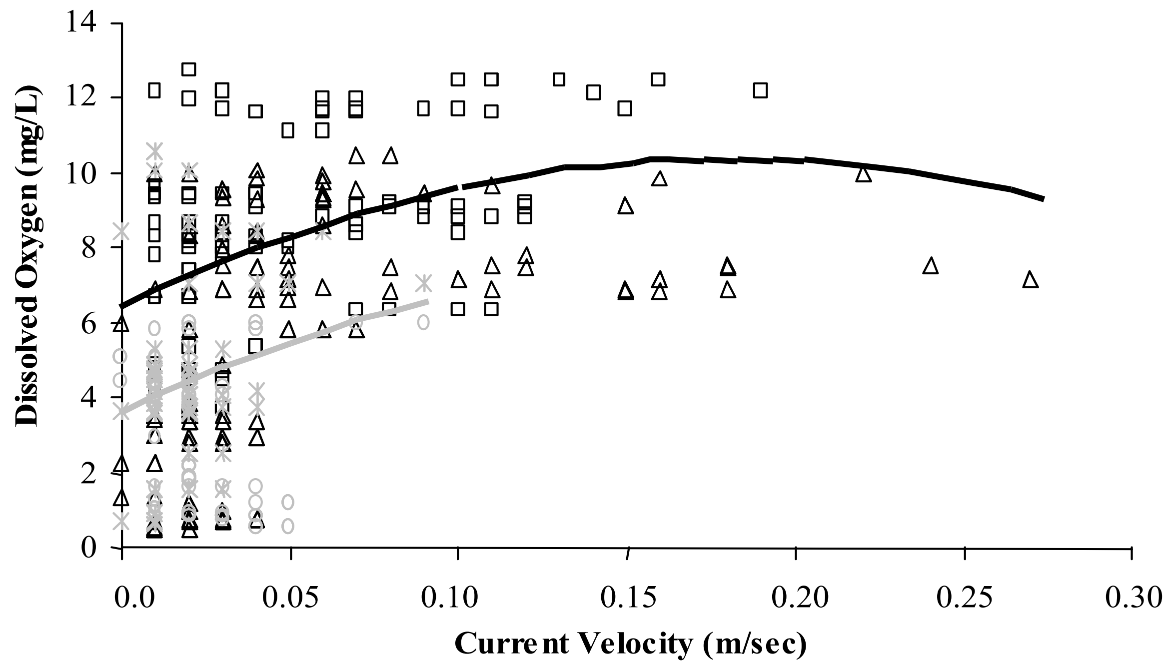

Figure 5. Relationship between current velocity, detritus, temperature, and dissolved oxygen in the lower FRB during spring, summer, and winter 2003-2004. * = Wooded wetland, temperature < 22^{o}C, ○ = Wooded wetland, temperature >22^{o}C, □ = Non-wooded, temperature < 22^{o}C, Δ = Non-wooded, temperature > 22^{o}C, — = Wooded wetland dissolved oxygen model predictions, and — = Non-wooded wetland dissolved oxygen model predictions. Wooded wetland represents Spring Creek and non-wooded wetland represents Mossy Creek and Pachitla Creek.

