INFLUENCE OF DAMS ON STREAM FISH BIODIVERSITY ACROSS A DIVERSE GEORGIA LANDSCAPE

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INFLUENCE OF DAMS ON STREAM FISH BIODIVERSITY ACROSS A DIVERSE GEORGIA LANDSCAPE

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A Thesis
Submitted to
the Graduate Faculty of
Auburn University
in Partial Fulfillment of the
Requirements for the
Degree of
Master of Science

Auburn, Alabama
August 4, 2007

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THESIS ABSTRACT

INFLUENCE OF DAMS ON STREAM FISH BIODIVERSITY ACROSS A DIVERSE GEORGIA LANDSCAPE

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Master of Science, August 4, 2007
(B.S., University of Illinois, 2005)

114 Typed Pages

Directed by Carol E. Johnston

The composition of a stream fish assemblage is strongly influenced by the drainage basin, physiographic region, and the stream order it occurs in. It is also well known that anthropogenic disturbances can dramatically influence stream communities. My study investigated responses of fish faunas in Georgia to an anthropogenic disturbance, non-hydroelectric dams, a very common disturbance in streams of the South-eastern U.S. Fish assemblage sensitivity to dams was compared across drainages (Alabama, Altamaha and Apalachicola), physiographic provinces (Ridge and Valley, Piedmont, and Coastal Plain), and stream orders (1-3). Overall, similarity within treatment sites was 5.6% ($P = 0.040$) higher than similarity within free-flowing reference sites across the landscape, suggesting that dams contributed to fish faunal homogenization. One major difference in the below-dam assemblages was a 13.37%

mean increase in relative abundance of *Lepomis* individuals. However, the relative abundances of darter individuals, non-native species, benthic fluvial specialists, and cyprinid insectivores did not change significantly. Overall biotic integrity was significantly lower for treatment site assemblages (P = 0.041), but native species richness was not significantly affected. I found no significant difference in habitat parameters between treatment and reference sites. Physiographic region, drainage basin, and stream order did not significantly influence assemblage sensitivity to dams as indicated with an Index of Biotic Integrity (IBI). Site distance downstream of a dam in the range of 0.2-10.5 km did not significantly impact IBI score or native species richness, and likewise proportion of the watershed dammed did not significantly influence either IBI score or native species richness.

ACKNOWLEDGEMENTS

I thank the Georgia Department of Natural Resources Stream Survey Team for collection of all data used in this project, and for calculation of the Index of Biotic Integrity (IBI) used in this study. I thank Patty Lanford of the Georgia Stream Survey Team for help accessing data and other information regarding the data set. I thank my committee members, Dr. Jack Feminella, Dr. Sharon Hermann, and Dr. Mark MacKenzie for helpful suggestions throughout the development of this thesis. I also thank the following individuals for suggestions on my thesis work: Dan Holt, Andrew Henderson, Adam Kennon, Rich Mitchell, Bryan Phillips, Cathy Phillips, and Dr. Mike Gangloff. Many thanks to Dr. Carol Johnston for introducing me to fishes of the Southeast and for guidance on many aspects of my graduate education.

Style manual or journal used: Environmental Biology of Fishes, Auburn University Guide to Preparation of Theses and Dissertations

Computer Software used: Microsoft Word 2002, Microsoft Excel 2002, Ecological Methodology, ArcGIS 9.1, SAS 9.1

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I. INTRODUCTION

The southeastern U.S. has among the most diverse temperate freshwater fish faunas in the world. The abundance of isolated drainage basins and diverse physiographic regions have been cited as factors contributing to the distinctiveness of this fauna (Hocutt & Wiley 1986; Matthews 1998; Boschung & Mayden 2004). Homogenization of the diverse southeastern freshwater fish fauna has been attributed to human activities (Scott & Helfman 2001; Rahel 2002), and alterations of the stream conditions can have a dominant structuring influence on fish assemblages. In my review of the literature, I found no study that has compared the sensitivity of fish assemblages to anthropogenic disturbances among multiple drainages, physiographic regions, and stream orders, despite the dominance of these factors in structuring stream fish assemblages.

River drainages are essentially islands (Matthews 1998). Fish assemblages of southeastern U.S. drainages are primarily composed of first degree freshwater fishes. Incapable of entering the salty ocean or crossing land, these fishes are locked into their respective drainage unless a rare drainage capture event takes place, cross-drainage stocking occurs, or humans connect previously isolated river systems. River drainage is the single most important factor regulating biogeography of freshwater fishes (Gilbert 1980; Matthews 1998), and several studies have indicated that fish assemblages are unique according to drainage (Hughes et al. 1987; Angermeier & Winston 1998, Angermeier & Winston 1999). Historically, fishes adapted to the conditions somewhere in their drainage between headwaters and the ocean or were extirpated. As rivers cross different physiographic provinces and stream orders, suites of habitat conditions change, and likewise the stream fauna can change as well (Matthews 1998).

Physiographic variation within the southeastern U.S. provides different habitats within drainages (Boschung & Mayden 2004). Diverse physiographic regions have provided diverse habitats for a wealth of species with contrasting life histories to occur in single drainage basins. There is some disagreement in the literature on which regional classification is most appropriate for stream fauna. This disagreement complicates interpretation of "regional" impact on stream communities based on the primary literature. A physiographic region is defined by parent geology and topography, while ecoregion is dependent on geology, vegetation, climate, and soils (Omernik 1987). For the purposes of my study, level III Ecoregion and physiographic region are considered identical, as the scope of this paper is limited to the Ridge and Valley, Piedmont, and Coastal Plain regions of Georgia.

Numerous studies have indicated distinctiveness of stream fauna according to ecoregion (Feminella 2000; Oswood et al. 2000; Rabeni & Doisy 2000; Van Sickle & Hughes 2000) and physiographic region (Angermeier & Winston 1998; Angermeier & Winston 1999; Smogor & Angermeier 2001; Cooke et al. 2004). More specifically, freshwater fishes are distinct according to physigraphic region (Angermeier & Winston 1998; Angermeier & Winston 1999; Smogor & Angermeier 2001; Cooke et al. 2004). Stream slope and stream bed substrate particle size are key habitat differences between physiographic regions. Stream bed particle size and stream slope tend to decrease as a river drainage flows from the mountains to the coastal plain. Walters et al. (2003)

indicated that geomorphic variables, particularly stream slope best explained fish assemblage composition within in a Piedmont river basin and that average stream bed particle size was positively correlated with stream slope. The authors' study was conducted within a single physiographic province in Georgia and was restricted to the Etowah River drainage. In Georgia, stream slope is highest in the Blue Ridge and Ridge and Valley physiographic provinces and lowest on the Coastal Plain. Therefore, it is probable that fish assemblages of the more mountainous regions of Georgia are distinct from assemblages on the Coastal Plain due to slope and substrate size alone.

Waite et al. (2000) compared classifications for stream benthic macroinvertebrates in the Mid-Atlantic Highlands region. The authors indicated that ecoregion resulted in low classification strength, but when sites were stratified by stream order, classification strength increased because noise resulting from stream order variation was reduced. This is one of many studies indicating that stream size must be taken into account when classifying stream communities. The role of stream order in structuring stream fish assemblages is well known. Multiple studies have suggested the existence of fish faunal breaks along a stream according to stream order. Matthews (1986) reviewed studies examining longitudinal patterns in fish assemblages in the eastern and central US. He found that such breaks occurred in some streams, concluding that the conditions associated with stream order can play a role in structuring fish assemblages. A more commonly observed change in fish fauna associated with stream order is a longitudinal addition of fish species downstream (Sheldon 1968; Jenkins & Freeman 1972; Evans & Nobel 1979; Rahel & Hubert 1991).

It is apparent from the primary literature that drainage, physiographic region, and stream order all play dominant roles in structuring stream fish assemblages. However, no single factor effectively classifies stream communities (Hawkins & Vinson 2000; McCormick et al. 2000; Sandin & Johnson 2000; Waite et al. 2000). Human alterations of the environment can significantly alter stream conditions and fish fauna, possibly as greatly as these dominant natural factors.

Environmental alterations associated with dams and consequences for stream fishes

Dams are extremely common in the southeastern U.S. They have been built for a wide range of functions including recreation, hydropower production, and mill operation among others. By altering the stream condition, a dam has the potential to influence the stream faunal composition. In general, dams tend to reduce flow and peak discharge downstream, trap sediment above the dam, and reduce the grain size of released sediment. All of these changes to stream conditions can influence fish assemblages**.** If environmental conditions, biota, and dams were identical for all streams, predicting the impacts of a dam would be very simple. This is largely how investigators have addressed questions regarding dam impacts on stream fauna. However, the downstream geomorphologic and ecologic consequences of impoundment depend on local environment, local biota, substrate, water and sediment released from the dam, dam location, and dam function (Brandt 2000). Local stream conditions and fauna are strongly influenced by physiographic region, drainage basin, and stream order, so it is likely that responses of both the stream and associated fish inhabitants to a dam are not vary in accordance with variations of these three factors. Gehrke et al. (1999)

investigated the influence of dams across three river drainages in the Hawkesbury-Nepean River System of Australia, and suggested that natural differences in fish assemblages among drainages may have confounded the impacts of dams on fish assemblages in their study.

