

VARIATION OF FISH ASSEMBLAGES AND SPECIES ABUNDANCES IN THE
UPPER FLINT RIVER SHOALS, GEORGIA

by

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(Under the Direction of Mary C. Freeman)

ABSTRACT

The Flint River, a major tributary of the Apalachicola drainage, is one of four rivers originating in the Piedmont of central Georgia. This study investigated relations between fish assemblages and habitat characteristics in shoals, one of the primary features of the upper mainstem. The study compared variation in fish assemblages and species abundances among shoals at two scales, the microhabitat and the reach. Shoals differed in terms of species assemblages, habitat composition, and species abundances. Habitat use by fishes was predicted by different variables at the microhabitat and reach scales. The predictive variables were depth, velocity, *Podostemum* coverage, bed sediment variables, and gradient. These findings should be useful for management decisions and in evaluating consequences of municipal water policy in the Flint headwaters.

INDEX WORDS: fish assemblages, Flint River, shoals, *Cyprinella callitaenia*, *Micropterus cataractae*, *Percina* sp.

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B.S. The University of Georgia, 1999

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial
Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2003

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August 2003

ACKNOWLEDGEMENTS

Thank you to the U.S. Fish and Wildlife Service and Bud Freeman for funding. Thanks to all who helped me in the field and with data entry, and to my major professor who provided unwavering support and knowledge.

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CHAPTER 1

INTRODUCTION

This study addressed the conservation status of one of the few remaining high quality, free-flowing rivers in the continental United States; the Flint River, a major tributary of the Apalachicola River drainage, is one of four rivers that originate in the Piedmont of central Georgia. It flows onto the Coastal Plain of southwest GA before it encounters the first of 3 mainstem impoundments. This approximately 322 km long undammed reach earned the Flint River national recognition as one of 42 unimpounded reaches >200km (Benke 1990).

Since before the Clean Water Act, this river has long been affected by growth of Atlanta in its headwaters. The focus of water issues, such as municipal withdrawals and discharges along with a controversial dam proposal, have shaped the history of the river. As the metropolitan Atlanta area continues to grow, off-stream water demands in the headwaters of the Flint River are increasing.

The upper Flint mainstem contains a reach of shoals, a series of shallow, swift, rocky habitats interspaced by long pools. In terms of fish assemblages and abundances of endemic species, the effects of urbanization from the Atlanta area have not reached the shoals of the upper Flint River. The focus of my study examined among shoal differences of fish assemblages and species abundances. This is the first attempt within

the past 17 years to investigate the fishes of the Flint River shoals. Specifically I investigated fish assemblages of the shoals and habitat associations of fishes endemic to this drainage at the microhabitat and reach scales.

Chapter 2 reviews the recent history of the Flint River, beginning with the launch of human development. It then introduces shoals as biologically diverse and ecologically significant riverine habitats. I also introduce prevalent conservation issues for the upper Flint River. Chapter 3 reports an investigation of relations between fishes and habitat characteristics of the shoals reach. The study asks what habitat characteristics, at the microhabitat and the reach scales, influence fish assemblages and species abundances. In the final Chapter, I summarize the major findings of this work and discuss and compare what variables best predict species presence at the microhabitat and reach scales. I also discuss the management implications of this information.

CHAPTER 2
STATUS AND CONSERVATION ISSUES OF AN UNDAMMED
PIEDMONT RIVER

“The lore of the South could not survive without rivers any better than the human body could survive without blood... Yet it is the South, more than any region except California, that has become a landscape of reservoirs, and southerners, more than anyone else, are still at the grand old work of destroying their rivers.”
-- Mark Reisner, 1986, Cadillac Desert

Containing approximately 322 out of 565 kilometers of undammed water, the Flint River mainstem is one of the longest free-flowing rivers in Georgia. It is also one of 42 relatively undegraded rivers in the United States with greater than 200 km of unimpeded flow (Benke 1990). These facts along with many other aspects make the Flint an ecologically significant river in Georgia. I will first present an historical overview to describe how the Flint River has come to its present condition. One of the consequences of the Flint River having escaped large-scale impoundment is the retention of river shoal habitat, which I will also describe. Finally I will compare water quality in the river before and after implementation of the Clean Water Act.

Setting and Early History

The headwaters of the Flint River emerge from a concrete culvert just north of the Hartsfield International Airport in Atlanta and then flow under several runways and through six industrial parks. In an essay from the Flint River Recreational Guidebook (2001), Eugene Methvin, a Georgia native, describes the Flint as a “greasy, sticky, industrial sludge” as it leaves Atlanta. As the waters flow through Clayton and Fayette counties, they pass through a series of swamps (Georgia Water Quality Control Board 1972). Approximately 87 km from its headwaters, in Pike and Upson counties, the sludge begins to resemble a river and then flows down the Piedmont region, crosses the fall line, and continues down the coastal plain. The watershed encompasses 21,902 square km (Frick 1996). Five hundred sixty-five km from its birth, the Flint joins the Chattahoochee River at Lake Seminole. Together these rivers form the Apalachicola River, which drains a combined 51,262 square km into the Gulf of Mexico (Marella 1993).

The first humans came to the Flint in the Paleo Period, 10,000 B.C. to 8000 B.C. During the Woodland Period, 1000 B.C. to A.D. 900, Native Americans left the traveling life and turned to hunting, farming, and pottery. According to Brown and Smith (2001), a few Native American burial mounds can still be found along the riverbanks. The Mississippian Period, A.D. 900 to mid 1500’s, found the Native Americans building large villages and using the fertile floodplains as cropland. The Muskogee Nation (Creeks) was the dominant tribe in the 18th century, until European settlers obliterated them during the 1813- 1814 Creek War. Other tribes inhabiting the Flint River valley included the Choctaw, Chickasaw, and Seminole (Brown and Smith 2001).

Spain claimed the Flint region after Ponce de Leon landed in Florida in 1513. Hernando De Soto arrived shortly after and crossed the Flint in 1540. Control over the territory passed to the English in the early 1700's (Brown and Smith 2001). When William Bartram came upon the Flint in 1776, the area was still relatively pristine and inhabited mainly by Native Americans (Van Doren 1928). In 1820 the frontier line moved to the Flint River when the land was bought from the Creek Indians for \$400,000 (~six million acres at 6.7 cents/acre) (GADNR 1976). Land lotteries in 1820, 1821, and 1827 spread colonization to these parts, and farming and mills became prominent.

Farming and agriculture were the dominant land uses from the mid- 1800s to the 1900's. The 1820's were a time of industrialization on the Flint River, and many mills were constructed in order to process the cotton that was already being grown in that region (GADNR 1976). The coming of the Civil War saw a shift of mill production to military textile, but when the war ended commerce came to a halt. There was a small upstart of the economy in the 1870s, but by 1900 the cotton industry was lifeless (GADNR 1976). Agriculture and the timber industry became the predominate commerce throughout the 1900's.

Large Dams on the Flint

Three major impoundments occur on the Flint, all of which are located on the lower 242 km. Two are regulated for electricity production, Lake Blackshear and Lake Worth. Lake Worth, a 1400-acre lake constructed in 1919, inundates 13 km of the Flint River mainstem, and Lake Blackshear inundates 37 km. Lake Blackshear was built in the early 1900s and was reconstructed after the flood of 1994. The third, Lake Seminole, is a 37,500acre multi-use unit constructed by the Army Corps of Engineers (GWQCB 1972).

Lake Seminole inundates 55 km of Flint River and the junction with the Chattahoochee River. All of these impoundments lie in the Coastal Plain, leaving the Piedmont portion of the Flint River unimpounded.

In the early 1950's, the U. S. Army Corps of Engineers began investigating a dam site at Sprewell Bluff, in the upper reaches of the Flint. The Corps cited hydroelectric power, recreation, and flood control as the expected benefits. They campaigned the dam to Congress, and the project was sanctioned in 1963. In 1970 the Georgia Natural Areas Council listed the Flint River as number one in order of scenic value in the Scenic Rivers Report (GADNR 1976). Members of the council immediately began to petition Governor Jimmy Carter to suspend the Sprewell Bluff Dam. The overwhelming number of river supporters spurred Carter to request that surveys be conducted on the Flint River in 1972, and he requested that the Army Corps send him their own reports (Brown and Smith 2001). Upon finding many discrepancies, a major failing being that the Corps neglected to analyze any alternatives to the dam, Carter called for a Congressional investigation of the Corps' cost/benefit analysis. According to Carter the results showed that the Corps "grossly misrepresented both benefits and costs" and that "it did not look for least-cost, just dam solutions" (Brown and Smith 2001). He also found that when the Army Corps was questioned about the economic benefits they tripled "the alleged benefits with no substantiating data to back [it] up" (Brown and Smith 2001). After much political debate Governor Carter called a press conference on October 1, 1974 and announced his decision to veto the dam. This experience with the proposed Sprewell Bluff Dam later went on to influence Carter's water reform policy after being elected president of the United States in 1976 (Reisner 1986).

Flint River Shoals

The Sprewell Bluff dam would have nearly bisected the shoals reach of the Flint River mainstem. Wharton (1978) describes a Piedmont shoal as “shallow, oxygenated water,” and shoals as “swift, rocky areas” that are “abundant with life.” The complex shoal bed sediment consist of bedrock ledges and boulders, gravel and cobble interspersed with sand. Habitats within a shoal encompass shallow and deep pools, fast chutes, shallow runs, and riffles. These stretches of river also host the riverweed *Podostemum ceratophyllum*, an angiosperm that attaches to hard substrates, and beds of waterwillow, *Justicia* sp. Shoal habitat was once a common feature of rivers across the southeastern United States, but the combined effects of channelizing and damming have left most shoals buried under sediment and reservoirs. Within the free-flowing, upper 322 km of the Flint is a stretch of river from Gay- Flat Shoals Road to Highway 19 that contains a series of shoals (figure 1). Each shoal ranges from approximately 25 to 500 meters in length, and the river width ranges from approximately 80 to 250 meters with intermittent islands.

Flat Shoals, which is the first in the series, is located approximately 284 km from the headwaters. This shoal has been used as a river crossing since Native Americans incorporated it into their Upper Creek Trading Route. The following description is from Brown and Smith (2001). From there the river flows down through the Pine Mountain range. Pine Mountain is approximately 250 million years old and once reached a peak of about 914 meters. Now the mountains stand between 274 and 427 meters. This unique range creates a hotspot of biodiversity. This small, isolated mountain range contains a mixture of Appalachian and Piedmont flora and fauna such as Carolina Rhododendron

(*Rhododendron minus* Michaux), Mountain Laurel (*Kalmia latifolia*), Spanish moss (*Tillandsia usneoides* L.), and Tupelos (*Nyssa sylvatica*), and the Eastern Coral Snake (*Micrurus fulvius fulvius*). Dripping Rocks and Thunder Springs are located in the lower section of the Pine Mountain region. At Dripping Rocks the river drops 3 meters in less than a mile and the bluffs rise up more than 355 m on both sides of the Flint. Confederate soldiers used the Thunder Springs area as a campground during the Civil War. In 1938 the Boy Scouts of America (BSA) acquired the land and turned it into two camps totaling 2200 acres. The BSA dammed Thunder Springs in 1950 to form Lake In-
To for recreational purposes. Sprewell Bluff Park, a 1,372-acre state park, marks the lower boundary of the Pine Mountain range. This area was the site of the controversial proposed dam and became a state park in 1994. Downstream from the Highway 36 crossing, the Flint River meets the Fall Line at Yellow Jacket Shoals. Here the river drops about 12 m in 1.6 km and offers Class III and IV rapids to boaters. Besides Sprewell Bluff State Park, this portion of the river corridor also hosts several other protected areas. The Joe Kurz Wildlife Management Area above Flat Shoals contains 3,691 acres, and the Big Lazar Creek WMA consists of 5,864 acres located below Yellow Jacket Shoals.