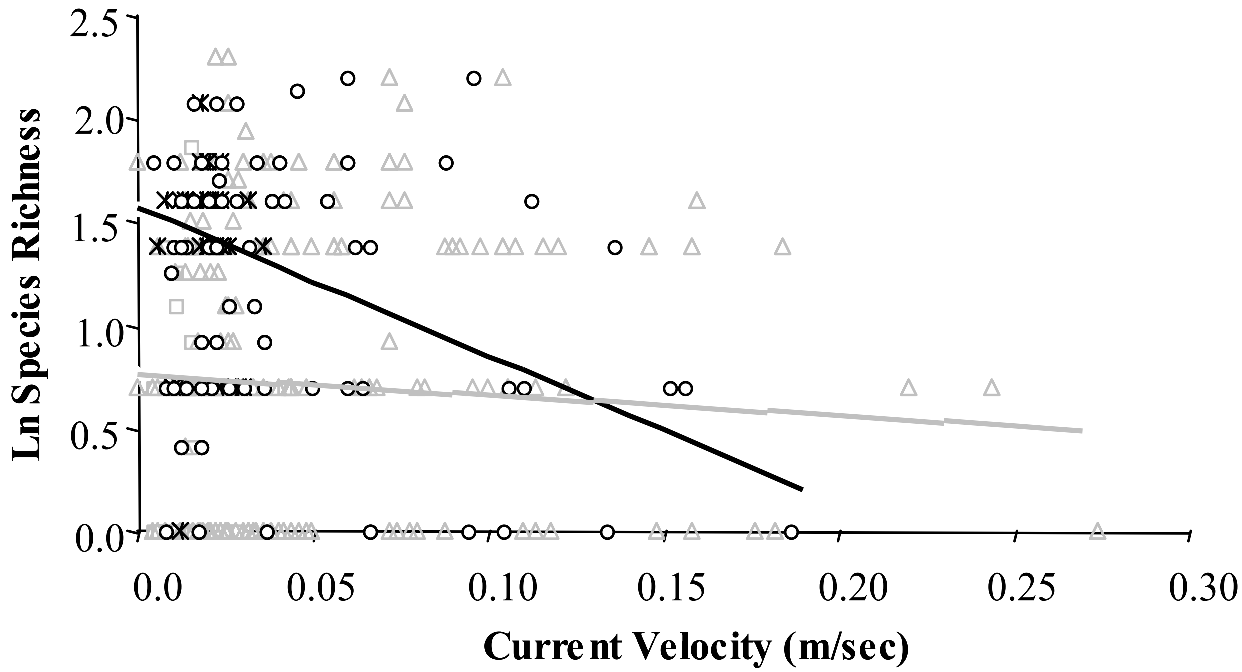

Figure 6. Relationship between season, dissolved oxygen, current velocity, and species richness in the lower FRB during spring, summer, and winter 2003-2004. □ = Spring and summer seasons, dissolved oxygen < 5 mg/L, △ = Spring and summer seasons, dissolved oxygen > 5 mg/L, ⁎ = Winter season, dissolved oxygen < 5 mg/L, ○ = Winter season, dissolved oxygen > 5 mg/L, ━ = Winter season prediction, and ━ = Spring and summer prediction.

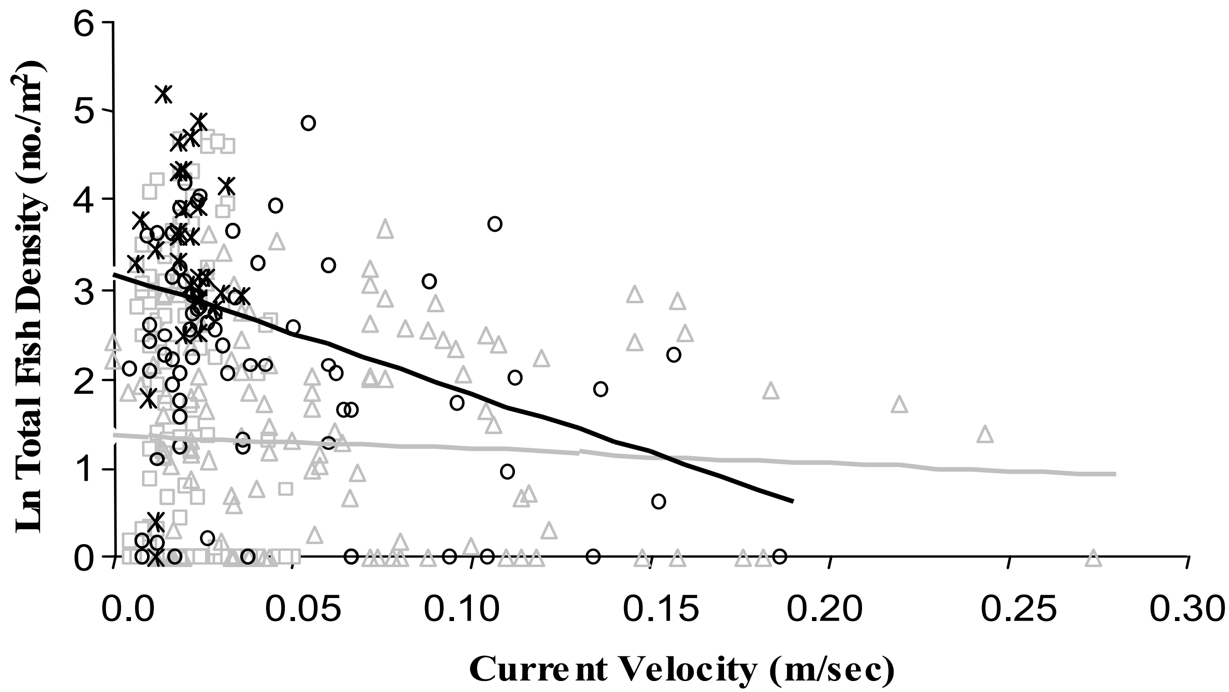

Figure 7. Relationship between season, dissolved oxygen, current velocity, and total fish density in the lower FRB during spring, summer, and winter 2003-2004. □ = Spring and summer seasons, dissolved oxygen < 5 mg/L, △ = Spring and summer seasons, dissolved oxygen > 5 mg/L, ⚹ = Winter season, dissolved oxygen < 5 mg/L, ○ = Winter season, dissolved oxygen > 5 mg/L, ━ = Winter season prediction, and ━ = Spring and summer prediction.