The natural flow regime is essential to stream ecological function (Poff & Allan 1997). The life cycles of native species are often timed according to local hydrological patterns. For example, stream fishes may rely on hydrological cues to begin longitudinal migrations (Montgomery et al. 1983, Trepanier et al. 1996) or to begin spawning (Nesler et. al 1988). Native fishes may be poorly adapted to the altered habitat conditions resulting from anthropogenic change of natural hydrological patterns (Lytle & Poff 2004; Poff & Allan 1997).

Disruption of natural flow can result in extirpation of native fishes (Meffe & Minckley 1987; Penczak et al. 1998; Mammaloti 2002) and may promote colonization by invasive species (Meffe 1984). A good example of this is drawn from a regulated California stream. Marchetti & Moyle (2001) reported that native species abundance declined and non-native species abundance increased in response to flow regulation in Putah Creek. The benefits of natural flow conditions to native fishes is evident in the desert southwest. Meffe (1984) observed that an invasive mosquitofish, *Gambusia affinis,* was low in abundance following flash floods. As a result, a native topminnow, *Poeciliopsis occidentalis*, increased in abundance following the flood, having been released from predation by an invasive species. Because the native topminnow was adapted to local dramatic flood events, it was able to persist even after an intense flood. However, because *G. affinis* was not adapted to the magnitude and velocity of desert floods, a flood dramatically reduced the population size of the mosquitofish. Local environmental dynamics, such as flooding, can protect a community from invasion if conditions are extreme enough to limit exotics. Downstream of non-hydroelectric dams, decreases in maximum flows as well as minimum flows may occur (Ligon 1995; Poff & Allan 1997; Magilligan & Nislow 2005). Stabilization of flushing flows through impoundment, therefore, may remove such an advantage for the native species, because invasive species such as the mosquitofish can readily invade a hydrologically benign environment.

Understanding the geomorphic consequences of impoundment is essential to predicting the response of fish assemblages. After reviewing the geomorphologic impacts of dams indicated in the literature, Brandt (2000) predicted downstream effects of dams. He suggested that sediment movement downstream of dams depends on the relationship between water discharge, sediment load, and stream transport capacity. Therefore, the movement and deposition of sediment downstream of impoundments may vary from dam to dam based on these three factors. A dam typically allows fine sediment to pass downstream while retaining coarse substrate (Poff & Allan 1997; Brandt 2000). This process often results in increased scour immediately downstream by clear water flowing over the dam (Poff & Allan 1997; Tiemann et al. 2004). In addition, several studies have indicated increased compaction of substrate both immediately upstream and downstream of dams (Tiemann et. al 2004; Gillette et al. 2005). At some distance downstream reduced stream power, typically associated with dams, may no longer be capable of flushing sediment deposited by tributaries. This may result in embedding of rocky substrate. Clearly, the impacts immediately downstream of a dam are not identical to impacts several kilometers downstream.

Both compaction of substrate and deposition of fine sediment can reduce circulation of oxygen within substrate (Beschta & Jackson 1978), resulting in direct consequences to any species which spawns on those substrates or uses them for cover. Eggs and fry of some fish species are susceptible to mortality without oxygenated water between rocky substrates (Sear 1993). In addition to covering and compacting rocky substrates, dams withhold them upstream and restrict recruitment of new rocky substrate from banks due to reduced flows. Ligon et al. (1995) suggested that reducing gravel recruitment can interrupt formation of mid-channel bars, reducing associated habitat.

The most striking influence of dams on stream communities is their role in blocking the migration of stream fishes. This is a well-known problem for anadromous Pacific salmon, but dams also disrupt fish species of other systems in this manner (Penczak et al. 1998; Porto et al. 1999; McCleave 2001). Beasley & Hightower (2000) found that a low-head dam on the Neuse River in North Carolina acted as a barrier to spawning migrations of stripped bass and American shad. Few individuals of these species could reach historic spawning sites, and as a result, spawned in suboptimal habitats downstream of the impoundment. In southwestern Japan, dam-induced habitat fragmentation was blamed for absence of white-spotted charr, *Salvelinus leucomaenis,* in numerous samples sites upstream of dams (Morita & Yamamoto 2001). Fragmentation of rivers has been a concern for imperilled sturgeon species. Cooke & Leach (2004) suggested that a dam blocking migration to upstream spawning habitat on the Cooper River, South Carolina may be contributing to the imperilment of the shortnose sturgeon, *Acipenser brevirostrum*. Despite these findings, a broad-scale study across the state of Wisconsin suggested that fish species richness was more strongly correlated with water volume and maximum summer temperature than dam-induced stream fragmentation (Cumming 2004). His findings indicate that dams may not be as important as human disruptions of other natural variables in impacting stream fish assemblages.

By reducing flood intensity, dams can reduce the connectivity of a stream to its flood plain (Sparks 1995; Ward & Stanford 1995; Thoms et al. 2005). Fishes of floodplain rivers may be dependent on the flood plain for foraging and spawning (Sparks 1995; Ward & Stanford 1995). Dams, therefore, may reduce productivity of floodplain streams by reducing the stream connection with fish forage and reproductive resources on the flood plain.

It is important not to overlook impacts of impoundments on other organisms of a community, as reductions in abundance of many stream species could potentially impact the fish fauna (Power et al. 1996). Fishes which spawn as nest associates may be entirely dependent on nest building by other fish species to spawn successfully (Wallin 1992; Johnston 1999). Fish assemblage structure can be influenced by changes in species that form the base of the food chain. Power & Stewart (1995) found that the scouring floods of an Oklahoma stream disproportionately favored one species of algae over another, and that flooding resulted in temporal dominance of the more palatable algal species to invertebrate grazers. In this case, natural flooding may have supported a more diverse and productive system. A process favoring one species of algae over another may ultimately cascade through an entire community. Furthermore, changes in fish assemblage composition downstream of a dam may be an indirect response to changes in abundance of other stream organisms rather than a direct response of fishes to the dam.

Comparisons between dammed and reference sites reveal that dams can alter the composition of a fish assemblage (Kinsolving & Bain 1997; Taylor et al. 2001; Phillips & Johnston 2004; Tieman et al. 2004). Scott & Helfman (2001) discuss that homogenization of habitats causes homogenization of fish assemblages, promoting native and foreign invasive species and loss of endemic specialists. Rahel (2002) defined homogenization as increasing similarity of communities over time and stated that dams are one of the major factors blamed for fish faunal homogenization in the Southeast**.** Homogenization is occurring on a broad geographic scale, but sometimes it is difficult to detect with traditional metrics such as species richness, because introduced species may initially increase overall richness, making a community appear more diverse (Scott & Helfman 2001). Dramatic increases in proportions of centarchids and decreases in proportions of cyprinids have been observed downstream of dams (Taylor et al. 2001). These authors indicated that although fish species richness increased downstream of a dam on Kinkaid Creek (Southern Illinois), a loss of several native species occurred and species composition was greatly altered. Kinsolving & Bain (1993) found that benthic fluvial specialists were replaced with centrarchids downstream of dams on the Tallapoosa River in Alabama. Tiemann et al. (2004) examined fish and invertebrate responses to impoundments in the Midwest and found that benthic fishes were less abundant downstream of lowhead dams than in corresponding reference sites. They also called for additional research to be conducted in other regions and drainages with different faunas and hydrological regimes to gain a broader perspective on impacts of non-hydroelectric dams on stream communities.

Objectives

The impacts of dams on stream fauna have been broadly generalized in the literature. In reviewing the literature, I have found no study that compares fish assemblage sensitivity to dams among multiple river drainages and physiographic region. Furthermore, I have found no study which compares assemblage sensitivity to any disturbance among multiple drainages and physiographic regions. These factors mainly arise as potential confounding variables (Gehrke et al. 1999). My study was designed to investigate the impacts of non-hydroelectric dams on stream fish assemblages across the state of Georgia. I have examined whether dams alter downstream fish assemblages. I hypothesized that IBI score and native species richness would be significantly lower in treatment sites than reference sites. I have identified which fish guilds are most impacted by dams. I hypothesized that the relative abundance of *Lepomis* individuals and nonnative individuals would be significantly greater in treatment sites than in reference sites, and I predicted that relative abundance of darter individuals, cyprinid insectivores, and benthic fluvial specialists will be lower in treatment sites than reference sites. In addition, I tested the hypothesis that stream fish assemblages of different major drainage basins (Fig. 1), physiographic regions (Fig. 2), and stream orders do not respond identically to dams across the state of Georgia.

Dams can alter abiotic stream conditions downstream. Based on the primary literature, I hypothesized that sediment deposition, substrate embeddedness, and turbidity will be greater downstream of dams than in free-flowing reference sites. I also expect total habitat score to be lower downstream of dams than in reference sites.