The Flint River shoals house a variety of rare and protected species. The Shoal Lily, (*Hymenocallis coronaria*), is found on a few select shoals and is listed by the state of Georgia as endangered. There are also four species of fishes, the undescribed halloween darter, *Percina* sp., the shoal bass, *Micropterus cataractae*, the bluestripe shiner, *Cyprinella callitaenia* (state threatened), and the undescribed greyfin redhorse, *Moxostoma* sp cf. *M. poecilurum* that are endemic to the Apalachicola drainage system.

At least two of these fishes are reported primarily from shoal habitats. *M. cataractae* inhabits the shoals or swift waters of the mainstem Flint River and some larger tributaries (Williams and Burgess, 1999). Hill (1996) found that *Percina* sp. is “restricted to high velocity habitats with substantial cover” and that they feed on insects that are found only in fast water. *Percina* sp. currently has three strong populations remaining. The shoals reach of the Flint River supports one of three known population centers of this undescribed darter along with the Chattahoochee River above Lake Lanier and the Flint River mainstem below Ichawaynochaway Creek (in limestone shoals; Freeman, unpublished data). Finally, at least 25 mussel species historically occurred in the upper Flint River, but currently, only 20 species were found (Brim Box and Williams (2000).

Water Quality in the Flint River

Although the Flint River has maintained physical habitat integrity in much of the upper system, urban development in the headwaters has caused water quality deterioration. The Georgia Water Quality Control Board conducted water quality studies in 1967, 1971 (Atlanta/Griffin region), and in 1972 (entire Flint Basin). The 1971 study assessed the health of the Flint River and its tributaries from the headwaters originating above the Atlanta airport to Georgia Highway 16, west of Griffin and 78 km from the headwaters. In both 1971 and 1972 the Board found that the system was severely degraded and contained high levels of fecal coliform and low levels of dissolved oxygen. The Georgia Highway 54 (16 km from the headwaters) vicinity was noted to be the most degraded reach of the river with average dissolved oxygen content of 0.7 mg/l in 1971. High fecal coliform levels (e.g. Pigeon Cr., confluence with Flint mainstem at river mile 269, contained 430,000 mpn/100 ml) were reported in the 1972 study. No benthic

invertebrates or fish were found in this region. Recovery of the benthic community was noted at Georgia Highway 16, but chemical analysis rated the system healthy-enriched (i.e. was relatively healthy but contained some indication of nutrient enrichment or biotic alteration). Overall, the 1971 Board found water quality to be “inferior to that existing in 1967.” Degradation was thought to be a result of increased organic inputs from waste discharges and surface water runoffs. The Board also noted that the “waste assimilative capacity of the swamps upstream from Georgia Highway 92 had been reached and exceeded” (Georgia Water Quality Control Board, 1971).

In 1972 the Board assessed the health of the entire Flint River Basin and found that complete recovery in chemistry, fauna, and flora began at Flat Shoals (102.6 km from headwaters). Owens Island (141 km from headwaters) was found to have “an extraordinarily varied and balanced benthic community” (GWQCB, 1972). Both sites were said to have “a fragile and highly complicated aquatic community” (GWQCB, 1972). Water quality was determined to be good in the Thomaston region (155 km from headwaters) even though the impact of eroded soils was noted in the faunal composition. Though the Flint was found to be healthy, according to the Board, many of its tributaries were moderately polluted (Camp Creek, Shoal Creek, Elkins Creek, Tarver Branch), polluted (Pigeon Creek and Town Bell Creek), and grossly polluted (Swift Creek).

The combined headwater and shoals reach of the Flint was found to have high concentrations and yields of dissolved nitrate, total phosphorus, total inorganic nitrogen, and dissolved ammonia during the 1972-90 period (Frick et al., 1996). Using at least eight years of quarterly nutrient data from 1980 to 1990, the U.S. Geological Survey found significant decreasing trends in dissolved ammonia, dissolved nitrate, and total

phosphorous for the headwaters and shoal reaches of the Flint (Frick et al., 1996). In contrast they found that trends of the same nutrients were increasing for the Chattahoochee River. Frick et al. cited the diversions of municipal-wastewater effluent from the Flint to the Chattahoochee and South Rivers (in the early- to mid- 1980s), improved wastewater treatment, and legislation aimed at reducing non-point source phosphorus as the causes of the decreasing trends. In 1994, the same stretch of the Flint was found to have nutrient concentrations an order of magnitude less than those in during 1972-90 years (Frick et al., 1996).

Since the adoption of the Clean Water Act in 1977 there has been a marked improvement of water quality in the upper sections of the Flint River. Improvements to wastewater treatment facilities and new legislation have lowered the concentrations of nutrients typical to degraded streams. Despite improvements, water quality problems remain in the upper Flint River. The Georgia Department of Natural Resources (DNR) conducted a 1998-1999 water quality analysis. They found that 8 km of the Flint River headwaters, 29 km of headwater tributaries, 69 km of Flint shoals, and 84 km of shoal tributaries were only partially supporting (some but not all samples are in violation) their designated use of fishing. Violations included fecal coliform (containing >200 MPN/100ml), biotic (studies showed a change in the biotic communities, based on fish), and fish consumption guidelines (excessive mercury levels in fish tissue). Elkins Creek, which was on the 1972 moderately polluted list for high levels of organic materials and altered faunae, was in violation of fecal coliform levels in 1998-99. Potato Creek was found to be healthy in 1972, but had since degraded to a biologically impaired stream. Seventy-nine km of Flint River headwaters, 35 km of headwater tributaries, and 34 km of

shoal tributaries were not supporting (all samples in violation) their designated uses. All segments were designated fishing, with one designated drinking/fishing, and the violations ranged from fecal coliform (the most prevalent), dissolved oxygen, fish consumption guidelines (mercury), to some metals (copper, lead, zinc). The two most common causes of degradation for both the partially supporting and not supporting lists were urban runoff and non-point sources (GADNR, 1999).

Conservation Issues

With the metropolitan Atlanta area now encompassing 27 counties and still growing, water quality and its effects on stream biota should be of concern for the upper Flint River. Increasing pressures from off-stream water demands and pollution could have profound effects on the shoal communities. Presently at least 114 mgd are permitted for municipal withdrawal from the Flint River system upstream of the shoals reach (taken from GA EPD records). Large withdrawals have the capacity to alter instream habitat conditions, especially the shallow, swift areas characteristic of the shoals. Encroaching pollution inputs near the Flint River headwaters (e.g. from non-point sources associated with urbanization) may also degrade the biological integrity downstream. The effects of contaminants may be exacerbated by lower stream flows.

Conserving the unique biological elements of the upper Flint, such as the endemic fishes, will require information on the current biological conditions, habitats critical to sustaining those biota, and how those habitats may be affected by future management decisions. The purpose of my study was to provide information on habitat relations of endemic and common fishes of the system in order to understand the consequences of water policy throughout the upper Flint.

CHAPTER 3
VARIATION IN FISH ASSEMBLAGES AND SPECIES ABUNDANCES IN
THE SHOALS OF THE FLINT RIVER, GEORGIA.

Introduction

Conserving species requires knowledge of habitat requirements in order to protect the areas that will most benefit species survival. Essential freshwater habitats vary widely according to species; for example, species may require flowing water (as opposed to impoundments), particular thermal regimes, particular channel features (deep pools, rocky substrates), or passage to the ocean. Understanding habitats needed by particular species or aquatic communities thus requires identifying the scale that is influencing habitat availability. Stream biologists currently identify requirements on the microhabitat level (velocity, substrate, depth) (Mattingly and Galat 2002, Freeman and Freeman 1994) and by fluvial hydraulic channel units (Rabeni and Jacobson, 1993). Recently a direct correlation has been made between species abundance and stream gradient, a reach scale variable (Walters 2002). There is also a link between drainage basin characteristics and instream habitat variables (Lanka et al. 1987). Another relatively new idea in stream ecology is the Process Domain Concept (Montgomery 1999). This concept states that spatial variability in geomorphic processes influence stream habitat and disturbance regimes that in turn structure the ecosystem community. Testing hypotheses between

geomorphic features and characteristics of stream biota could improve our ability to predict species richness and abundance in the Piedmont shoals.

I tested the relevance of geomorphic features versus microhabitat availability to fish assemblages in shoal habitats of a southeastern U.S. river. Shoals, shallow, rocky habitats, are characteristically productive and biologically diverse. In my study system, the Flint River, GA, at least three endemic fishes are presently associated with the shoal habitats. I am interested in the extent of faunal variation among the shoals and the relations between faunal composition and physical characteristics of the shoals. Specifically, I will be addressing three questions concerning the upper Flint River shoals: (1) What physical features and fish assemblages are characteristic of the shoals? (2) What microhabitats (velocity, depth, substrate) are used by the most common fish species? (3) How well do reach characteristics (slope, size, and habitat heterogeneity) predict abundance of the most common species? I will thus compare habitat characteristics at two different scales (microhabitat and reach) and each scale's usefulness in predicting species presence and abundance.

Methods

Field Procedures

I surveyed the shoals along the upper Flint River from Gay-Flat Shoals Road to Pobiddy Road, spanning 50 km, during summer of 2001 (Figure 1). At this time, the locations of each shoal and their approximate lengths were recorded. In order to obtain lengths, a handheld GPS unit was used to record the upstream and downstream boundaries of large shoals (> 100 m) and small shoals (< 100 m) were measured with a tape measure. River miles for shoals (i.e. distance upstream from the mouth of the Flint

River) were obtained from the U.S. Army Corp of Engineers (1985) or were approximated using GIS. Preliminary fish and habitat data were obtained during July and August of 2001. Four sites were chosen based on accessibility, and fishes were quantitatively sampled using the methodology described below for 2002 sampling. To collect data on fish species richness of the Flint River shoals reach, qualitative sampling was also conducted at this time. A four person crew used a Smith Root backpack electroshocker and seine to sample all wadeable habitat types at nine sites selected from the shoals reach (Figure 2). All captured fishes were identified and counted.

Sampling in 2002 was conducted in order to obtain quantitative data relating fish abundances to habitat characteristics. The shoals identified in 2001 were categorized by both size (< 100 m and > 100 m) and location within the reach (upper or lower). Sixteen sites were randomly chosen, eight from the upper half and eight from the lower (four large and four small from each region; Figure 3). Three of the 2001 quantitative sites were randomly selected for sampling in 2002. Fieldwork was conducted during July and August using a field crew of six to eight. Fishes and habitat were sampled at 30-70 randomly selected coordinates across each shoal. Each random coordinate represented a percent width and percent length of the shoal. For extremely wide shoals (> 200 m) sampling occurred on half (divided lengthwise) of the shoal. Each sample, or kickset, was approximately 1.5 m x 2.0 m in area and was sampled using a backpack electroshocker and seine. Captured fish were either measured and released or euthanized in MS222 and preserved in 10 % Formalin for lab identification. Fish data (identification and total lengths) were recorded separately for each kickset, and kept fish were stored with a kickset identification tag in separate jars. Habitat measurements were also taken

separately at each kickset. Habitat parameters were depth, velocity, percent vegetation (visual estimation), and dominant particle size (dps; phi scale). Depth was measured to the nearest 1.5 cm with a top-setting wading rod, velocity with a Marsh- McBirney Flo-Mate at 60 % depth, and particle size was measured to the nearest mm with a ruler.