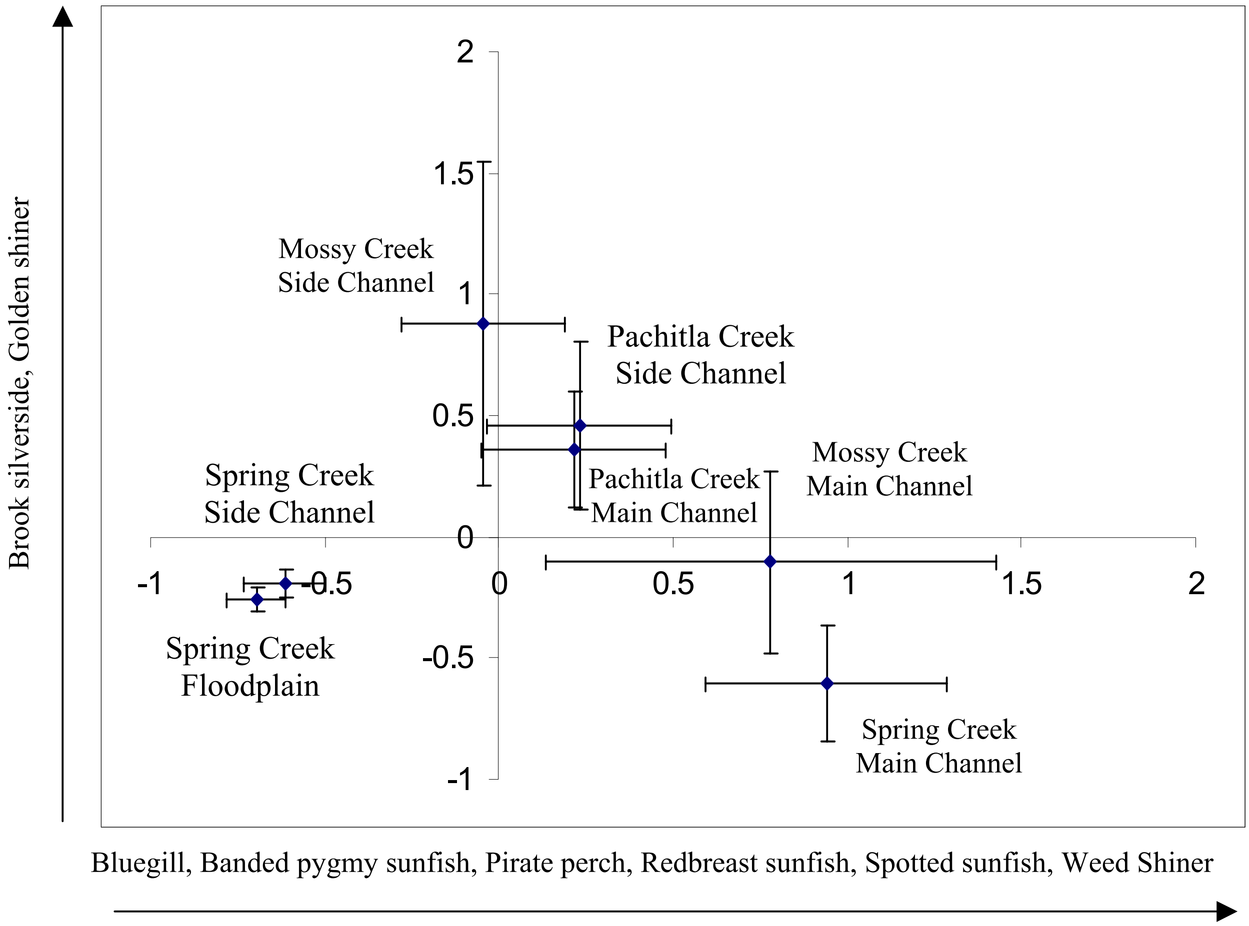

Figure 8. Discriminant function bi-plots for two functions from the analysis of total fish density of wetland stream habitats in the three wetland study sites in the lower Flint River Basin during spring. Brackets are standard errors of discriminant function scores.