Rahel (2002) claimed that dams and reservoirs homogenize freshwater habitats by creating conditions more suitable to lentic fishes. I tested whether dams homogenized the stream fish fauna of Georgia and compared the proportion of non-native species between dammed and free-flowing sites.

Most studies investigating the influence of dams on stream fauna have not accounted for the intensity of damming in the watershed. Instead, they focus on stream sections immediately downstream and only account for the impact of a single upstream dam. While these studies provide information on the impacts of dams on communities immediately downstream of a single dam, they are not necessarily representative of impacts throughout the watershed, where dam intensity differs at each location. I defined dam intensity as a product of both distance of a site from the nearest upstream dam and the proportion of the upstream watershed that is severed by dams.

Kinsolving & Bain (1997) and Phillips & Johnston (2004) found that stream fish assemblages near dams were more impacted than assemblages several kilometres downstream. I tested whether fish assemblages responded to dam intensity in the watershed, and I hypothesized that 1) assemblages would recover as distance from the nearest dam increased and 2) similarity of an assemblage to reference conditions would decrease as proportion of the watershed severed by dams increased.

II. METHODS

Study Sites

The data used in this study was collected by the Georgia Department of Natural Resources Stream Survey between 1998 and 2003 as part of a statewide biomonitoring program. The survey sampled 621 sites across several physiographic provinces and drainages of Georgia (Fig. 3). Stream Survey methods are covered in detail in the Standard Operation Procedures (Georgia Department of Natural Resources 2005). In general, the Georgia Stream Survey sampled road accessible sites, upstream of bridges. Each site equalled 35 x the mean standard width of the stream, but not exceeding 500 m in length. At least 3 pools, 3 runs, and 3 riffles were sampled at each site. Fish were collected using electroshock backpack units and seines. All fish with total lengths of 25 mm and greater were included in the samples. The Stream Survey calculated both IBI score and Total Habitat Scores based on fish and habitat data respectively. The Index of Biotic Integrity (IBI) assesses biological integrity of a community based on species richness, evenness, proportional composition data, among other factors (Karr 1981; Georgia Department of Natural Resources 2005). Total habitat score was calculated in a similar manner utilizing several habitat metrics in the calculation (Georgia Department of Natural Resources 2005).

The National Inventory of Dams (NID) (http://crunch.tec.army.mil/nidpublic/webpages/nid.cfm) identifies 4,158 dams in the state of Georgia (Fig. 4). Of those dams, I have identified 3,886 candidates for my study.

Candidate dams were selected based on the following criteria. The dams are not: 1) hydro-power production dams, 2) associated with sewage treatment, 3) associated with mining (tailings dams), 4) and they are not deep-release dams. In addition, dams with unknown functions were generally not included. Dams with the following functions were considered for this study: flood control, water supply, recreation, farm ponds, irrigation, and mill dams.

Of the 621 sites sampled by the Stream Survey, I used sites that fell within 10 km downstream of an eligible dam. This falls well within the affected range documented by Kinsolving & Bain (1993) and Phillips & Johnston (2004). Dammed sites may be downstream of one or several eligible dams; however for inclusion, they must be at least 10 km away from any dam downstream of the site.

Reference sites were selected from the 621 Stream Survey sites. Reference sites occur on free-flowing streams, and they fall both within the same physiographic region and the same drainage as the dammed sites. Reference sites were at least 10 km away from downstream dams, with no impoundment occuring upstream.

ArcMap (2005) was used to choose study sites, by calculating distances of both reference sites and dammed sites from impoundments to ensure that they fell within the specified ranges. It was also used to determine stream order of each site. Thirty-seven treatment sites and thirty-seven reference sites were used and are shown in Table 1 and

Fig. 5, and general information about each site is shown in Appendix A. All data analyses were run using SAS 9.1 (2001).

Broad scale impacts of dams on fish assemblages

To determine whether non-hydroelectric dams alter stream fish assemblages, I compared mean IBI scores and mean native species richness between reference and treatment sites spanning regions, drainages, and stream orders (Fig. 5). The number of native species was calculated by subtracting the number of non-native species (exotic and cross-drainage transfers) from the total species richness. Information on non-native species was gathered from the USGS: Nonindigenous Aquatic Species Database (http://serc.carleton.edu/resources/22354.html). I did not use native species richness as calculated by the Georgia Stream Survey, because they did not account for all inter-basin transfer species. IBI scores were calculated by the Stream survey. Scores ranged from 8 (Very Poor) to 60 (Excellent). Several metrics were used in the calculation of IBI scores. Scoring was very similar across regions, drainage basins, and stream orders and is discussed in detail in (Georgia Department of Natural Resources 2005). I used a balanced study design to ensure factors of interest in this study did not confound impacts of dams, therefore slight differences in IBI metrics are irrelevant because distribution of sites among regions is exactly the same for treatment and reference sites. I used a Kolmogorov-Smirnov test to test for normality on all metrics used in this study and Levene's Test to examine the assumptions of equal variance associated with the two sample t-test and ANOVAs. IBI score data were normal ($P > .1500$) and the assumption of equal variances was upheld ($P = 0.287$), so I used a two-sample t-test to determine whether IBI score significantly differed between treatment and reference sites. Native species richness was non-normal (*P* = 0.0208), and a log transformation normalized this data (*P* > 0.1500). The equal variance assumption was upheld for native species richness data (*P* = 0.2309), therefore I used a two-sample t-test on the log transformed data to determine if native species richness significantly differed between treatment and reference sites.

I compared relative abundance of darters, cyprinid insectivores, benthic fluvial specialists, sunfishes, and non-native species between dammed and free-flowing sites using two-sample Wilcoxon Rank Sum tests because percentage data generally does not fit the assumption of normality. Levene's Test indicated that the assumption of equal variances was upheld for relative abundances of darters (*P* = 0.111), cyprinid insectivores (*P* = 0.437), benthic fluvial specialists (*P* = 0.546), sunfishes (*P* = 0.051), and non-native individuals (*P* = 0.1152).

Abundances for fish species at each sample site are shown in Appendix B. Relative abundances of cyprinid insectivores and sunfishes were calculated by the Georgia Stream Survey. The percent cyprinid insectivores (PerCypIns) compared the relative abundance of individuals of the family Cyprinidae, which feed on insects at various levels of the water column. This metric spanned 15 genera and included 64 species in Georgia (Georgia Departement of Natural Resources 2005). The relative abundance of sunfishes (% *Lepomis*) compared abundance of individuals in the genus *Lepomis* to total individuals collected at each site. I calculated the relative abundances of benthic fluvial specialists, darters, and non-native individuals. I defined benthic fluvial specialists as any species which is morphologically adapted to living close to the stream bed and in lotic conditions. The relative abundance of darters was calculated by dividing the number of darter individuals to the number of all individuals. Relative abundances of darters and non-native species were calculated in the same manner. I used the USGS: Nonindigenous Aquatic Species Database to define non-native species by drainage basin. All species classifications are shown in Table 2 and relative abundances in Table 3. Cyprinid Insectivores were classified by the Stream Survey, and specific designations were not available from the data set, so they are not included in Table 2 classifications.

Broad scale impacts of dams on downstream habitat

Based on the literature reviewed above, dams have been known to alter substrate and sediment conditions downstream. I compared the overall turbidity, sediment deposition, substrate embeddedness, and total habitat scores between reference and treatment sites. All site habitat data is listed in Appendix C. All four of these metrics were calculated by the Georgia Stream Survey. Turbidity of the stream water was measured using a turbidity meter. The sediment deposition metric was a visual assessment of the proportion of fine sediments (sands and silts) in the deposition areas of the stream. Values ranged from 0 (100% sediment deposition) to 20 (no sediment deposition). The embeddedness metric was a visual assessment of the depth rocky substrate was buried with fines. This measurement was only taken in the Ridge and Valley and Piedmont regions because rocky substrate is rare on the coastal plain. Values ranged from 0 (100% embedded) to 20 (<10% embedded). Total habitat score was calculated from numerous habitat variables including the ones listed above and ranged from 0 (Very Poor) to 170 (Excellent). I tested assumptions of normality (Kolmogorov-

Smirnov) and equal variances (Levene's Test) to determine the appropriate two-sample test to use for these data. Total Habitat Score data was normal ($P = 0.129$), and variances were equal ($P = 0.274$), so a two-sample t-test was used to determine if there was a significant difference between treatment and reference site habitat scores. Turbidity data was non-normal (P<0.010), but a square root transformation normalized the data ($P > 0.150$), and variances of turbidity value square roots was equal ($P = 0.113$). I used a two-sample t-test on the square root transformed turbidity values to determine differences in reference and treatment site turbidity. The assumption of normality was suspect for both embeddedness and sediment deposition data ($P < 0.010$ and $P = 0.088$) respectively, but variances were equal ($P = 0.953$ and $P = .182$) respectively. Embeddeness and sedimentation data were analyzed using Wilcoxon Rank Sum Test.