Gradient at each shoal was obtained by using either an electronic total station or Top con autolevel. To measure gradient, I recorded the difference in water surface elevation from the top of the shoal to the downstream end of the shoal. Gradient was measured over the length of the sample reach, which equaled the entire shoal, for all but three shoals. For these shoals, the gradient was measured over the entire length of the shoal, which was longer than the sample reach. Preserved fish were taken back to the laboratory and kept on 10 % formalin for no less than one week. They were then transferred to 35 % ethanol for no less than one week and put on 70 % ethanol for final storage. After transfer to ethanol, the fish were identified using taxonomic keys and measured for total length. Voucher specimens were annexed into the Georgia Museum of Natural History collection.

Data analysis

Analyses were used to address three questions. I first examined variation in physical characteristics and asked if it was related to fish assemblage variation among shoals. Secondly, I used data for individual kicksets to describe microhabitat use by the target species and to ask what variables best predict occurrence of each species. Finally, I asked what shoal level habitat characteristics were most strongly associated with abundances of target species. I also compared my fish collections with the previous

studies of Flint River fishes by Ellis and Clark (1986) and Martin (1973) by examining abundance trends and species collected in the different years.

In order to describe differences between shoals, the means and standard deviations of depth, phi, velocity, and the % vegetation (*Podostemum ceratophyllum*) were computed from the data collected at each kickset. Bedrock and sand were assigned phi values of -10.5 and 2, respectively. Dominant particle size data for each kickset were used to compute the proportion of all samples in a shoal dominated by sand, gravel, cobble, boulder, and bedrock. The numbers of fish per kickset were used to calculate the catch per unit effort of each species at every shoal. Size frequencies were plotted for the three target species using length data combined for all shoals. These plots were then used to identify lengths corresponding to young of the year (YOY/Age 0), and older fish (Age 1+).

I analyzed among shoal differences in species composition using nonmetric multidimensional scaling (NMS). Ordination was performed with PCORD Ver. 4 (McCune and Grace 2002). The numbers of fish per kickset (all species, all shoals) were root-root transformed and used to rank the shoals based on their dissimilarities using the Bray-Curtis distance measure. The ordination procedure used random starting configurations and 20 runs with the real data to find a stable solution (McCune and Grace 2002). Shoals were placed into multidimensional 'species' space. Correlations between fish species abundances, habitat variables, and NMS axes were then overlaid onto the ordination to examine correspondence with among - shoal relationships.

To obtain information about microhabitats for each of the six species, saturated predictability models were created using logistic regression in SAS Ver. 9.0. Data from

all kicksets at all shoals were used to model the probability of occurrence of all fishes found commonly across all shoals (average CPUE ≥ 0.2 , present at ≥ 14 shoals). I modeled young of the year (YOY) and adult of *C. callitaenia* and *Percina* sp. separately to investigate ontogenetic differences in habitat associations. Depth, velocity, five dominant particle size class variables (bedrock, boulder, cobble, gravel, sand), and *Podostemum* coverage were used as predictor variables in logistic regression models. *Podostemum* coverage was coded as “1” if $> 50\%$ cover and “0” otherwise. Correlation coefficients and tolerance of the four habitat variables were calculated to test for multicollinearity. A Shoal ID class variable was created as a dummy variable to account for non-measured differences among shoals. I used “generalized estimating equations” to account for clustering by using the repeated option (on Shoal ID) in PROC Genmod (Allison 1991). Odds ratios were calculated for the effects of habitat variables on the likelihood of the presence of a species at a kickset.

Each variable used for describing shoal-species interactions was tested for normality using a Kolmogorov-Smirnov or Shapiro-Wilk test and transformed if necessary. Gradient, shoal size, river mile, and CPUE of fishes were log transformed ($\ln x + 1$), and proportion of dominant particle sizes were arcsine transformed (arcsine (square root x)). Variables were plotted against one another to examine for nonlinear relationships. Pearson or Spearman correlation coefficients were computed using SAS Ver. 9.0. Variables were examined for multicollinearity using Pearson's r (< 0.6) and tolerance (> 0.4) computed by PROC Reg (Allison 1991). A group of eight uncorrelated variables were chosen to represent shoal habitat conditions: percent of kicksets containing $> 50\%$ coverage by *Podostemum*, shoal size, average shoal velocity, shoal

gradient, standard deviation of phi, and proportions of kicksets dominated by cobble, boulder, bedrock. Relations between shoal characteristics and abundances of the target species were described using forward stepwise multiple regression.

Results

Physical and fish assemblage variation among shoals

I located and measured 30 individual shoals within the 50 km sample reach from Gay-Flat Shoals Rd. to Pobiddy Rd. Shoals of the upper Flint River differed in terms of physical characteristics (Table 1). The 30 measured shoals ranged in lengths from 50 – 553 m, and gradient varied from 0.11% to 1.4 %. Dominant bed sediment at the 16 shoals where fish were sampled in 2002 ranged from 100 % of kicksets having bedrock to 50% - 75 % of kicksets dominated by cobble and gravel, respectively. Percent of kicksets containing ≥ 50 % coverage by *Podostemum* ranged from 0 % to 58 %. The modal habitat across all shoals was 63 % run, velocity of 0.31 m/s, and a depth of 0.34 m/s (table 4).

Number of species collected at each shoal ranged from seven to 18 (2001 and 2002 combined, Appendix A). There was a total of 34 species collected throughout the shoals reach. The most abundant species across the entire shoals reach were *Cyprinella callitaenia*, *Cyprinella venusta*, *Noturus leptacanthus*, *Micropterus cataractae*, *Lepomis auritus*, *Percina nigrofasciata* and *Percina* sp. These seven species made up 96 % of the total catch of the 16 shoals in 2002. Of this total catch, *Percina* sp. alone made up 46 %.

Five of these species (excepting *L. auritus* and *N. leptacanthus*) had average CPUEs ≥ 0.2 , occurred at ≥ 14 shoals, and were selected for modeling relations to

habitat. I also included the benthic insectivore *Noturus leptacanthus* in the analyses for comparison with the darters. There were higher numbers of species found during the 2001 qualitative sampling than the 2002 kickset sampling. Of the three shoals that were sampled in both 2001 and 2002, more species, but not necessarily the same species were found at two of the 2001 sites.

Shoals differed in fish assemblages and abundances of the most common species. *C. callitaenia* increased in abundance in the downstream direction, and *C. venusta* was most abundant at the 5th most downstream shoal (Figure 4). The highest abundance of *N. leptacanthus* was in the middle of the shoals reach. *M. cataractae*, though present at all but two shoals, was nearly 10 times more abundant in kickset samples at Flat Shoals than any other shoal with a CPUE of 1.3 (all other shoals ≤ 0.12). Only 15 % of *M. cataractae* collected were adults (T.L. > 85 mm). *P. nigrofasciata* was most abundant at the 2nd – 4th most upstream sites (FS2, FS4, and FS5), and *Percina* sp. was most abundant in the shoals near the middle of the sample reach (Figure 4).

Ordination from the NMS procedure also showed that species composition differed among the shoals. NMS arranged the sites into a two-dimensional solution in which the axes represented 90% of the variation in the dissimilarity matrix (figure 5A). I examined fish and habitat variables having correlations with the ordination axes of $r > 0.6$ and $r > 0.4$, respectively. Several species-shoal relationships were present (Figure 5B). For example, *Percina nigrofasciata* and *Percina* sp., varied in opposite directions on Axis 1, (i.e. shoals to the right of Axis 1, had more *Percina* sp.) *N. leptacanthus* varied with *Percina* sp. along Axis 1. Moving toward the bottom of Axis 2, shoals had a higher number of species (e.g. shoal FS at bottom of the plot with 17 species vs. shoal FS4 at the

middle left edge of the plot with few species and no *Percina* sp.). Few of the habitat variables were strongly correlated with the ordination axes (Figure 5C). The strongest correlations were with vegetation, river mile, and depth along Axis 1. *Percina* sp. correlated with increasing vegetation, while *P. nigrofasciata* correlated with increasing depths (Table 2).

Comparison with previous studies

Ellis and Clarke (1986) sampled six flat-water (i.e. pools between the shoals) stations and six shoal stations with a boat shocker and hand anodes during June of 1984. They recorded 15 species from the flat-water stations and 27 species from the shoals, 31 species overall. In the shoals, they collected three species that I did not, and I collected seven species that they did not (Table 3). Ellis and Clark found *C. callitaenia* and *C. venusta* to be absent from the flat-water sections and their abundances to be negatively associated with river mile, (i.e. moving upstream; $p < 0.05$). *N. leptacanthus* and *Percina* sp. were also absent from the flat-water sections. They found *M. cataractae* to be more abundant than *M. salmoides*, and *M. cataractae* and *Lepomis auritus* to be the dominant centrarchids in the shoals. Martin (1973) used rotenone and a boat shocker to sample sites across the entire Flint River drainage. Four of his mainstem sites fell within my shoals reach, and he had several other tributary sites in the upper Flint system. In these four sites he collected five species that I did not collect, and I collected 13 species that he did not collect (Table 3). Of the 13 species that Martin did not collect in the shoals, 11 of them he collected elsewhere in the upper Flint River. Martin collected *C. callitaenia*, *C. venusta*, *M. cataractae* from all four mainstem shoal sites, and *N. leptacanthus* from three. He collected *C. callitaenia* from three tributary sites, *C. venusta* from 10, and *N.*

leptacanthus from eight; and *M. cataractae* was widespread in the rest of the Flint River drainage. Martin reported *Ambloplites rupestris*, while I collected *Ambloplites ariommus*. When Martin sampled, *ariommus* was a subspecies, subsequently elevated to species status. For both the 1986 and 1973 studies, *P. nigrofasciata* specimens were re-identified as either *Percina* sp. or *P. nigrofasciata* from the collections stored at Auburn University, Auburn, AL, and (M.C. Freeman, personal communication). Both species were present in the collections. *P. nigrofasciata* occurred in a variety of habitats (e.g. shoals and flat-water); *Percina* sp. occurred exclusively in shoal samples.

Microhabitat associations of the target species

Modal microhabitat use was described using data for all kicksets containing the target species, combined for all shoals. All fishes modally occupied runs. *Noturus leptacanthus* and *Percina* sp. modally occupied faster, shallower water with higher coverage by *Podostemum* than the other four species. *C. venusta* and *P. nigrofasciata* occupied areas of lower percent coverage by *Podostemum* than the other four fishes. All fishes were found in areas of cobble and bedrock > 60 % of the time and rarely occupied areas of sand or boulder (Table 4).

Logistic regression identified different microhabitat variables associated with occurrence of fishes in the Flint River shoals. None of the variables used were significant in predicting the presence of *C. callitaenia* adults and young of the year (YOY) combined, *C. callitaenia* adults alone, or *C. venusta*. The presence of YOY *C. callitaenia* could be significantly related to velocity and depth, with decreasing depths and velocities making the presence of *C. callitaenia* more likely (Table 5). The presence of *N. leptacanthus* was positively affected by velocity and *Podostemum* coverage and

negatively affected by depth. The presence of boulder and cobble increased the chances of finding *M. cataractae* compared to samples dominated by sand. Decreasing depths and *Podostemum* coverage increased the likelihood of finding *P. nigrofasciata* at a kickset. Similar to *N. leptacanthus*, velocity, depth, and *Podostemum* coverage were significant in predicting the presence of *Percina* sp. YOY, adults, and YOY/adults combined. The likelihood of finding *Percina* sp. individuals increased with increasing velocity and *Podostemum* coverage and decreased with increasing depths (table 5).