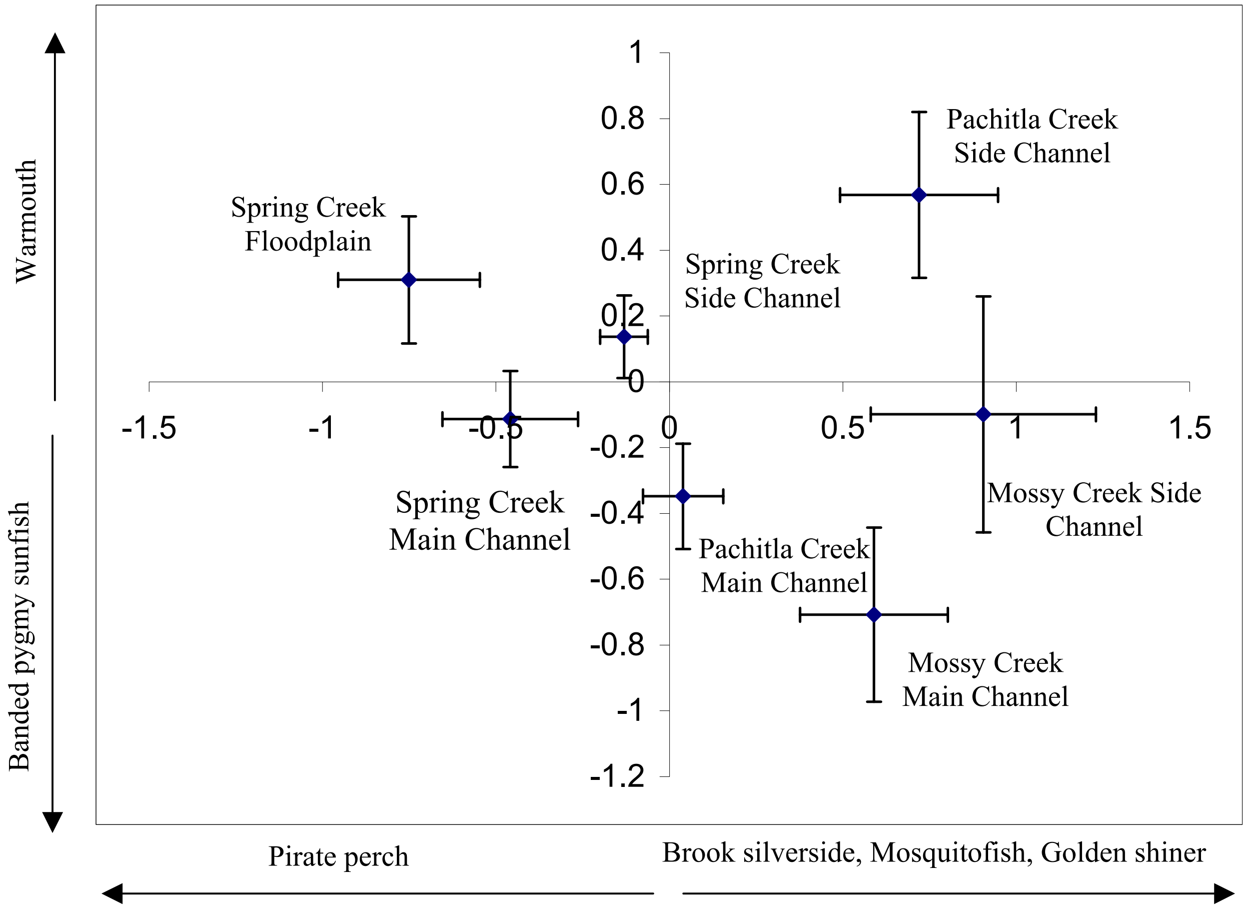

Figure 9. Discriminant function bi-plots for two functions from the analysis of total fish density of wetland stream habitats in the three wetland study sites in the lower Flint River Basin during summer. Brackets are standard errors of discriminant function scores.