Fish fauna homogenization

In determining whether dams cause broad-scale homogenization of freshwater fish faunas across the state, I calculated the Bray-Curtis Similarity within selected reference sites and compared it with similarity within selected treatment sites. For this comparison, I used eighteen treatment sites and eighteen references sites. To control for stream order, I only calculated similarity between sites of the same order. I randomly selected one treatment site and one reference site from each of the six drainage-physiographic units for first order streams. I randomly selected two treatment sites and two reference sites from each drainage-physiographic unit for second order streams. Similarity was only calculated between sites of different drainage-physiographic provinces. I then compiled all similarity values for reference sites and compared them to all values for treatment sites. Seventy-five similarity values were calculated between reference sites, and seventy five similarity values were calculated between treatment sites.

In theory, faunal heterogeneity exists on a broad scale due to natural habitat heterogeneity across the state. As mentioned above, habitat heterogeneity is enhanced by diversity of physiographic provinces, drainages, and stream orders. My study sites spaned different levels of these three factors. If dams truly reduce habitat and fish faunal heterogeneity (Sensu Rahel 2002), then within-treatment similarity should be greater than within-reference similarity. Similarity data for this comparison was non-normal ($P <$ 0.0100), but an ArcSine(sqrt) transformation normalized the data so that I could analyze it using a . The assumption of equal variances was upheld (P = 0.530).

I calculated Bray-Curtis Similarity using Ecological Methodology software (Kenny & Krebs 2000). Bray-Curtis Similarity Index was chosen over other similarity indices because it is a commonly used presence/absence based metric. Bray-Curtis was choosen as a metric for this study, because it is sensitive to changes in rare species.

Intensity of Disturbance

All treatment sites occurred between 0.2-10.5 km downstream of the nearest dam. In addition, several dams may occur upstream of a treatment site. I used the ArcMap measure tool (ArcMap 2005) to determine distance between dams and sample sites. I also used it to determine the percentage of the upstream river miles that were severed by dams. Calculations of site distance from the nearest dam and percentage of the watershed severed by dams (% dammed) are shown in Appendix C. I used simple linear regression to determine if either of these two factors influenced fish assemblage response to dams. Because percentage data typically do not meet assumptions of normality, I arcsine-square-root transformed proportion of the watershed that was dammed. I then used simple linear regression in SAS to predict IBI score with the transformed values. I also predicted IBI score based on distance from the nearest dam. Native species richness data were normalized with natural log transformation. I predicted native species richness using simple linear regression, using transformed native species richness data with transformed (% dammed) data and distance data independently.

Influence of Drainage, Physiographic Region, and Stream Order

I compared the sensitivity of fish assemblages to dams between physiographic provinces, drainage basins, and stream orders. I first tested for significance of interaction effects between each factor independently. I used an ANOVA to compare IBI scores and Similarity among the three drainage basins (Table 4), three physiographic provinces (Table 5), and three stream orders (Table 6).

It was not possible to use a balanced factorial design to investigate the response of fish assemblages to dams across all regions, drainages, and stream orders simultaneously, because all river drainages did not flow through all regions of interest, and sites of all three stream orders were not always available (Table 1). Therefore, I split this analysis into two 2-factorial designs. I compared assemblage sensitivity to dams between the Ridge and Valley and Piedmont regions and between 1st and 2nd order streams in the Alabama River Drainage using a three factor ANOVA (Table 7), although I compared assemblage sensitivity to dams between the Apalachicola and Altamaha River drainages, the Piedmont and Coastal Plain regions, and stream srders 1 and 2 using a four factor ANOVA (Table 8).

Comparison between Ridge and Valley and Coastal Plain was not possible, because they did not share a common drainage. I compared the response of Altamaha River Drainage with Apalachicola drainage fish assemblages in the Piedmont and Coastal Plain regions. I also compared the influence of stream order (1-3) on fish assemblage response to dams. IBI score was used as a metric for these analyses. IBI score was included in two separate multi-factor ANOVAs. One ANOVA examined the influence of physiographic province and stream order in the Alabama River Drainage. The other examined the influence of drainage basin, physiographic province, and stream order on fish assemblage response to dams in the Apalachicola and Altamaha River drainages.

III. RESULTS

Broad-scale impacts of dams on fish assemblages

Results for all fish assemblage metric comparisons between treatment and reference sites are shown in Table 9. Treatment and reference sites significantly differed in IBI score (*P* = 0.041). IBI score was on average 4.76 +/- 2.29 (x +/- SE) higher for reference sites than treatment sites (Fig. 6). Native species richness was on average 0.973 (+/- 1.38) higher in reference sites, but was not significantly greater than native richness in treatment sites (P = 0.483, Fig. 7).

The mean percentage of *Lepomis* individuals was significantly greater (*P* = 0.022, Fig. 8) in treatment sites (35.181 +/- 4.26 %) than reference sites (21.81 +/- 3.29 %). Mean percent darter individuals was not significantly greater (*P* = 0.512, Fig. 8) in reference sites (5.98 +/- 1.04 %) than treatment sites (4.46 +/-0.68 %). Mean percentage of cyprinid insectivore individuals was higher in reference sites (35.64 +/- 3.63 %) than treatment sites (27.53 +/- 4.05 %), but the difference was non-significant (P = 0.079, Fig. 8). The proportion of non-native species was compared between treatment and reference sites. Percent non-native species was on average 5.42 +/- 2.97 % greater in treatment sites than reference sites but the difference was non-significant (*P* = 0.080, Fig. 9). Relative abundance of benthic fluvial specialists was 6.17 +/- 4.38 % higher in reference sites than treatment sites, but this difference was non-significant (*P* = 0.113, Fig. 10).

Broad-scale impacts of dams on downstream habitat

Results for all habitat comparisons between treatment and reference sites are shown in Table 10. Mean total habitat score for reference sites was not significantly higher than for treatment sites. Neither substrate embeddedness and sediment deposition scores were higher in reference sites than treatment sites (*P* = 0.220, *P* = 0.166) respectively. Higher scores for each of these metrics are given to sites with minimal embeddedness and sediment deposition. Turbidity was not significantly higher higher in reference sites than treatment sites (*P* = 0.977).

Fish Fauna Homogenization

Results of all pairwise Bray-Curtis similarity values within treatment sites and within reference sites are shown in Tables 11. Mean similarity within treatment sites was 0.368 +/- 0.020, while Mean similarity within reference sites was 0.312 +/- 0.018. There was a significant difference (*P* = 0.040) between within-treatment site similarity and within-reference site similarity was 0.056 +/- 0.027 (Fig. 11).

Intensity of Disturbance

Treatment sites ranged from 0.2-10.5 km downstream of the nearest dam (mean =3.36 km) and received flows from watersheds that were between 1.66-98.89 % regulated (mean = 45.87 %). Results of simple linear regression suggested that distance downstream of a dam was not a strong predictor of IBI Score or native species richness (r^2 = 0.001, *P* = 0.823, Fig. 12) and (r^2 = 0.0329, *P* = 0.283, Fig. 13). I also used simple linear regression to predict IBI score and Native Species Richness based on proportion of the watershed that was severed by dams (% dammed). The transformed % dammed values were not strong predictors of IBI score or native species richness ($r^2 = 0.033$, $P = 0.281$, Fig. 14) and ($r^2 = 0.033$, $P = 0.283$, Fig. 15).

Influence of Drainage Basin, Physiographic Region, and Stream Order

I analyzed the influence of drainage, region, and stream order individually on assemblage sensitivity to dams as measured by IBI score and found that although the dams significantly influenced IBI score, drainage ($P = 0.341$), region ($P = 0.896$), and stream order ($P = 0.170$) did not significantly interact with the impact of dams (Table 12).

I investigated the interaction of region (Ridge and Valley and Piedmont) and stream order (1 and 2) on assemblage sensitivity to dams in the Alabama River Drainage using a three factor ANOVA (Table 13). This analysis revealed no significant difference in IBI score between treatment and reference sites ($P = 0.534$), and no significant interaction with region ($P = 0.378$) or stream order ($P = 0.758$).

I investigated the interaction of drainage (Apalachicola and Altamaha), region (Piedmont and Coastal Plain), and stream order (1 and 2) with assemblage sensitivity to dams in the Apalachicola and Altamaha River drainages using a four factor ANOVA (Table 14). I found no significant difference in IBI score between treatment and reference sites ($P = 0.352$) using this analysis. Interactions with drainage ($P = 0.544$), region ($P = 0.461$), and stream order ($P = 0.702$) were all non-significant (Table 14). In addition the 3-way interaction between drainage-physiographic unit and treatment was also non significant ($P = 0.439$).