Shoal effects on fish abundances

Results from correlation analysis show that several habitat variables are related to each other and also to the CPUE of the fishes. Proportions of cobble and boulder decreased with river mile (moving upstream). Average depth was negatively correlated with shoal size and gradient. Vegetation decreased with the standard deviation of depth and increased with gradient. Many of the substrate variables were also intercorrelated (Table 6).

Table 7 summarizes correlations among fishes and habitat variables. *C. callitaenia* was negatively correlated with river mile and positively correlated with proportion cobble. *C. venusta* was negatively correlated with shoal size and bedrock, but it was positively correlated with average depth. *N. leptacanthus* was negatively correlated with bedrock and river mile and positively correlated with boulder. *P. nigrofasciata* was positively correlated with river mile and average phi and negatively correlated to vegetation and cobble. *Percina* sp. was found to be positively correlated with gradient, vegetation, and shoal size and negatively correlated with the standard deviation of depth and river mile (Table 7). *Percina* sp. was intercorrelated with *C.*

venusta ($r = -0.51$, $p = 0.04$), *N. leptacanthus* ($r = 0.63$, $p = 0.01$), and *P. nigrofasciata* ($r = -0.54$, $p = 0.03$).

The eight habitat variables chosen from the correlation analyses were regressed with CPUE of *C. callitaenia*, *C. venusta*, *N. leptacanthus*, *P. nigrofasciata*, and *Percina* sp. Catch per unit effort of the six fishes were dependent variables, and habitat variables were independent. Due higher abundances at shoal FS than any other shoal, regression was not run with *M. cataractae*. The p-value had to be greater than 0.1 for a variable to enter the model. Of the five species for which multiple regression was run, strong models (adjusted $r^2 > 0.5$) were formed for two. For CPUE *P. nigrofasciata*, 66 % of the variance was explained by vegetation, proportion cobble, and proportion bedrock. For *Percina* sp., 75 % of the variance in CPUE was explained using three variables, *Podostemum* coverage, proportion bedrock, and shoal gradient. Abundance of *Percina* sp. increased with gradient and vegetation and decreased with proportion bedrock. The models for the other three fish explained less than 40 % of the variance of CPUE of each species (Table 8).

Discussion

Shoals of the upper Flint River exhibit substantial variation in terms of fishes and habitat characteristics. Fish assemblages vary from shoal to shoal, with some having more species and others having higher abundances of particular species. These differences can be explained in part by physical differences among the shoals. Specifically, the target species varied differently in abundances among shoals and were most affected by different microhabitat and reach scale variables. Recent studies have shown relations between presence of fish species and habitat variables at various scales

(i.e. stream, reach, microhabitat). For example Mattingly and Galat (2002) describe the distribution of a darter at three different spatial scales, and Freeman and Freeman (1994) describe the importance of microhabitat for an endangered darter. The two scales at which I analyzed fish and habitat characteristics provided different information about the shoals reach. The microhabitat scale gave a specific description of the variables that best described habitat use by the fishes. Reach scale variables described a broader view of what is happening in the shoals reach. At both scales, the differences in how the three endemic fishes, *Cyprinella callitaenia*, *Micropterus cataractae*, and *Percina* sp., vary in relation to habitat have implications for management strategies.

Cyprinella callitaenia

Little is known concerning the habitat preferences of *Cyprinella callitaenia*. In the original species description, it was stated that *C. callitaenia* does not appear to occur over a “soft, organic bottom,” (Bailey Gibbs 1956), which is supported by our correlations between CPUE and proportion cobble. My findings indicate that, in the shoals, adults tend to be generalists, as evidenced by a lack of effect of depth, velocity, bed sediments, or vegetation on the probability of adult occurrence in a kickset. In contrast, YOY occupied slower, shallower water. Aadland (1993) found that age 0 shiners of many species are common in these shallow pool type habitats.

The downstream trend in increasing abundances of *C. callitaenia* in the Flint River suggests that there could be other habitat variables that I did not measure affecting abundances. Sampling flat water sections (i.e., pools between the shoals) would allow us to test whether *C. callitaenia* only occupies shoal habitats, and if not, whether the downstream increase in abundance seen in shoal habitats also occurs in pools. Ellis and

Clark's (1986) negative correlation between abundances of *C. callitaenia* and *C. venusta* with river mile lead me to believe that this downstream trend is not a result of sampling efficiency. Absence in their flat-water sections could mean that the shiner may rely on the shoals for habitat.

Micropterus cataractae

The high abundance of *M. cataractae* YOY verses adults in the Flint River samples suggests that shoals may be important rearing habitat. Wright (1967) observed that *M. cataractae* tend to nest in shoals, and Hurst (1969) observed shoal bass nesting at the end of a long pool in eight inches of water with the eggs adhering to small pebbles and rocks. Adult shoal bass have been observed in pools upstream and downstream of shoal habitat (Wheeler and Allen 2003, Freeman and Marcinek, personal observations). A large pool upstream of Flat Shoals may contain good habitat for adults and therefore could be one reason for high YOY abundances at Flat Shoals.

Ellis and Clark (1986) found *M. cataractae* to be significantly ($p < 0.05$) more abundant in shoals than flat-water; as compared to *M. salmoides*, YOY and adult *M. cataractae* in the Chipola River, Florida were found in significantly high proportions in the shoals, particularly in areas of boulder and cobble (Wheeler and Allen 2003). This corresponds to our findings of the increasing probability of detecting *M. cataractae* around areas of boulder and cobble.

Because the abundance of benthic macroinvertebrates is positively correlated to *Podostemum* (Grubaugh et. al, 1995), food preferences could explain why the YOY were found in areas of high *Podostemum* coverage in almost half (48%) of the Flint River samples. In other studies, it has been found that the primary food of YOY *M. cataractae*

is insects (Hurst 1969, Williams and Burgess 1999 and Wheeler and Allen 2003). *M. cataractae* was found to be 10 times more abundant at Flat Shoals (the uppermost shoal) than at any other site. It could be that other characteristics that I did not measure make Flat Shoals particularly good habitat for the YOY *M. cataractae*. I do not believe that the higher abundance at Flat Shoals reflects higher capture efficiency because similar bedrock and *Podostemum* habitat occurred in other shoals where *M. cataractae* were not nearly as abundant.

Percina sp.

The undescribed *Percina* specializes on shallow, fast habitat. My findings for the habitat use of *Percina* sp. are concurrent with those of Hill (1996). In my Flint River shoals samples, *Percina* sp. (YOY and adults) were found in shallower, faster, water with *Podostemum* cover indicating that the species would not thrive in flat water or impoundments. In the mainstem and larger tributaries of the upper Flint, Hill (1996) similarly found that *Percina* sp. were virtually absent from pool habitats within shoals.

Like the YOY *M. cataractae*, *Percina* sp. feed mainly on macroinvertebrates (Hill 1996), explaining in part their association with *Podostemum*. In swift water, *Podostemum* may also provide cover for the darters. It has been noted in other studies that areas containing emergent and submerged vegetation serve as nurseries for many juvenile fish (Lobb and Orth, 1991). In contrast to our findings, some studies found that the YOY of benthic stream fishes tend to occupy deeper, slower water with little cover, and slower riffles (Greenberg and Stiles 1993, Aadland, 1993). *Percina* sp. adults and YOY appear to use the same fast-flowing riffle habitats, especially with abundant cover by *Podostemum*. Strong associations with *Podostemum* suggest that abundant

Podostemum is a good indicator of habitat quality for the darter, as it may provide food and cover. Decreasing flows can have negative effects on the vitality of *Podostemum* (Everitt and Burkholder 1991), which in turn may affect the abundance of *Percina* sp. The correlations of *Percina* sp. with *Podostemum* at both the microhabitat scale and shoal scale suggest that *Podostemum* is the best overall indicator of presence of this darter.

Similar species did not necessarily exhibit similar relations to habitat characteristics. As shown by the reach scale analyses and partly from the microhabitat analyses, the effects of velocity and *Podostemum* coverage suggest that habitat partitioning may be occurring between the two darters (effects on *Percina nigrofasciata* opposite the effects on *Percina* sp.). In contrast, *Noturus leptacanthus* (another benthic invertivore) displayed similar microhabitat affiliations to those of *Percina* sp., occurring in shallow, swift, vegetated areas. However, among – shoal differences in CPUE of *N. leptacanthus* were not strongly correlated with shoal characteristics.

To describe habitat associations in low gradient streams, Rabeni and Jacobson (1993) scale up from microhabitats to hydraulic habitat units, which are combinations of depth, velocity, substrate particle size, and cover. Inoue and Nunokawa (2002) found that longitudinal variations in fish abundances were correlated more with subunits (microhabitats) than channel units (pool, riffle, run, etc) and therefore suggest the use of subunits in determining habitat use. In the Flint River, fish abundances were correlated with both microhabitat characteristics and shoal characteristics. For example, many of the variables that influenced probability of presence of the fishes at the microhabitat scale were correlated with shoal scale variables. In particular, depth, a microhabitat predictor of *Percina* sp. was found to decrease with gradient, a shoal scale predictor of *Percina* sp.

Podostemum, both a microhabitat and shoal scale predictor of *Percina* sp., increased with gradient and decreased with depth. The result that *Percina* sp. was the only modeled species that was strongly associated with habitat variables at the reach scale may have been a consequence of the strong correlations between its microhabitat characteristics (shallow, swift, vegetated) and the reach scale variable gradient. In contrast, *N. leptacanthus* exhibited similar associations at the microhabitat level but neither gradient nor other reach scale variables were good predictors of *Noturus* abundance across shoals.

Management implications

Shoal habitats and fish assemblages vary in the study reach, suggesting that individual shoals contribute differently to the biotic integrity of the upper Flint River. Comparison of my collections to historic collections leads me to conclude that fish assemblages in the shoals have changed little over the past 30 years. Considering the extraordinary growth of urban areas and increased water use in the metropolitan Atlanta area, the shoals are placed in a state of vulnerability. Shoal habitats are vulnerable to desiccation during flow reductions, and the shoals of the upper Flint River are directly affected by urban discharges and runoff in its headwaters.

In order to maintain the populations of unique fishes and biological integrity, conservation efforts should encompass the entire reach, not individual shoals. All three of the endemic species are considered vulnerable by Warren et al. (2000). Conservation efforts for *C. callitaenia* should be focused at the lower end of the shoals reach. *M. cataractae* has lost extensive habitat in the Chattahoochee due to extensive damming, as with the lower Flint, and habitat is limited and degraded in Florida (Williams and

Burgess 1999). Flat Shoals, containing the highest CPUE, may be considered an important area for conservation of the bass in the upper Flint.

Only three strong populations of *Percina* sp. still exist; all are isolated by impoundments: the Chattahoochee above Sidney Lanier Reservoir, the Ichawaynochaway Creek system below Blackshear Reservoir, and the upper Flint River shoals (Freeman et al. 2003). Freeman et al. (1997) found that microhabitat criteria were transferable between streams for specialist (riffle-dwelling) species but not for the generalist species. This finding suggests that the predictor variables of *Percina* sp. could be helpful in monitoring abundances in other reaches, such as the upper Chattahoochee River or lower Flint. Given my findings on the use of fast riffle habitat, it is likely that the darter would not survive impoundment of the upper Flint River shoals reach. The high abundance of the darter in the middle of the shoals reach, particularly Sprewell Bluff, indicates that this area may be key for conservation.

I found that characteristics at both the microhabitat and reach scales are significant in determining habitat use by fishes. Each scale provides different insight into the ecological associations between the physical and biological characteristics of the Flint River. These relations may be useful in influencing municipal water policy throughout the headwaters of the Flint.