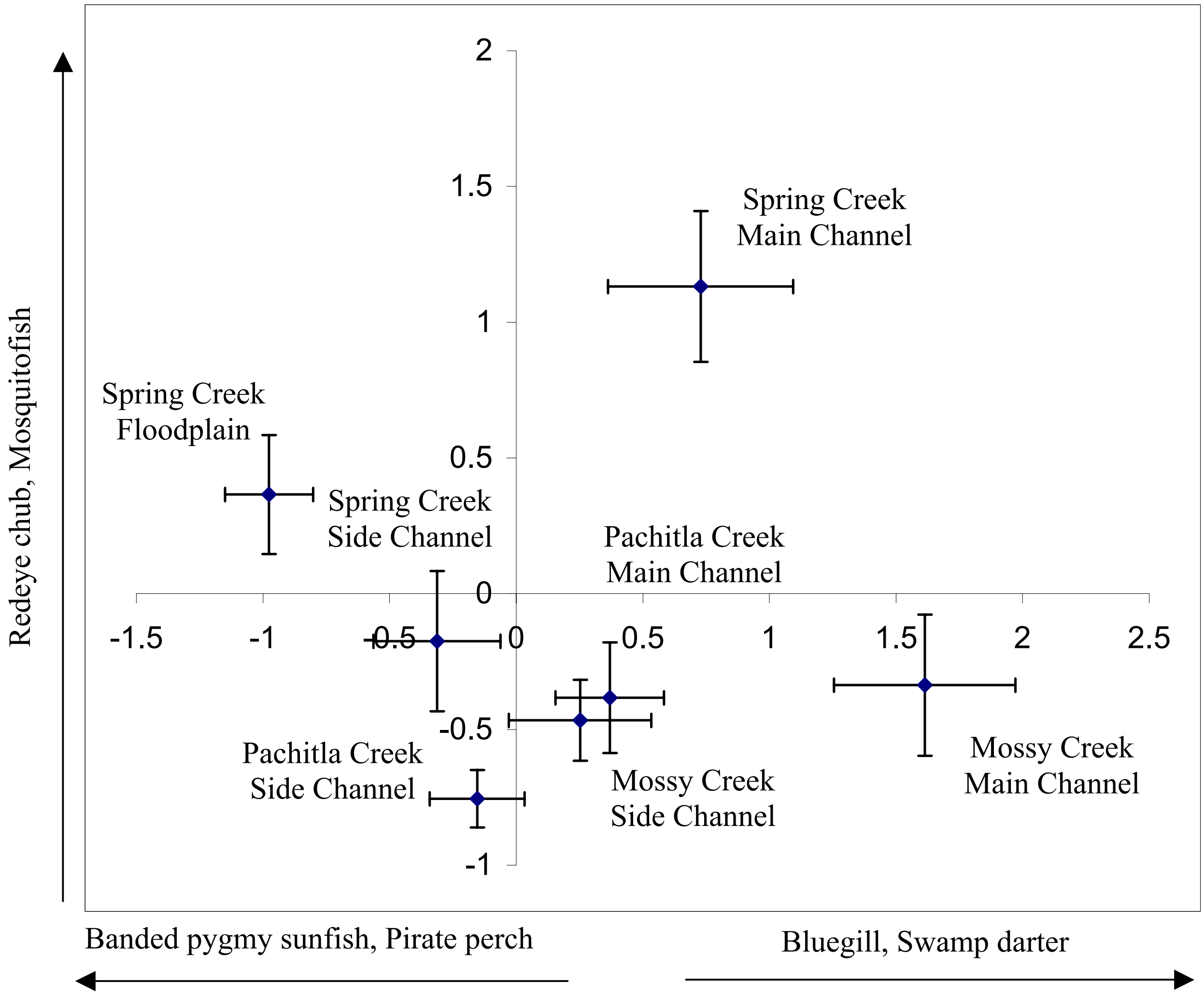

Figure 10. Discriminant function bi-plots for two functions from the analysis of total fish density of wetland stream habitats in the three wetland study sites in the lower Flint River Basin during winter. Brackets are standard errors of discriminant function scores.

APPENDIX A

Table A1. Length (mm) and associated range of fishes collected from the lower Flint River Basin during spring, summer, and winter 2003-2004 listed by site and season. TMUCK = Un-named tributary to Muckalee Creek, * = species not collected, and NS = site not sampled.