IV. DISCUSSION

Broad scale impacts of dams on Georgia's fish fauna

It is apparent from the analyses in this study that dams have severely impacted the fish fauna of Georgia. Overall biotic integrity was significantly lower in sites that occurred below dams than in free-flowing reference sites. In addition, the overall fish fauna of Georgia was homogenized in the presence of dams. Fish assemblages downstream of dams were significantly ($P = 0.040$) more similar to one another than within free-flowing reference sites. Dams are only one of many human alterations of streams in the Southeast, and if non-hydroelectric dams alone have reduced fish faunal heterogeneity by 5.6% among drainage-physiographic provinces, the cumulative impacts of all anthropogenic disturbances including land-use and chemical pollutants must be devastating the southeastern fish fauna. Not only are current human actions influencing stream fish assemblages, but the ghost of land-use past may be even harder to detect and could have a substantial impact on a fish fauna.

Rahel (2002) attributed homogenization of freshwater faunas to introduction of non-native species, extirpation of native species, and changes in habitat conditions. Homogenization of the fish fauna observed in this study is likely due to changes in downstream habitat associated with dams, reservoir stocking of centrarchids, and loss of fishes more adapted to lotic conditions. Several authors have suggested an increase in cosmopolitan species and a loss of local specialist species in disturbed habitats (Scott &

Helfman 2001; Rahel 2002; and Roy et al. 2005). Consistent with findings in other we found a general decrease in species more adapted to lotic conditions. Relative abundances of darters and cyprinid insectivores were lower downstream of dams. On average relative darter abundance was 1.5 % lower at treatment sites than at reference sites, and relative abundance of cyprinid insectivores was 8.12 % lower at treatment sites than at reference sites. However, neither difference was significant (P = 0.5139 and P = 0.1401) respectively. This may have occurred due to abundance of generalist species in both groups. It is likely that there are species within these groups that are particularly impacted while generalists are not, yielding differences in relative abundances that are not significant.

Intensity of Disturbance

I hypothesized that the impact of a dam depends on the distance of a study site from the nearest dam and the proportion of the upstream watershed that was severed by dams. I found that neither of these factors had a significant influence on IBI Score or native species richness. As mentioned above, several studies have suggested stream fauna recover as distance increases from a dam over longer distances. For example, Phillips & Johnston (2003) found that fish assemblages became increasingly similar to historical reference sites 10-20 km downstream of a dam. Other studies indicated much longer distances. My study investigated sites ranging from 0.2-10.5 km downstream of dams, and it is apparent that fish assemblages in the Southeast cannot recover in such a short distance. This has implications for dam placement. For freshwater fish biodiversity to be maintained in the southeast, it is imperative that stretches of stream longer than 10.5

km exist for recovery to occur when an assemblage is impacted by a dam. Dam removal can open up longer stretches of stream, however the pulse of water and sediment following dam demolition may have dramatic effects on the downstream fish assemblages.

Surprisingly, the proportion of upstream watershed impounded did not significantly influence IBI score or native species richness. It is possible that this study was conducted over such a broad scale that independently insignificant confounding variables cumulatively masked the influence of dam intensity in the watershed. I would be interested to see how randomly selected sites at any distance downstream or upstream, % watershed impounded, and variations of other factors influenced metrics of fish biodiversity.

Habitat alterations downstream of dams

Although none of the habitat metrics significantly differed between dammed and free-flowing sites, information can be gathered from the statistically non-significant differences. Total habitat, embeddedness, turbidity and sediment deposition all scored higher in reference sites. As mentioned above, a high score for embeddedness, turbidity, and sediment deposition relates to minimal impacts of the respective factor.

Influence of Drainage Basin, Physiographic Region, and Stream Order

Fish assemblages of different drainage basins, physiographic provinces, and stream orders are often distinct; however, none of these three factors significantly interacted with fish assemblage response to dams. If the univariate analyses in this study are representative of all streams in the southeast, we can conclude that effects of dams can be generalized across the Ridge and Valley, Piedmont, and Coastal Plain regions of Georgia. We can assume that impacts of dams can be generalized among the Alabama, Apalachicola, and Altamaha River drainages and across stream orders 1, 2, and 3. Gehrke et al. (1999) investigated the influence of dams across three river drainages in the Hawkesbury-Nepean River System of Australia. The authors suggested that natural differences in fish assemblages may have confounded the impacts of dams on fish assemblages. If we extend the assumption that fishes of river drainages don't respond significantly differently to dams, then confounding by drainage should not be a consideration in this Australian study.

Sample size was low in analyses examining these factors simultaneously. It was not possible to compare the Ridge and Valley region to the Coastal Plain in these multivariate analyses because they did not share a common river drainage, nor was it possible to compare interaction of drainage on assemblage sensitivity to dams between the Alabama and Altamaha River drainages. It is possible, however, that assemblages of adjacent physiographic regions and drainage basins were simply not distinct enough to be differentially sensitive to dams.

It is not as surprising that fish assemblages of different stream orders (1-3) did not react differently to dams. However, if a wider range of stream sizes was employed, a stronger trend may have been observed. If assemblage sensitivity to dams is truly not impacted by stream order, then regardless of where a dam is placed in a stream longitudinally, it will have the same effect on the local fish assemblage. This result, if true, would have implications for dam construction. In choosing the site for construction of a non-hydroelectric dam, placement in the stream longitudinally is irrelevant to the impact it will have on the stream fish assemblage for first, second, and third order streams.

Alternative Quantitative Methods

A resourceful way of gaining information from a large dataset would be to use data reduction techniques such as Principle Component Analysis (PCA) or Canonical Correspondence Analysis (CCA) to identify dominant factors when investigating trends in large data sets. I made *a priori* hypotheses based on the primary literature and tested them specifically. The advantage of this is that I reduced the amount of type I error (false positive) at the expense of type II error (missing a trend). I only tested factors I thought would bear a significant influence on stream fish assemblages; however it is possible that a factor quantified in the dataset was overlooked. Data reduction techniques would also allow for identification of the species that changed most dramatically between dammed and free-flowing sites without having to rely on general groups such as benthic fluvial specialists. However, the same techniques increase the possibility of falsely finding that a given species changed between the site types.

V. CONCLUSIONS

This study supports the statement made by Rahel (2002) that dams are homogenizing the stream fish fauna of the southeastern U.S. Similarity of fish assemblages downstream of dams was significantly higher than similarity of fish assemblages occurring in free-flowing conditions. Downstream of dams, we found an overall decrease in biotic integrity of fish assemblages, but no significant difference in native species richness. Overall, we found a general increase in relative abundance of sunfishes (% *Lepomis*) downstream of dams when compared to free-flowing reference sites, however we found no significant difference in relative abundance of other groups (cyprinid insectivores, benthic fluvial specialists, darters, and non-native fishes) between below-dam and free-flowing sites.

We did not find that physiographic province (Ridge and Valley, Piedmont, and Coastal Plain), drainage basin (Alabama, Apalachicola, and Altamaha), or stream order (1, 2, and 3) significantly influenced fish assemblage response to a dam.

Despite findings in other studies that fish assemblages recover as distance from a dam increases, we found that assemblage sensitivity to dams could not be predicted by distance of an assemblage from the dam in the range of (0.2-10.5 km). It is possible that fishes need more unregulated stream distance to recover to a reference state below dams. In addition, we could not predict IBI score with proportion of the upstream watershed that was regulated (% dammed) in a range of (1.66-98.89 %) regulated.

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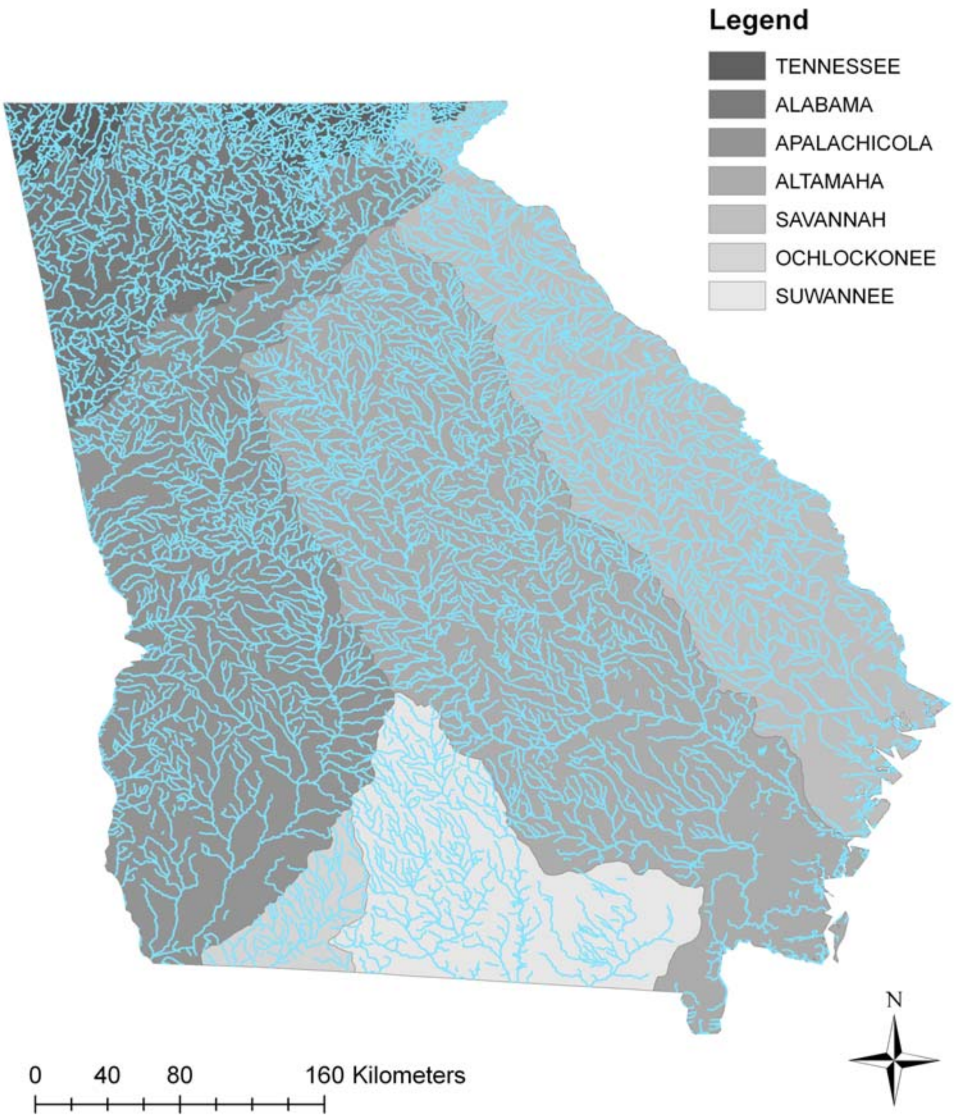