CHAPTER4

CONCLUSIONS

The Flint River, one of two rivers in Georgia that is not dammed at the Fall Line, is ecologically significant. It retains a free-flowing mainstem from its origins in the Piedmont and onto the Coastal Plain. This is the consequence of then Governor Jimmy Carter's decision to veto federal plans to dam the mainstem in the 1970's, thus preserving one of the few extended, high-quality riverine reaches in the continental U.S. Because of this, the upper Flint River shoals could be considered endangered habitat.

Conservation of the upper Flint River presently depends on how growth in the headwaters region is managed. This management includes how water demands are met in the municipalities throughout the upper Flint River system. These management decisions in the headwaters will affect the rest of the upper Flint River, especially the biologically diverse and ecologically sensitive shoal reach.

This study has investigated faunal relations to habitat characteristics in shoals, one of the primary mainstem features. I have compared variation in fish assemblages and species abundances among the shoals at two scales, the microhabitat and the reach. I found that shoals were different from each other in terms of physical and faunal characteristics. Species assemblages, habitat composition, and species abundances varied among shoals. Habitat use by fishes was predicted by different variables at the

microhabitat and reach scales. The undescribed, endemic darter *Percina* sp. exhibited the strongest correlations with both microhabitat and reach variables.

These findings should be useful in evaluating consequences of municipal water policy in the Flint headwaters. Potential effects of proposed future impoundments or flow diversions in the Flint headwaters could have negative effects on instream flow, which may be detrimental to the shoals reach. Habitat use information from this study could also be used monitor the status of *Percina* sp. elsewhere in the Apalachicola system.

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Table 1. Habitat descriptions of the shoals. Habitat descriptions for each of the 16 shoals, listed from upstream to downstream. Variables include river mile (from mouth), shoal size, modal habitat, percent kicksets containing >50 % coverage by *Podostemum*, average velocity, standard deviation velocity, average depth, standard deviation depth, categorical dominant particle size (dps), and gradient; n = the number of kicksets at the site.

Shoal	River mile	Size, m	Modal habitat	<i>Podostemum</i> coverage	Average velocity, m/s	Std dev. Velocity, m/s	Average depth, m	Std dev. Depth, m	dps	Gradient
FS n = 60	284.4	353	Run	43	0.29	0.34	0.28	0.16	Bedrock	0.014
FS2 n = 60	284.0	323	Run	12	0.44	0.26	0.25	0.10	Gravel	0.012
FS4 n = 30	283.1	50	Run	0	0.39	0.23	0.52	0.27	Bedrock	0.002
FS5 n = 30	282.8	75	Run	0	0.36	0.22	0.43	0.22	Bedrock	0.002
Elk n = 30	277.8	100	Run	43	0.27	0.18	0.35	0.18	Bedrock	0.004
S30 n = 60	264.3	553	Run	73	0.21	0.16	0.25	0.11	Bedrock	0.007
SpB1 n = 66	263.4	200	Riffle	83	0.43	0.24	0.31	0.10	Gravel	0.014
S34 n = 56	261.4	350	Riffle	41	0.28	0.30	0.30	0.13	Bedrock	0.007
S36 n = 60	260.6	200	Riffle	40	0.27	0.15	0.25	0.13	Gravel	0.007
S37 n = 43	260.3	75	Run	23	0.31	0.21	0.49	0.23	Boulder	0.004
S38 n = 30	260.1	50	Run	40	0.44	0.26	0.48	0.18	Cobble	0.003
S40	259.3	75	Run	58	0.40	0.30	0.40	0.14	Bedrock	0.010

Table 2. NMS correlations. Fish and habitat variables and their correlations (r-value) to Axis 1 and Axis 2 of the NMS ordination. Significant correlations ($r > 0.6$ for fish variables and $r > 0.4$ for habitat variables) are in bold.

variable	Axis 1	Axis 2
<i>Nocomis leptacephalus</i>	-0.081	-0.693
<i>Campostoma pauciradii</i>	0.272	0.177
<i>Cyprinella callitaenia</i>	0.345	0.704
<i>Cyprinella venusta</i>	-0.452	0.495
<i>Notropis hudsonius</i>	-0.194	0.282
<i>Notropis hypsilepis</i>	-0.674	-0.581
<i>Notropis longirostris</i>	-0.272	0.092
<i>Notropis lutipinnis</i>	0.327	-0.227
<i>Notropis petersoni</i>	-0.396	0.152
<i>Hybopsis</i> sp. cf. <i>H. winchelli</i>	0.229	-0.713
<i>Ericymba buccata</i>	0.217	0.269
<i>Moxostoma</i> sp. cf. <i>M. poecilurum</i>	-0.265	-0.518
<i>Scartomyzon rupiscartes</i>	-0.361	-0.703
<i>Ictalurus punctatus</i>	-0.311	0.308
<i>Ameiurus brunneus</i>	0.273	-0.662
<i>Ameiurus natalis</i>	-0.105	-0.732
<i>Pylodictus olivarius</i>	0.200	-0.438
<i>Noturus leptacanthus</i>	0.714	0.529
<i>Labidesthes sicculus</i>	-0.537	-0.183
<i>Ambloplites ariommus</i>	-0.041	-0.076
<i>Micropterus cataractae</i>	-0.442	-0.603
<i>Micropterus salmoides</i>	-0.531	-0.587
<i>Lepomis auritus</i>	-0.458	-0.353
<i>Lepomis cyanellus</i>	-0.140	-0.228
<i>Lepomis macrochirus</i>	-0.785	-0.032
<i>Lepomis punctatus</i>	-0.105	-0.732
<i>Lepomis</i> YOY	-0.528	-0.530
<i>Percina nigrofasciata</i>	-0.648	-0.109
<i>Percina</i> sp. cf. <i>P. palmaris</i>	0.851	0.048
<i>Etheostoma swaini</i>	-0.105	-0.732
% sand	-0.263	0.305
% gravel	-0.086	0.068
% cobble	0.426	0.379
% boulder	0.104	0.183
% bedrock	-0.152	-0.454
% vegetation	0.643	-0.339
average velocity, m/s	-0.307	0.168
average depth, m	-0.465	0.361
phi	-0.176	0.418
gradient	0.339	-0.540
river mile	-0.704	-0.411
shoal size, m	0.236	-0.417

Table 3. Comparison of past and present studies. List of species not shared by all three sampling efforts in the mainstem shoals of the upper Flint River. Dashes indicate that Martin collected the species at sites in the upper Flint other than the mainstem shoals. Dates listed are sampling years.

Species not in common	Marcinek, 2001, 2002	Martin, 1971 (4 mainstem sites)	Ellis, 1984
<i>Ichthyomyzon gagei</i>		-	X
<i>Lepisosteus oculatus</i>			X
<i>Lepisosteus osseus</i>	X		
<i>Dorosoma cepedianum</i>		X	X
<i>Esox niger</i>		X	
<i>Nocomis leptcephalus</i>	X	-	X
<i>Campostoma pauciradii</i>	X		
<i>Ericymba buccata</i>	X	-	X
<i>Cyprinella callitaenia x venusta</i>			X
<i>Notropis emilie</i>		X	
<i>Notropis hudsonius</i>	X		X
<i>Notropis longirostris</i>	X	-	X
<i>Notropis lutipinnis</i>	X	-	
<i>Notropis petersoni</i>	X	-	
<i>Notropis texanus</i>	X	-	X
<i>Carpoides carpio</i>			X
<i>Scartemyzon rupescartes</i>	X	-	
<i>Ameiurus natalis</i>	X	-	
<i>Labidesthes sicculus</i>	X	-	
<i>Pomoxis nigromaculatus</i>		X	
<i>Lepomis microlophus</i>		X	
<i>Etheostoma swaini</i>	X	-	

Table 4. Microhabitat descriptions of the fishes. Microhabitat descriptions for the shoals and *C. callitaenia*, *M. cataractae*, and *Percina* sp. Variables include modal habitat, mean velocity, mean depth, percent kicksets containing >50 % coverage by *Podostemum*, and percent of occupied samples dominated by sand, gravel, cobble, boulder, bedrock; n = number of kicksets occupied by the target species across all sites.

	Modal habitat	Mean velocity, m/s	Mean depth, m	Podostemum coverage	Percent sand	Percent gravel	Percent cobble	Percent boulder	Percent bedrock
shoals	run	0.31	0.34	41	10	26	19	7	38
<i>Cyprinella callitaenia</i> n = 309	run	0.31	0.34	45	11	28	19	6	34
<i>Cyprinella venusta</i> n = 169	run	0.28	0.36	26	13	28	17	5	37
<i>Noturus leptacanthus</i> n = 120	run	0.43	0.29	66	5	34	26	6	29
<i>Micropterus cataractae</i> n = 65	run	0.31	0.30	48	2	15	14	8	62
<i>Percina nigrofasciata</i> n = 209	run	0.30	0.31	31	9	31	22	5	34
<i>Percina</i> sp. n = 416	run	0.35	0.28	58	8	29	21	5	37

Table 5. Logistic regression results. Listed for each species are the variables and their corresponding estimates, standard error, probability levels, scaled odds ratios (OR), and the lower and upper 95% confidence limits of the scaled odds ratios. Odds ratios units are cm/s for velocity and cm for depth. Bold parameters indicate significance at the $p < 0.05$ level.

Variable	Estimate	Standard Error	Probability	Scaled OR	OR 95% Confidence Limits	
					Lower	Upper
<i>C. callitaenia</i> , YOY						
Intercept	-0.3729	0.4702	0.4278	0.6887	0.2741	1.7308
<i>Podostemum</i>	0.1527	0.2111	0.4694	1.1650	0.7703	1.7619
Velocity	-1.0317	0.4277	0.0159	0.9897	0.9815	0.9981
Depth	-1.6224	0.6997	0.0204	0.9839	0.9705	0.9975
Bedrock	-0.1215	0.3730	0.7446	0.8856	0.4263	1.8395
Boulder	-1.0895	0.5860	0.0630	0.3364	0.1067	1.0609
Cobble	-0.6623	0.3650	0.0696	0.5157	0.2522	1.0545
Gravel	-0.6109	0.4724	0.1959	0.5429	0.2151	1.3701
<i>C. callitaenia</i> , adult						
Intercept	-1.0055	0.5360	0.0606	0.3659	0.1280	1.0460
<i>Podostemum</i>	0.2129	0.2631	0.4183	1.2373	0.7388	2.0720
Velocity	0.4291	0.2585	0.0969	1.0043	0.9992	1.009
Depth	0.8042	0.5668	0.1560	1.0081	0.9969	1.0193
Bedrock	-0.3793	0.5493	0.4898	0.6843	0.2332	2.0081
Boulder	-0.2499	0.3513	0.4768	0.7789	0.3913	1.5504
Cobble	-0.3373	0.4701	0.4731	0.7137	0.2840	1.7934
Gravel	0.1121	0.4862	0.8176	1.1186	0.4314	2.9011
<i>C. venusta</i>						
Intercept	-0.8518	0.4049	0.0354	0.4266	0.1929	0.9435
<i>Podostemum</i>	-0.2196	0.2006	0.2737	0.8028	0.5418	1.1896
Velocity	-0.7198	0.4908	0.1424	0.9305	0.8452	1.0245
Depth	0.3592	0.4651	0.4400	1.0366	0.9463	1.1355
Bedrock	0.0531	0.4467	0.9053	1.0545	0.4394	2.5307
Boulder	-0.7746	0.5016	0.1226	0.4609	5.7991	1.2320
Cobble	-0.1875	0.4315	0.6639	0.8290	0.3558	1.9315
Gravel	-0.0173	0.4890	0.9718	0.9828	0.3769	2.5631
<i>N. leptacanthus</i>						
Intercept	-1.8602	0.4796	0.0001	0.1556	0.0608	0.3985
<i>Podostemum</i>	0.7981	0.2762	0.0039	2.2213	1.2928	3.8168
Velocity	1.7266	0.4109	< 0.001	1.1885	1.0965	1.2881
Depth	-2.569	0.6856	0.0002	0.7734	0.6762	0.8847
Bedrock	-0.2828	0.4251	0.5059	0.7537	0.3276	1.7339
Boulder	-0.1348	0.7125	0.8499	0.8739	0.2162	3.5318
Cobble	0.2108	0.4488	0.6385	1.2347	0.5124	2.9755
Gravel	0.3445	0.4439	0.4377	1.4113	0.5913	3.3686