		Confined Channel			Wetland		
Season	Species Code	Kiokee	TMUCK	Wolf	Mossy	Pachitla	Spring
Summer 2003	BBD	*	*	67.0 (67-67)	*	62.0 (62-62)	*
Summer 2003	BLG	*	*	*	44.4 (19-110)	57.8 (24-108)	118.0 (49-187)
Summer 2003	BOF	*	180.0 (180-180)	*	*	*	*
Summer 2003	BPS	*	*	*	20.5 (20-21)	33.0 (33-33)	22.0 (20-26)
Summer 2003	BRD	*	*	*	40.0 (40-40)	30.6 (27-37)	34.0 (30-48)
Summer 2003	BRS	*	*	*	49.5 (32-69)	37.1 (20-67)	*
Summer 2003	BTS	*	*	*	*	*	*
Summer 2003	CCS	*	*	*	72.0 (72-72)	*	*
Summer 2003	CLC	*	*	*	*	*	*
Summer 2003	DOS	*	*	*	*	*	*
Summer 2003	FLI	*	*	*	*	*	*
Summer 2003	GAM	27.7 (25-32)	25.8 (14-45)	*	*	28.3 (17-39)	*
Summer 2003	GOS	*	*	*	87.0 (87-87)	39.8 (25-68)	*
Summer 2003	GSF	*	39.9 (39-39)	*	*	*	*
Summer 2003	LCS	*	*	*	*	*	*
Summer 2003	LMB	67.0 (67-67)	105.5 (91-117)	*	67.0 (60-74)	43.7 (38-53)	77.0 (50-94)
Summer 2003	LNS	*	*	*	*	45.0 (45-45)	*
Summer 2003	PIP	62.5 (36-76)	68.2 (55-92)	70.0 (63-76)	*	65.7 (31-103)	40.1 (24-65)
Summer 2003	RBS	*	100.0 (100-100)	*	71.6 (25-143)	59.9 (25-147)	*

Table A1. Continued.

Season	Species Code	Confined Channel Kiokee	TMUCK	Wolf	Wetland Mossy	Pachitla	Spring
Summer 2003	REC	39.5 (27-55)	30.9 (23-40)	*	*	35.0 (34-36)	35.3 (20-50)
Summer 2003	RES	*	*	*	*	*	*
Summer 2003	RFP	*	139.8 (113-165)	170.5 (153-188)	*	86.0 (65-107)	141.0 (140-142)
Summer 2003	SBL	*	*	*	*	103.0 (103-103)	*
Summer 2003	SFS	*	45.0 (25-57)	37.0 (35-39)	*	43.1 (27-49)	*
Summer 2003	SMT	*	*	90.0 (90-90)	*	31.0 (22-4)	*
Summer 2003	SPB	*	*	*	*	*	*
Summer 2003	SPG	*	*	*	520.0 (520-520)	*	*
Summer 2003	SPS	*	*	*	235.0 (235-235)	*	*
Summer 2003	SPT	157.0 (157-157)	*	107.6 (97-120)	39.0 (29-49)	75.0 (18-127)	*
Summer 2003	SWD	*	*	*	42.0 (42-42)	*	*
Summer 2003	TLS	*	*	*	*	36.0 (21-62)	*
Summer 2003	WAR	*	*	*	98.0 (36-189)	68.0 (26-118)	28.0 (28-28)
Summer 2003	WES	*	*	69.0 (69-69)	57.0 (54-62	54.5 (23-77)	35.8 (32-40)
Summer 2003	YBH	*	90.0 (82-101)	*	*	*	*
Winter 2004	BBD	*	*	45.0 (42-48)	*	28.0 (28-28)	*
Winter 2004	BLG	*	*	23.0 (23-23)	39.3 (27-56)	43.6 (29-104)	23.3 (20-30)
Winter 2004	BOF	*	*	*	*	*	343.0 (343-343)

Table A1. Continued.

Season	Species Code	Confined Channel Kiokee	Confined Channel TMUCK	Confined Channel Wolf	Wetland Mossy	Wetland Pachitla	Wetland Spring
Winter 2004	BPS	*	*	*	26.5 (23-43)	24.1 (22-27)	31.8 (27-39)
Winter 2004	BRD	29.0 (29-29)	*	40.0 (33-47)	*	37.2 (32-40)	41.5 (37-47)
Winter 2004	BRS	*	*	*	*	41.8 (28-63)	50.0 (50-50)
Winter 2004	BTS	*	33.0 (33-33)	*	*	*	*
Winter 2004	CCS	*	*	145.0 (145-145)	123.5 (97-173)	*	108.8 (103-114)
Winter 2004	CLC	*	*	*	*	*	*
Winter 2004	DOS	*	*	*	*	*	*
Winter 2004	FLI	*	*	*	*	*	95.0 (95-95)
Winter 2004	GAM	35.0 (22-48)	33.4 (20-51)	*	31.0 (31-31)	27.0 (27-27)	32.3 (26-38)
Winter 2004	GOS	*	*	*	*	100.0 (43-123)	27.0 (21-37)
Winter 2004	GSF	*	*	*	*	*	*
Winter 2004	LCS	*	*	*	*	*	*
Winter 2004	LMB	*	*	*	*	66.0 (66-66)	*
Winter 2004	LNS	*	*	*	*	*	*
Winter 2004	PIP	82.6 (70-95)	74.0 (53-103)	56.4 (31-86)	64.0 (64-64)	59.6 (32-94)	57.1 (38-110)
Winter 2004	RBS	83.1 (49-126)	*	77.6 (39-110)	33.3 (25-43)	55.0 (34-68)	27.0 (27-27)
Winter 2004	REC	46.9 (32-65)	50.2 (41-62)	*	*	*	41.8 (29-65)
Winter 2004	RES	*	*	*	*	*	*

Table A1. Continued.