Fig. 1. Boundaries of the major river drainages of Georgia.

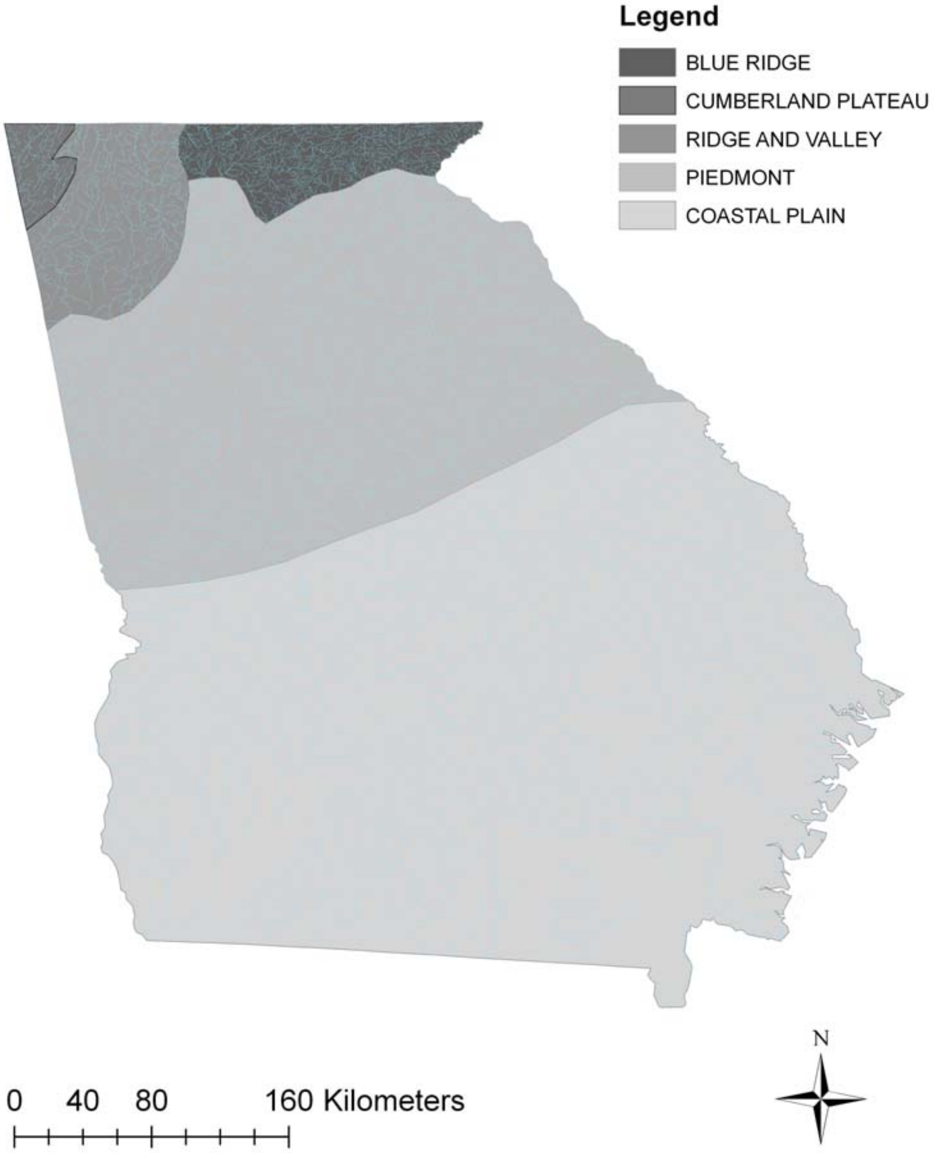

Fig. 2. Major physiographic provinces of Georgia

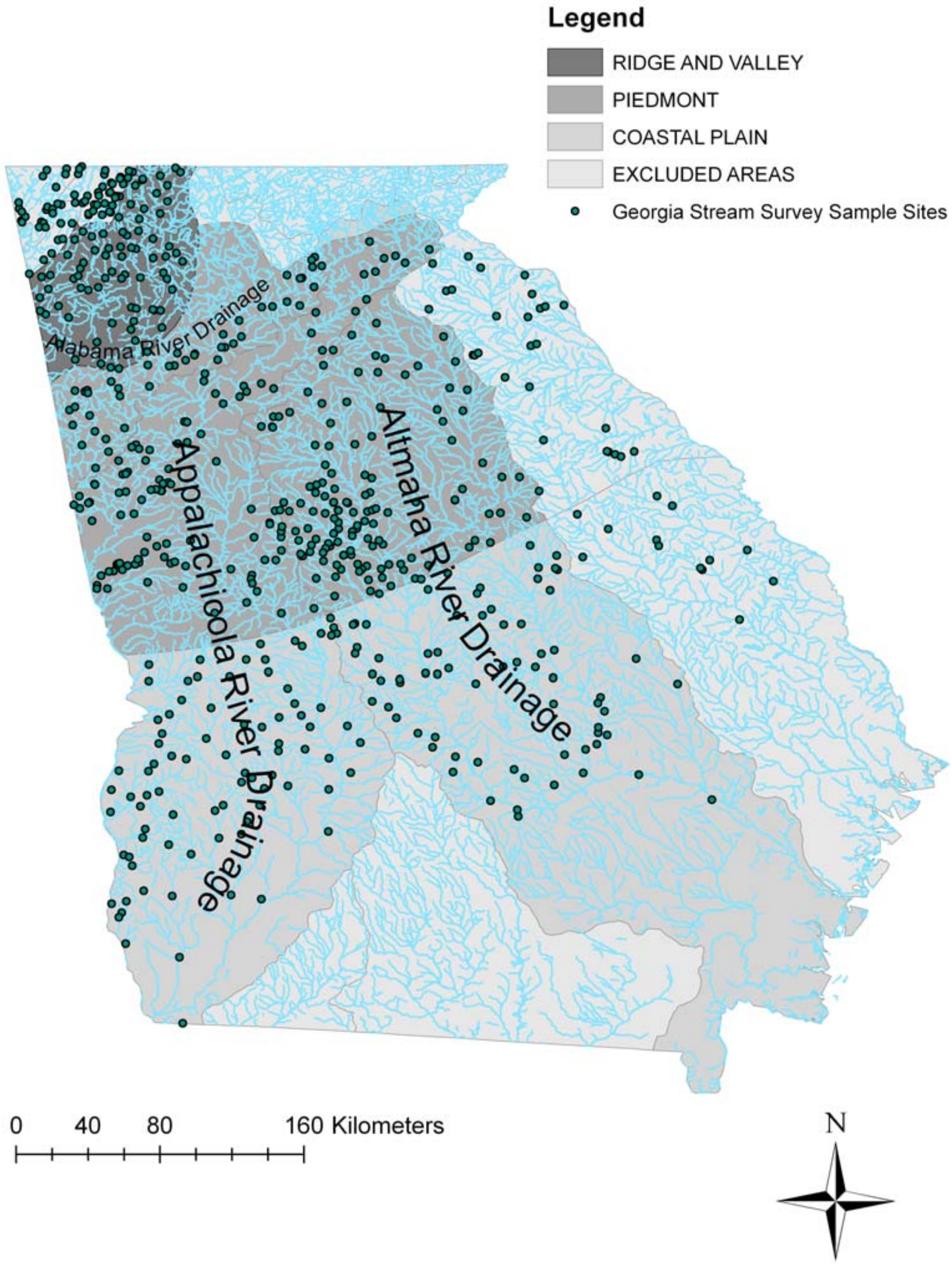

Fig. 3. Distribution of Georgia DNR Stream Survey sample sites from 1998-2003. Sample sites spanned eight major drainage basins.