<i>M. cataractae</i>						
Intercept	-3.3824	0.8764	0.0001	0.0340	0.0060	0.1893
<i>Podostemum</i>	0.3612	0.2364	0.1266	1.4351	0.9028	2.281
Velocity	-0.1580	0.6177	0.7981	0.9984	0.9864	1.0106
Depth	-1.1097	1.1575	0.3377	0.9890	0.9668	1.0117
Bedrock	1.3331	0.6944	0.0549	3.7928	0.9726	14.791
Boulder	1.8433	0.7173	0.0102	6.3174	1.5488	25.767
Cobble	1.2803	0.5435	0.0185	3.5977	1.2399	10.44
Gravel	0.8261	0.6352	0.1934	2.2844	0.6578	7.934
<i>P. nigrofasciata</i>						
Intercept	-0.3276	0.5238	0.5317	0.7207	0.2581	1.952
<i>Podostemum</i>	-0.4397	0.1702	0.0098	0.6442	0.4615	0.8992
Velocity	-0.2892	0.3717	0.4366	0.9715	0.9032	1.0449
Depth	-1.9417	0.6007	0.0012	0.8235	0.7321	0.9264
Bedrock	0.2858	0.3678	0.4372	1.3308	0.6471	2.7366
Boulder	0.1388	0.5291	0.793	1.1489	0.4073	3.2407
Cobble	0.5802	0.4638	0.2109	1.7864	0.7198	4.4335
Gravel	0.2968	0.4223	0.4821	1.3455	0.5881	3.0790
<i>Percina</i> sp., YOY						
Intercept	-0.2817	0.4615	0.5416	0.7545	0.3054	1.8641
<i>Podostemum</i>	1.0067	0.1976	< 0.0001	2.7366	1.8578	4.0309
Velocity	1.168	0.5286	0.0271	1.0117	1.0013	1.0223
Depth	-3.1190	0.8884	0.0004	0.9693	0.9525	0.9863
Bedrock	0.1072	0.3434	0.7549	1.1132	0.5679	2.1819
Boulder	0.1715	0.5935	0.7726	1.1871	0.3709	3.7992
Cobble	-0.2281	0.4150	0.5825	0.7960	0.3529	1.7954
Gravel	0.6143	0.3477	0.0773	1.8484	0.9350	3.6543
<i>Percina</i> sp., adult						
Intercept	-0.1572	0.4152	0.7049	0.8545	0.3787	1.928
<i>Podostemum</i>	1.030	0.1759	< 0.0001	2.801	1.984	3.954
Velocity	1.994	0.6934	0.0040	1.020	1.006	1.034
Depth	-2.207	0.7867	0.0050	0.9782	0.9632	0.9934
Bedrock	-0.4917	0.2905	0.0906	0.6116	0.3460	1.081
Boulder	-0.6149	0.5727	0.2830	0.5407	0.1760	1.661
Cobble	-0.1927	0.2191	0.3791	0.8247	0.5368	1.267
Gravel	0.0405	0.2911	0.8894	1.041	0.5885	1.842

Table 6. Pearson correlations for habitat variables. Significant ($p < 0.05$) Pearson Correlation coefficients and their probability levels (p-value) for habitat variables.

	River Mile	Shoal size	Sand	Gravel	Cobble	Bedrock	Gradient	Standard deviation velocity	Vegetation	Average depth
River Mile										
Shoal size										
Sand										
Gravel										
Cobble	-0.87 ($<.0001$)									
Boulder	-0.54 (.030)				0.54 (.032)					
Bedrock				-0.69 (.003)	-0.57 (.021)					
Gradient		0.56 (.023)								
Average velocity										
Standard deviation velocity				-0.56 (.025)		0.61 (.012)				
Vegetation							0.58 (.017)			
Average depth		-0.79 (.0002)					-0.75 (.001)			
Standard deviation depth		-0.76 (.001)					-0.72 (.002)		-0.70 (.003)	0.78 (.0004)
Average phi			0.54 (.032)	0.88 ($<.0001$)		-0.66 (.006)		-0.65 (.006)		
Standard deviation phi			0.95 ($<.0001$)				-0.52 (.038)			

Table 7. Pearson correlations for fishes. Significant ($p < 0.05$) Pearson correlation coefficients and their probability levels (p-values) for the catch per unit efforts of *C. callitaenia*, *C. venusta*, *P. nigrofasciata*, and *Percina* sp. *M. cataractae* was not included due to non-normality. Sample size=16

	Gradient	Vegetation	Average depth	Standard deviation depth	River mile	Shoal size	Average phi	Cobble	Boulder	Bedrock
<i>Cyprinella callitaenia</i>					-0.72 (0.002)			0.55 (0.028)		
<i>Cyprinella venusta</i>			0.65 (0.007)			-0.61 (0.012)				-0.69 (0.003)
<i>Noturus leptacanthus</i>					-0.58 (0.019)				0.54 (0.032)	-0.57 (0.021)
<i>Percina nigrofasciata</i>		-0.76 (0.006)			0.64 (0.008)		0.55 (0.027)	-0.58 (0.019)		
<i>Percina</i> sp.	0.71 (0.002)	0.74 (0.001)	-0.62 (0.010)	-0.71 (0.002)	-0.53 (0.036)	0.53 (0.033)				

Table 8. Multiple regression results showing the selected variables ($p < 0.1$ cutoff) and the resulting equations.

	Variable 1	Variable 2	Variable 3	Formula
<i>Cyprinella callitaenia</i>	Standard deviation phi p = 0.078	Proportion cobble p = 0.008		$\ln \text{CPUE } C. \text{ callitaenia} = 0.17 + 0.10 (\text{std dev phi}) + 0.86 (\text{proportion cobble})$ adj. $r^2 = 0.37$
<i>Cyprinella venusta</i>	shoal size p = 0.01			$\ln \text{CPUE } C. \text{ venusta} = 2.13 - 0.30 (\ln \text{ shoal size})$ adj. $r^2 = 0.34$
<i>Noturus leptacanthus</i>	Proportion cobble p = 0.05			$\ln \text{CPUE } N. \text{ leptacanthus} = 0.09 - 0.29 (\text{proportion cobble})$ adj. $r^2 = 0.19$
<i>Percina nigrofasciata</i>	Vegetation p = 0.058	Proportion cobble p = 0.025	Proportion bedrock p = 0.097	$\ln \text{CPUE } P. \text{ nigrofasciata} = 1.16 - 0.006 (\text{vegetation}) - 0.72 (\text{proportion cobble}) - 0.33 (\text{proportion bedrock})$ adj. $r^2 = 0.66$
<i>Percina</i> sp.	Gradient p = 0.018	Vegetation p = 0.005	Bedrock P = 0.013	$\ln \text{CPUE } Percina \text{ sp.} = 3.1 + 0.41 (\ln \text{ gradient}) + 0.015 (\text{vegetation}) - 0.60 (\text{proportion bedrock})$ adj. $r^2 = 0.75$

Figure 1. Map of the study reach. Map of the upper Flint River system showing the locations of the city of Thomaston, major roads, Spirewell Bluff State Park, Big Lazar WMA, and Goat Mt. Identified shoals are shown as red dots.

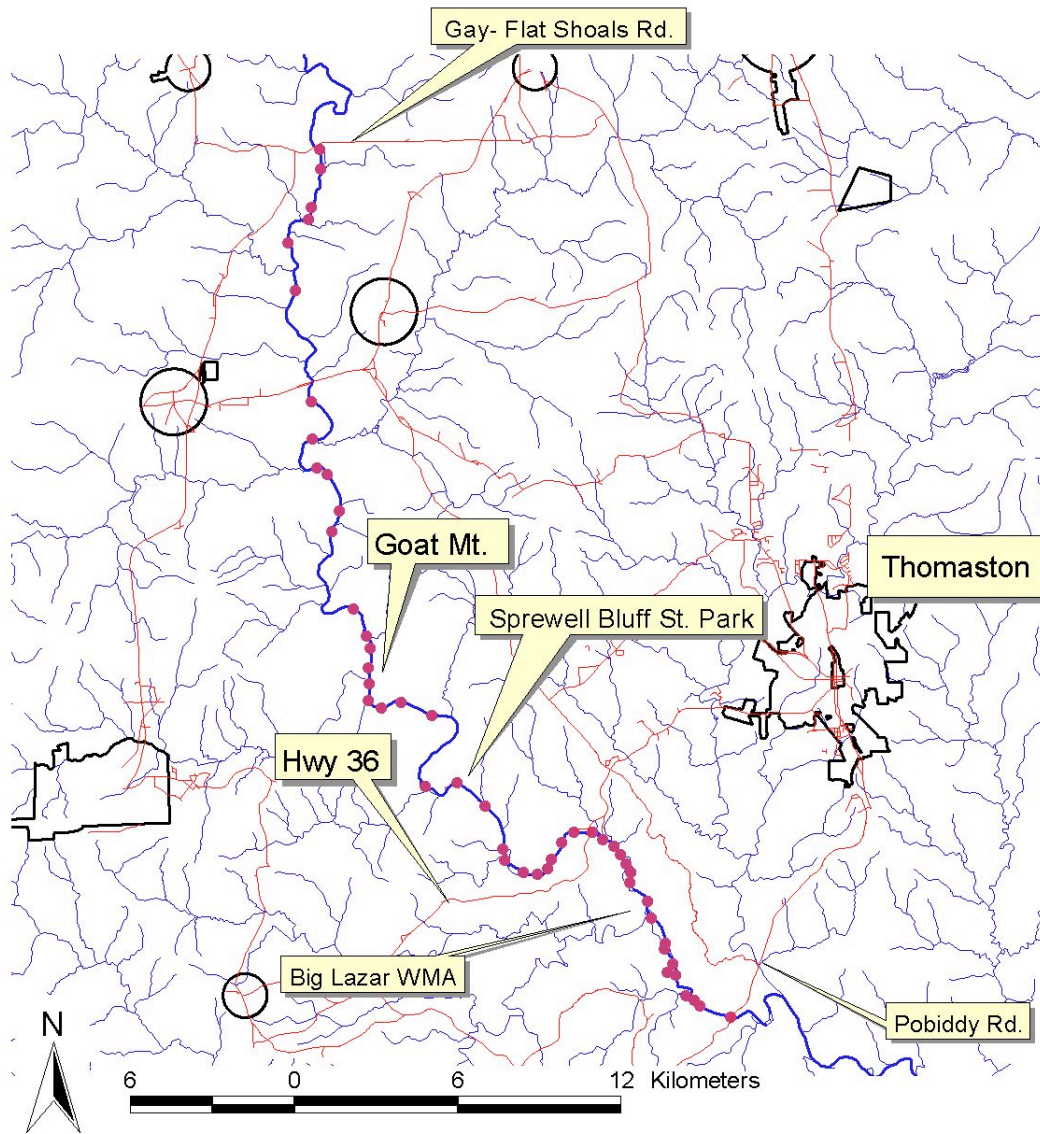


Figure 2. Map of 2001 sites. Map of the upper Flint River system showing the locations of the 2001 quantitative sites (red) and qualitative sites (red with, denoted with 'Q'). All other identified shoals are in purple.