Season	Species Code	Confined Channel Kiokee	Confined Channel TMUCK	Confined Channel Wolf	Wetland Mossy	Wetland Pachitla	Wetland Spring
Winter 2004	RFP	224.0 (224-224)	171.0 (164-178)	203.7 (188-230)	232.0 (232-232)	*	149.0 (124-174)
Winter 2004	SBL	*	*	110.0 (110-110)	*	101.5 (95-108)	*
Winter 2004	SFS	*	*	41.7 (25-55)	*	36.8 (22-50)	35.1 (24-51)
Winter 2004	SMT	*	87.0 (82-92)	71.5 (55-88)	*	42.5 (36-49)	*
Winter 2004	SPB	*	*	*	*	*	*
Winter 2004	SPG	*	*	*	*	*	*
Winter 2004	SPS	*	*	110.70 (77-134)	*	*	*
Winter 2004	SPT	79.0 (46-122)	47.0 (47-47)	102.0 (42-162)	57.0 (35-128)	89.0 (50-144)	52.7 (30-99)
Winter 2004	SWD	*	*	*	47.5 (37-56)	*	38.5 (35-41)
Winter 2004	TLS	*	*	*	*	50.1 (43-58)	*
Winter 2004	WAR	*	66.8 (59-73)	*	77.0 (45-130)	104.0 (104-104)	*
Winter 2004	WES	*	*	47.0 (38-63)	*	49.7 (18-77)	*
Winter 2004	YBH	100.8 (67-131)	78.0 (78-78)	*	*	*	*
Spring 2004	BBD	*	*	64.7 (40-87)	*	48.0 (48-48)	*
Spring 2004	BLG	*	*	*	72.3 (51-119)	46.6 (22-78)	107.0 (107-107)
Spring 2004	BOF	*	*	*	*	*	*
Spring 2004	BPS	*	*	*	19.3 (15-29)	* *	27.2 (17-35)
Spring 2004	BRD	*	*	40.0 (40-40)	49.0 (49-49)	37.8 (34-43)	42.3 (32-50)

Table A1. Continued.

Season	Species Code	Confined Channel Kiokee	TMUCK	Wolf	Wetland Mossy	Pachitla	Spring
Spring 2004	BRS	*	*	57.0 (57-57)	32.8 (12-68)	47.2 (32-62)	72.0 (72-72)
Spring 2004	BTS	*	*	*	69.0 (69-69)	54.0 (54-54)	*
Spring 2004	CCS	*	*	*	41.7 (22-94)	*	*
Spring 2004	CLC	*	*	*	67.0 (67-67)	*	*
Spring 2004	DOS	*	*	89.0 (89-89)	79.0 (67-91)	79.0 (79-79)	*
Spring 2004	FLI	*	*	*	*	*	*
Spring 2004	GAM	36.0 (23-45)	36.4 (23-50)	*	*	*	29.0 (27-31)
Spring 2004	GOS	*	*	40.7 (34-50)	97.8 (83-118)	81.7 (24-132)	*
Spring 2004	GSF	88.2 (73-103)	*	*	*	*	*
Spring 2004	LCS	*	*	*	150.0 (150-150)	*	*
Spring 2004	LMB	*	*	*	42.0 (42-42)	*	*
Spring 2004	LNS	*	*	*	*	*	*
Spring 2004	PIP	84.7 (82-87)	67.4 (53-83)	62.7 48-77	*	49.7 (19-82)	44.9 (17-88)
Spring 2004	RBS	*	*	*	29.3 (14-55)	79.3 (42-144)	*
Spring 2004	REC	45.0 (32-60)	*	*	*	*	38.7 (31-48)
Spring 2004	RES	*	*	*	*	121.0 (121-121)	*
Spring 2004	RFP	*	*	200.0 (200-200)	67.0 (67-67)	153.0 (153-153)	44.0 (44-44)
Spring 2004	SBL	*	*	104.3 (93-119)	*	119.9 (100-143)	*

Table A1. Continued.