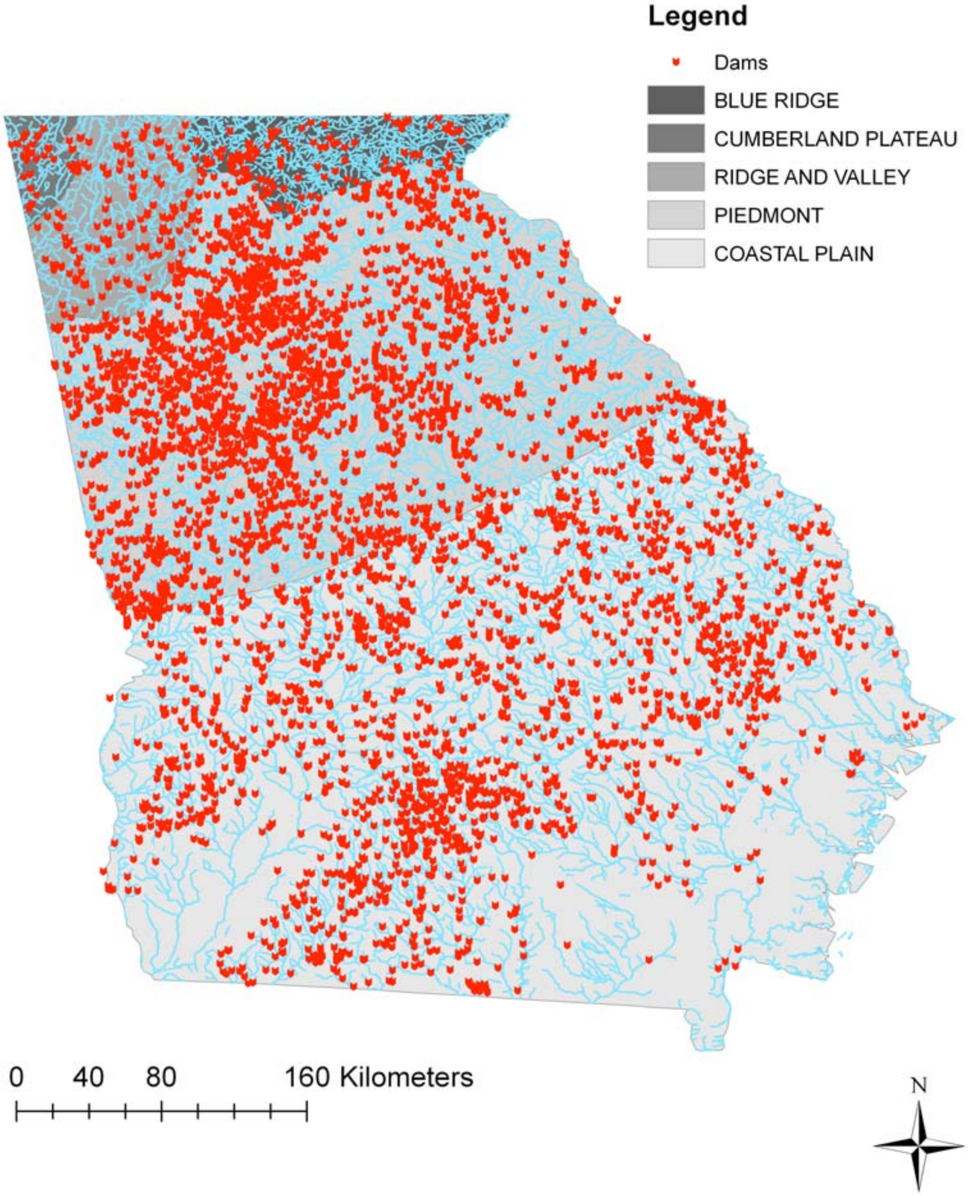

Fig. 4. Distribution of dams identified by the National Inventory of Dams (NID) throughout the state of Georgia.

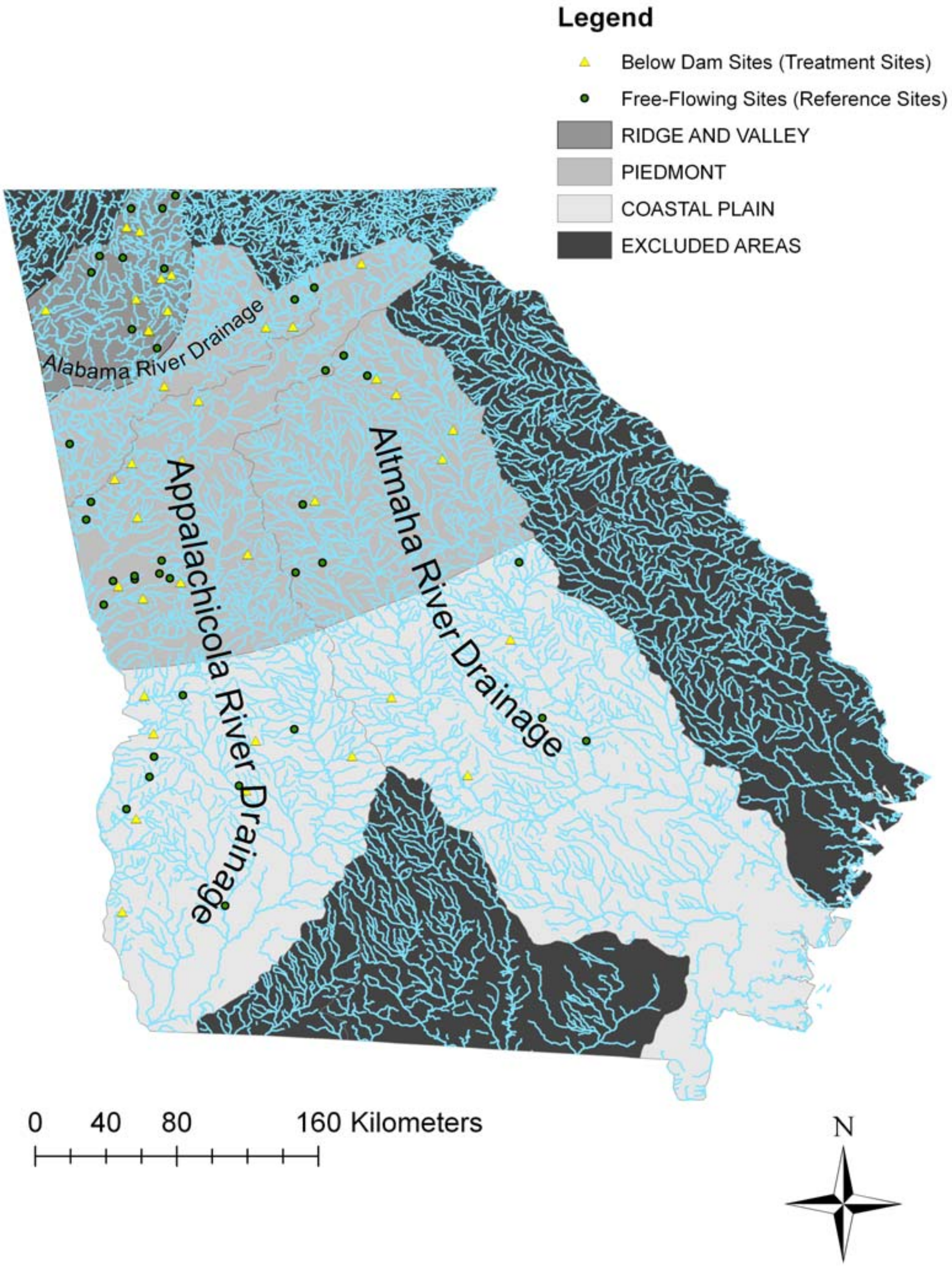

Fig. 5. Distribution of sample sites selected from the Georgia DNR data set. Study sites spanned three major river drainages, three major physiographic provinces and occurred on stream orders 1, 2, and 3.