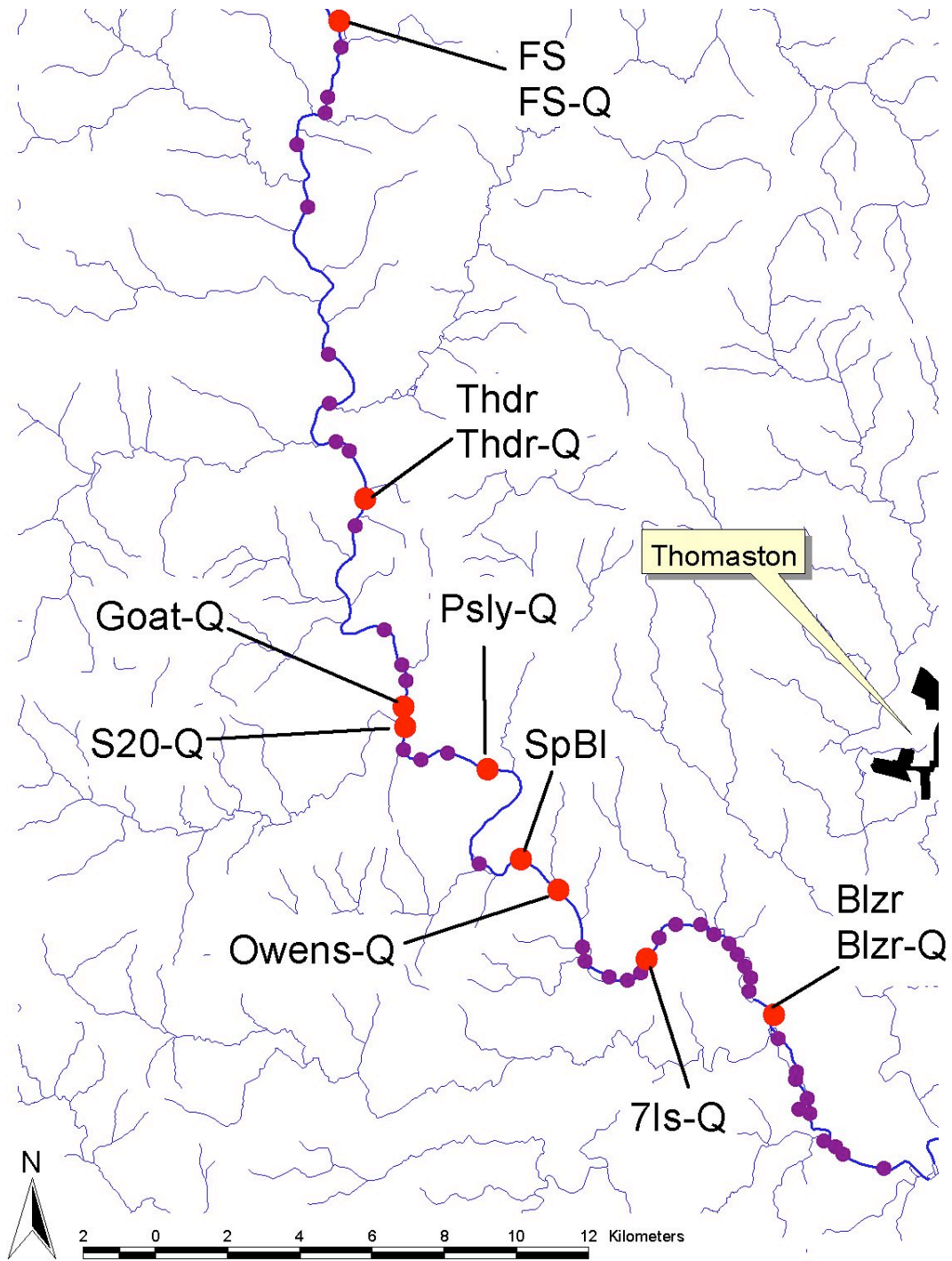


Figure 3. Map of the 2002 sites. Map showing the locations of the 2002 quantitative sites (red dots). All other identified shoals are in purple.

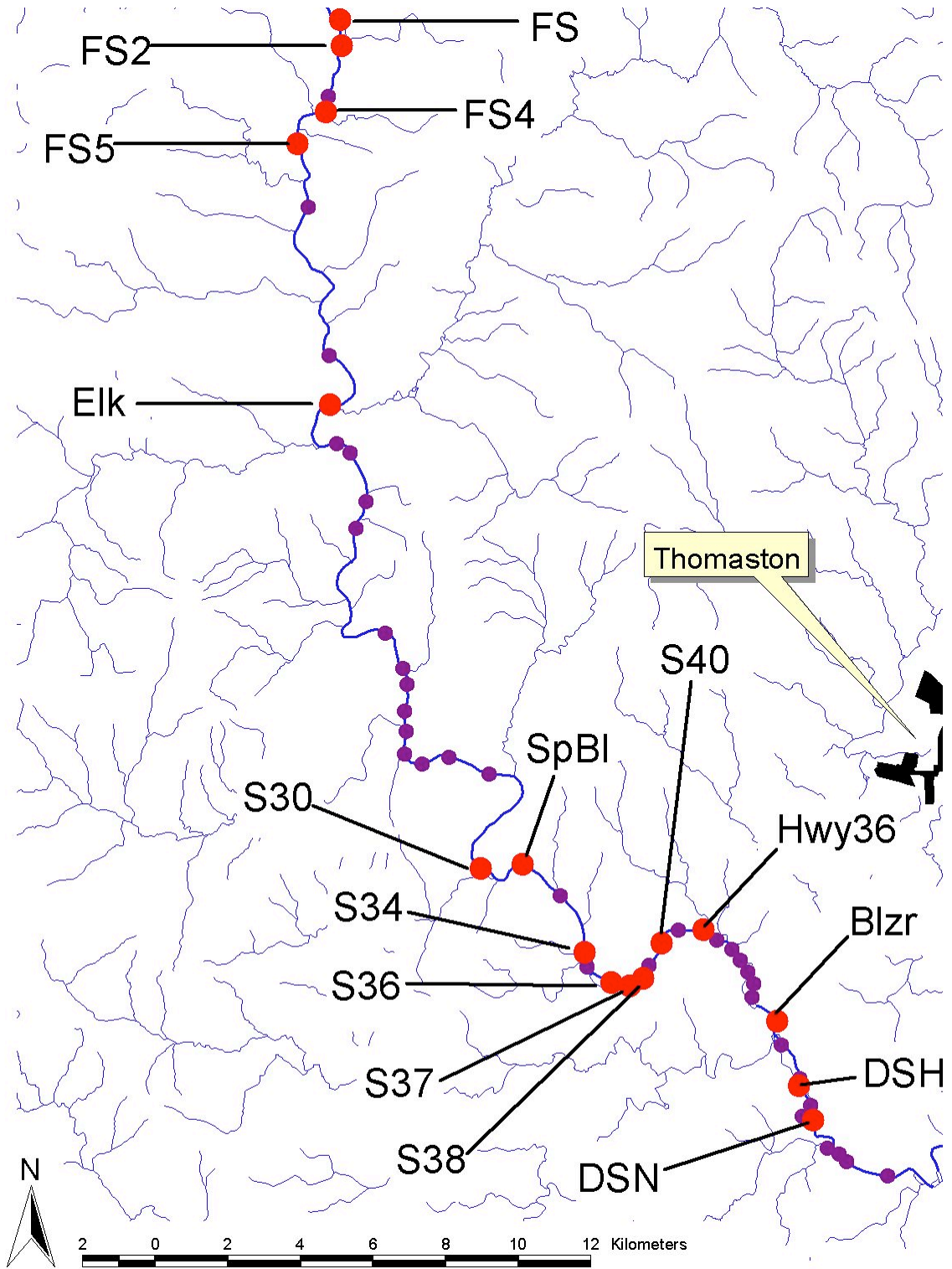


Figure 4. CPUE of water column fishes. Catch per unit effort of the minnows, *Cyprinella callitaenia* (hatched bars), *C.venusta* (closed bars), and the shoal bass, *Micropterus cataractae* (open bars). Shoals are ordered from upstream to downstream.

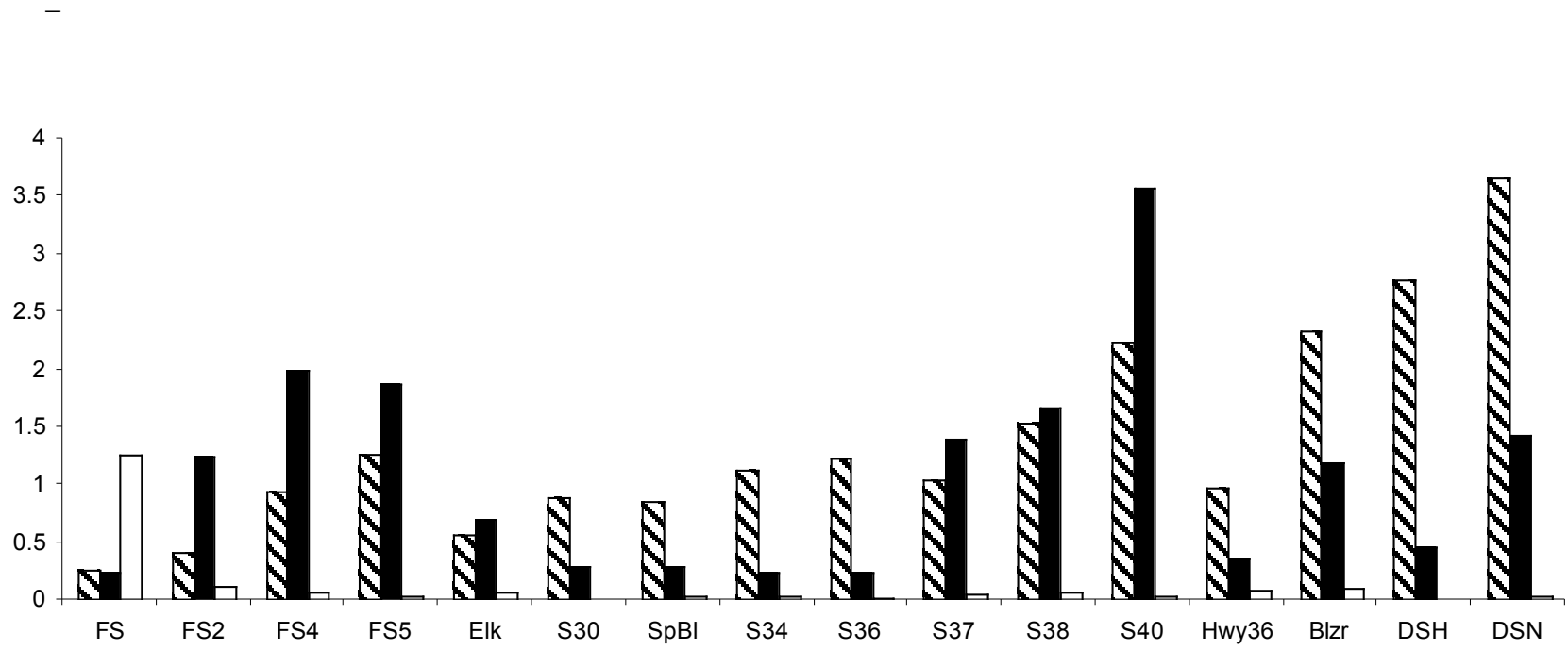


Figure 5. CPUE of the benthic fishes. Catch per unit effort of the benthic invertevores, *Noturus leptacanthus* (hatched bars), *Percina nigrofasciata* (closed bars), and *Percina* sp. (open bars). Shoals are ordered from upstream to downstream.