Season	Species Code	Confined Channel: Kiokee	Confined Channel: TMUCK	Confined Channel: Wolf	Wetland: Mossy	Wetland: Pachitla	Wetland: Spring
Spring 2004	SFS	*	*	49.8 (39-60)	*	*	*
Spring 2004	SMT	*	*	51.0 (51-51)	*	35.5 (35-36)	*
Spring 2004	SPB	*	*	*	*	*	*
Spring 2004	SPG	*	*	*	*	*	*
Spring 2004	SPS	*	*	*	*	*	*
Spring 2004	SPT	70.4 (39-93)	*	78.0 (66-90)	37.8 (12-68)	89.8 (28-250)	44.0 (43-45)
Spring 2004	SWD	*	*	*	39.8 (31-44)	*	*
Spring 2004	TLS	*	*	*	*	46.0 (33-56)	*
Spring 2004	WAR	*	64.0 (55-73)	*	91.5 (47-136)	90.5 (85-96)	*
Spring 2004	WES	*	*	50.5 (48-53)	67.7 (63-71)	56.3 (37-77)	*
Spring 2004	YBH	103.0 (102-104)	76.3 (66-86)	*	*	*	*
Summer 2004	BBD	*	NS	*	*	*	*
Summer 2004	BLG	17.0 (17-17)	NS	*	33.0 (19-66)	*	23.0 (23-23)
Summer 2004	BOF	*	NS	*	*	*	*
Summer 2004	BPS	*	NS	23.5 (22-25)	21.2 (16-31)	20.0 (20-20)	27.0 (12-36)
Summer 2004	BRD	*	NS	*	*	53.0 (31-75)	46.5 (43-50)
Summer 2004	BRS	*	NS	*	28.5 (16-46)	31.4 (19-52)	62.0 (62-62)
Summer 2004	BTS	*	NS	*	*	*	*

Table A1. Continued.

Season	Species Code	Confined Channel: Kiokee	Confined Channel: TMUCK	Confined Channel: Wolf	Wetland: Mossy	Wetland: Pachitla	Wetland: Spring
Summer 2004	CCS	*	NS	*	27.0 (22-32)	*	*
Summer 2004	CLC	*	NS	*	*	*	*
Summer 2004	DOS	*	NS	87.5 (82-93)	61.0 (42-76)	85.0 (85-85)	*
Summer 2004	FLI	*	NS	*	*	*	*
Summer 2004	GAM	38.0 (26-50)	NS	21.0 (20-22)	28.3 (20-44)	30.8 (18-46)	15.0 (15-15)
Summer 2004	GOS	60.2 (54-68)	NS	*	62.0 (30-114)	37.7 (20-48)	*
Summer 2004	GSF	*	NS	*	70.0 (70-70)	*	*
Summer 2004	LCS	*	NS	172.0 (172-172)	*	*	*
Summer 2004	LMB	*	NS	170.0 (124-229)	59.7 (38-71)	*	*
Summer 2004	LNS	*	NS	*	*	34.0 (34-34)	*
Summer 2004	PIP	64.0 (50-82)	NS	66.2 (30-97)	*	38.0 (38-38)	65.9 (43-91)
Summer 2004	RBS	*	NS	90.8 (52-138)	52.5 (11-142)	89.0 (46-146)	*
Summer 2004	REC	*	NS	*	*	*	*
Summer 2004	RES	126.0 (126-126)	NS	23.0 (23-23)	81.5 (38-125)	*	*
Summer 2004	RFP	*	NS	173.4 (104-262)	*	74.0 (74-74)	*
Summer 2004	SBL	*	NS	126.0 (125-127)	*	116.0 (112-120)	*
Summer 2004	SFS	*	NS	41.3 (20-67)	*	*	*
Summer 2004	SMT	*	NS	75.0 (62-95)	*	*	26.0 (26-26)

Table A1. Continued.

Season	Species Code	Confined Channel Kiokee	TMUCK	Wolf	Wetland Mossy	Pachitla	Spring
Summer 2004	SPB	90.0 (90-90)	NS	*	*	*	*
Summer 2004	SPG	*	NS	*	*	*	*
Summer 2004	SPS	*	NS	48.00 (44-52)	*	*	*
Summer 2004	SPT	85.0 (80-90)	NS	91.6 (60-139)	47.4 (12-88)	62.0 (62-62)	*
Summer 2004	SWD	*	NS	*	*	*	*
Summer 2004	TLS	*	NS	*	35.0 (35-35)	28.3 (23-33)	29.3 (16-41)
Summer 2004	WAR	*	NS	123 (123-123)	*	54.0 (54-54)	*
Summer 2004	WES	*	NS	57.0 (51-68)	41.0 (36-44)	38.7 (26-54)	*
Summer 2004	YBH	111.0 (111-111)	NS	173.5 (147-200)	*	*	*