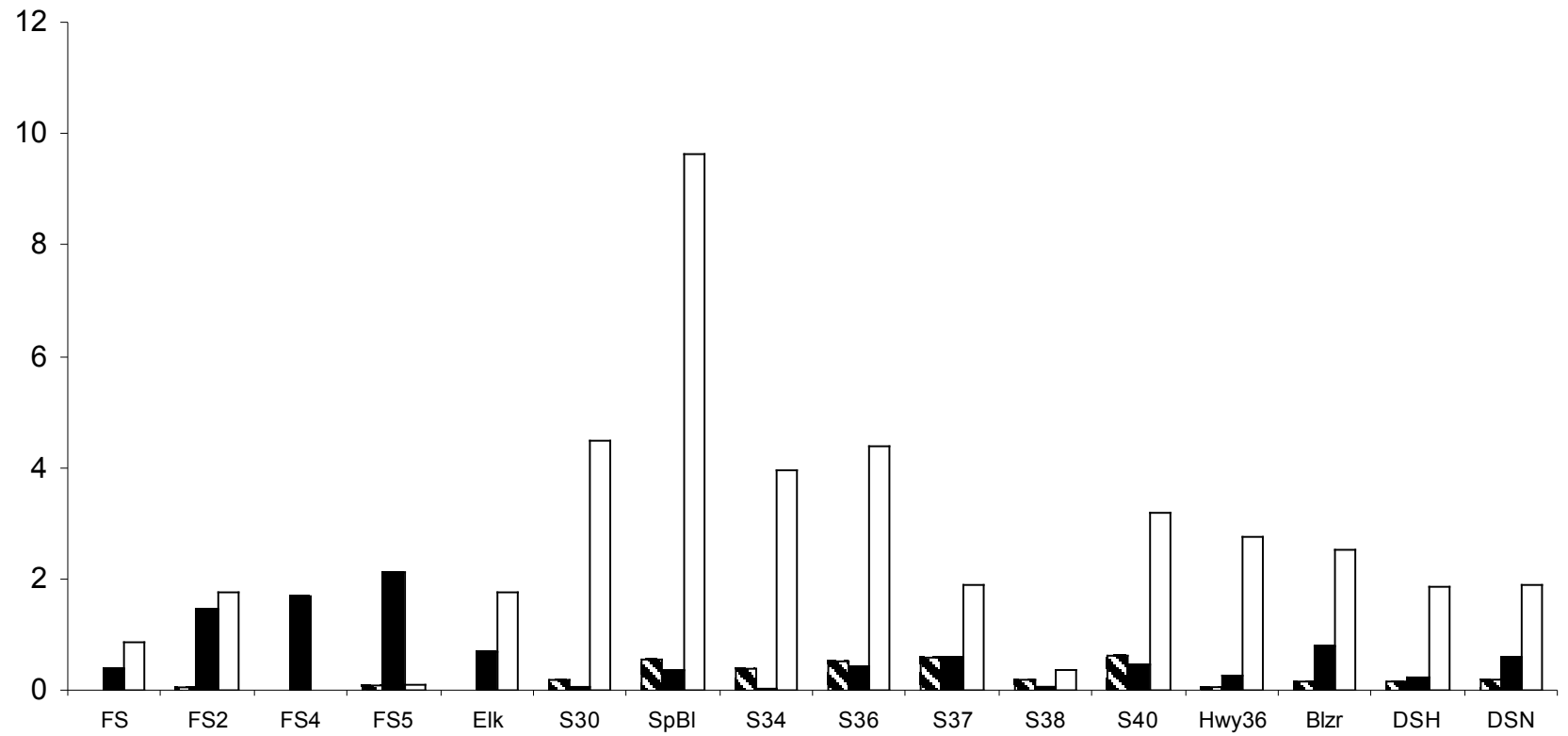


Figure 6. NMS ordination showing variation of shoals. Ordination plot showing sites in “species space.” The two axes represent 90 % of the variance in the dissimilarity matrix.

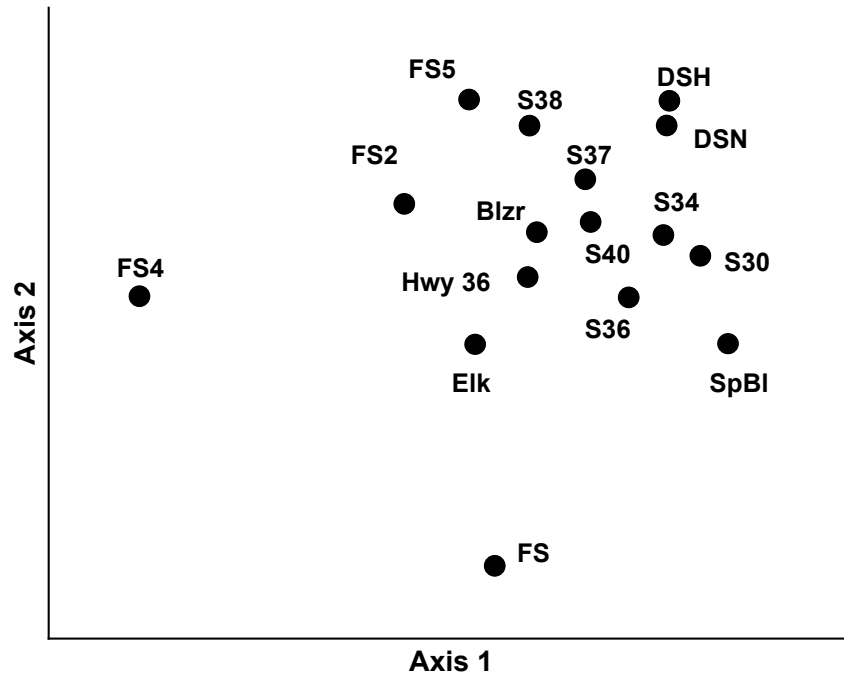


Figure 7. NMS ordination of shoals overlaid with species. Ordination plot showing sites in “species space” overlaid with significantly correlated ($r > 0.6$) species. The two axes represent 90 % of the variance in the dissimilarity matrix.

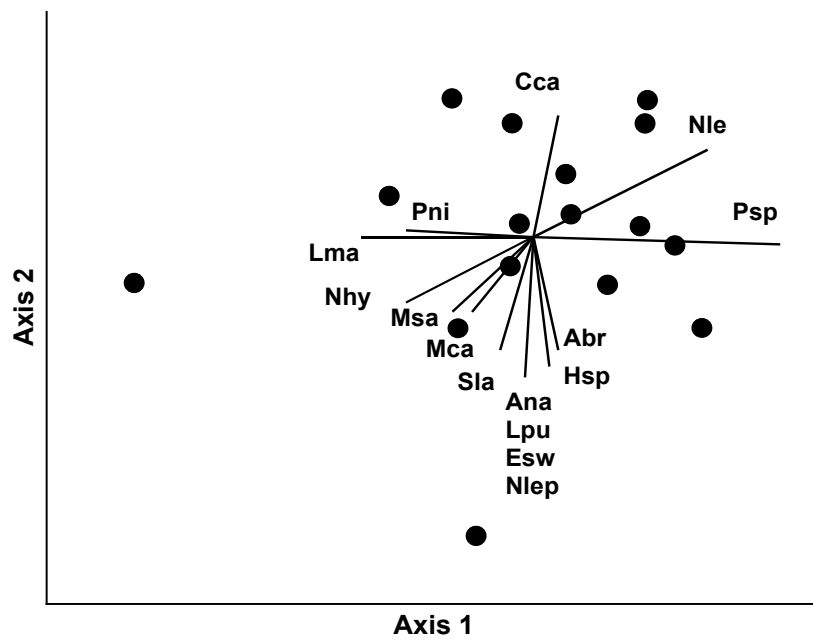
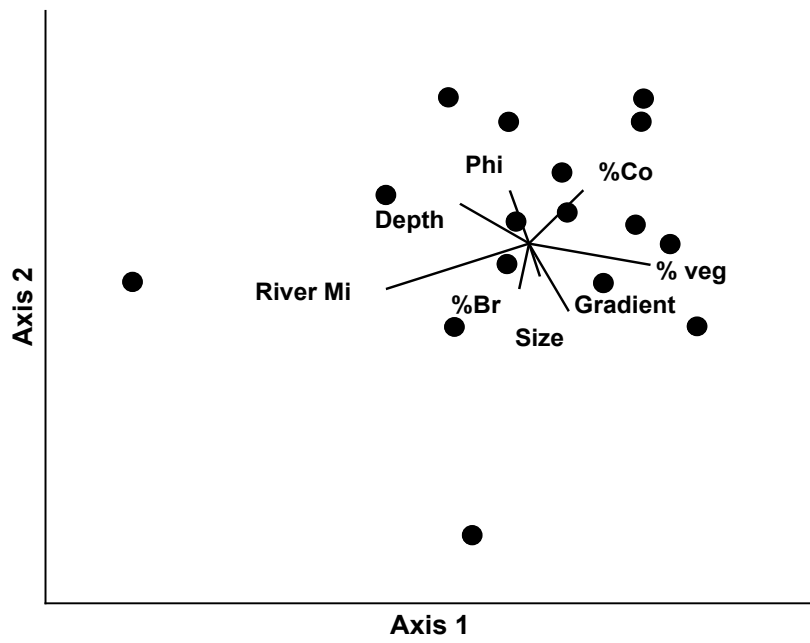


Figure 8. NMS ordination of shoals overlaid with habitat variables. Ordination plot showing sites in “species space” overlaid with significantly correlated ($r > 0.4$) habitat variables. The two axes represent 90 % of the variance in the dissimilarity matrix.



APPENDIX A

Fishes caught in 2001.

Total number of individuals per species caught at each site during 2001, quantitative (random kicksets) and qualitative. Sites are ordered from upstream to downstream. Qualitative sampling sites are noted with a "Q." Bold indicates species not found at the site during 2002.

<i>Percina nigrofasciata</i>	52	25	3	71	72	50	7	60	10	14	26	25	34
<i>Percina</i> sp. cf <i>P. palmaris</i>	90	118	540	179	75	117	82	83	76	273	144	278	94
Total individuals	296	157	579	342	300	215	113	182	129	389	246	426	397
Total species	18	9	11	14	15	15	12	11	13	13	13	17	15

APPENDIX B

Fishes caught in 2002

Total number of individuals per species caught at each site during 2002. Sites are ordered from upstream to downstream. Bold indicates species not found at the site during 2001.

<i>Percina nigrofasciata</i>	23	88	51	64	21	3	24	2	26	26	2	12	22	48	7	18
<i>Percina</i> sp. cf <i>P. palmaris</i>	52	106	0	3	53	280	636	221	263	82	11	83	220	151	56	57
<i>Etheostoma swaini</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total individuals	283	320	176	173	134	380	795	339	426	242	123	274	386	441	169	236
Total species	17	15	11	8	11	9	12	9	13	8	9	10	13	10	8	7