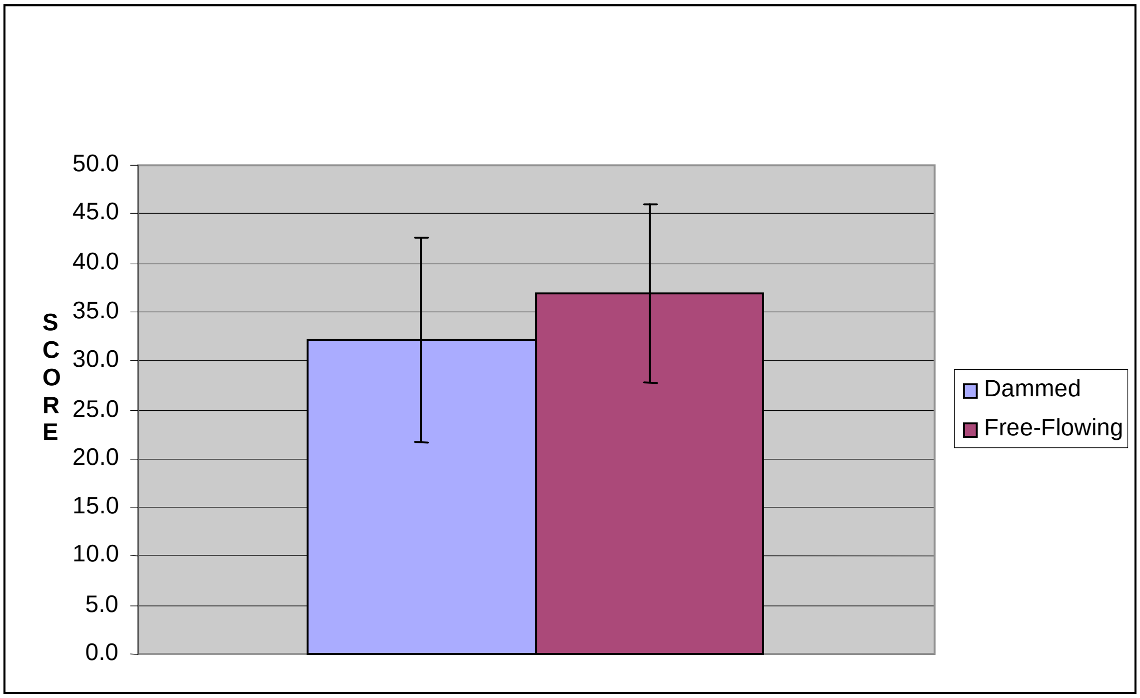

Fig. 6. Mean IBI score between dammed and free-flowing sites across Georgia. Mean IBI score for reference sites (36.92 +/- 1.50 SE) and (32.162 +/- 1.73 SE) Mean difference in IBI score between Dammed and Free-flowing sites was significant (P=0.041).

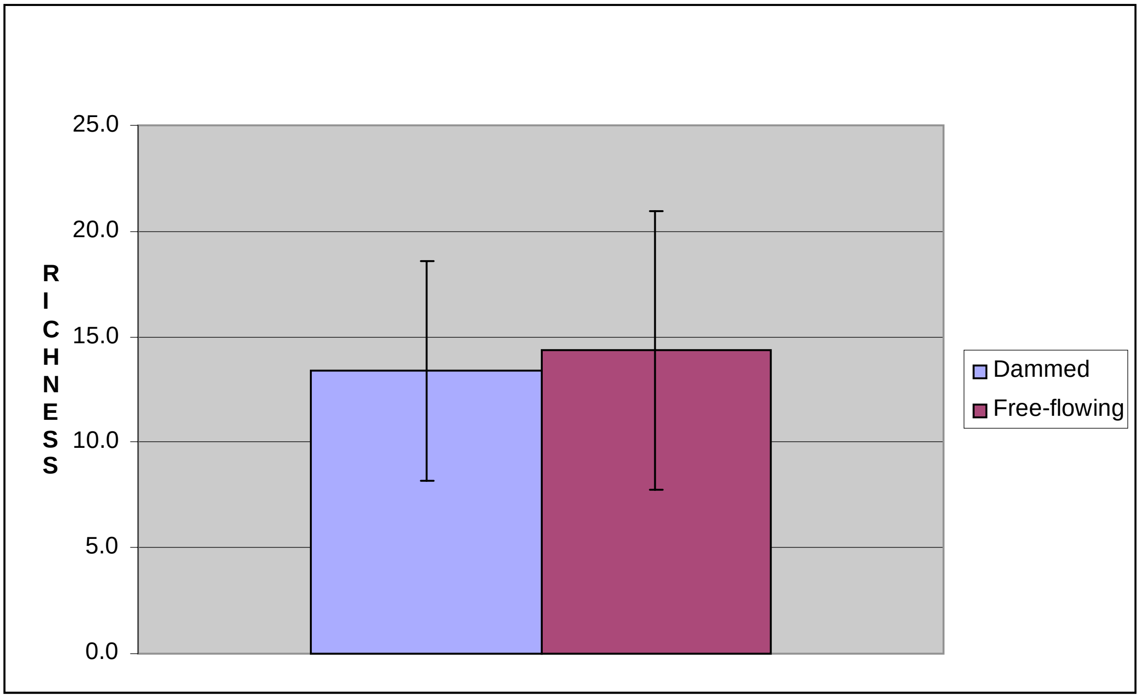

Fig. 7. Comparison in native species richness between dammed and free-flowing sites. Mean native species richness for free-flowing sites was 14.35 +/-1.08 SE and 13.378 +/-0.85 SE for below dam sites. The mean difference in richness was not significant (P=0.483).

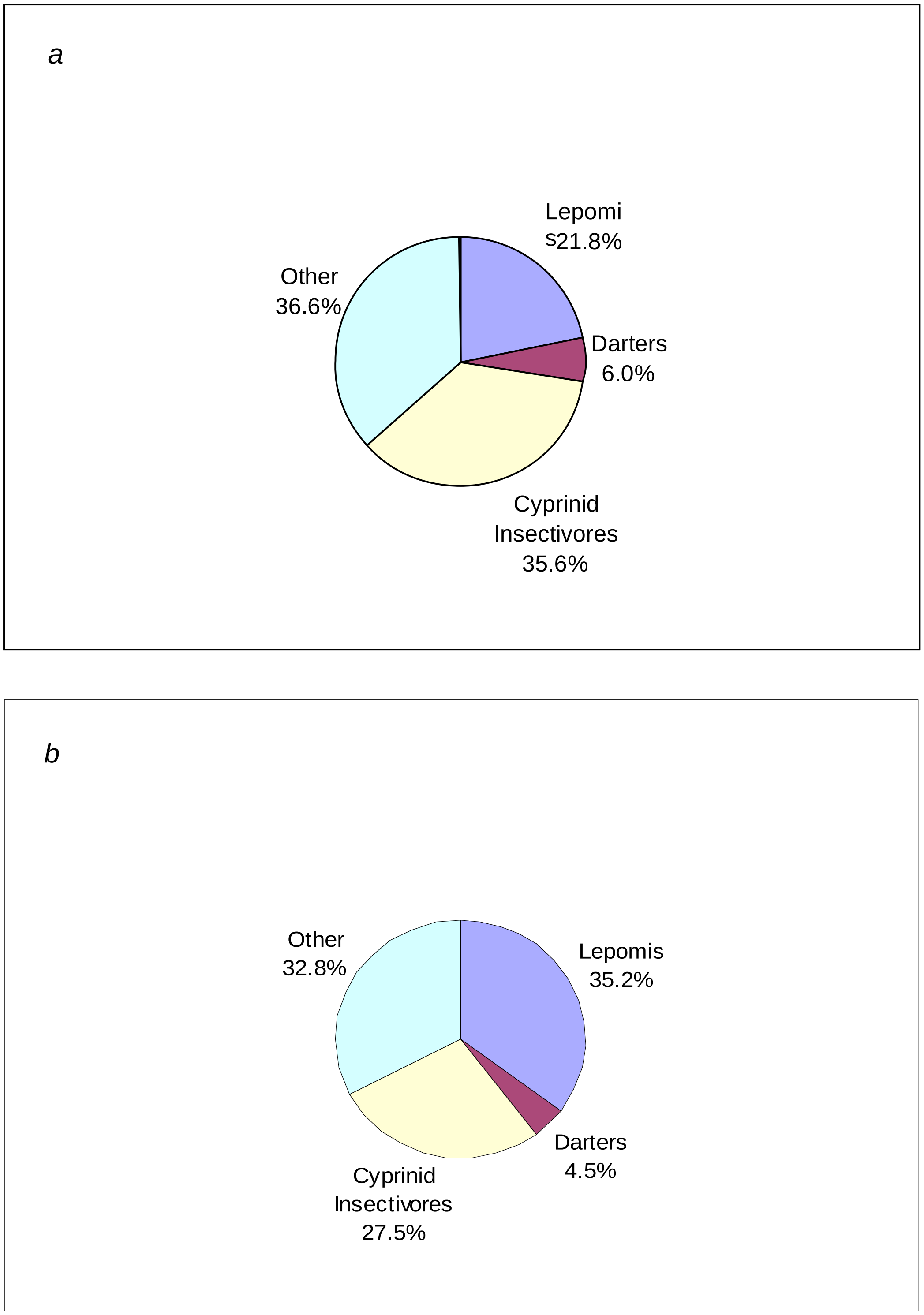

Fig. 8. Composition of (*a*) reference site and (*b*) treatment site fish assemblages across Georgia.

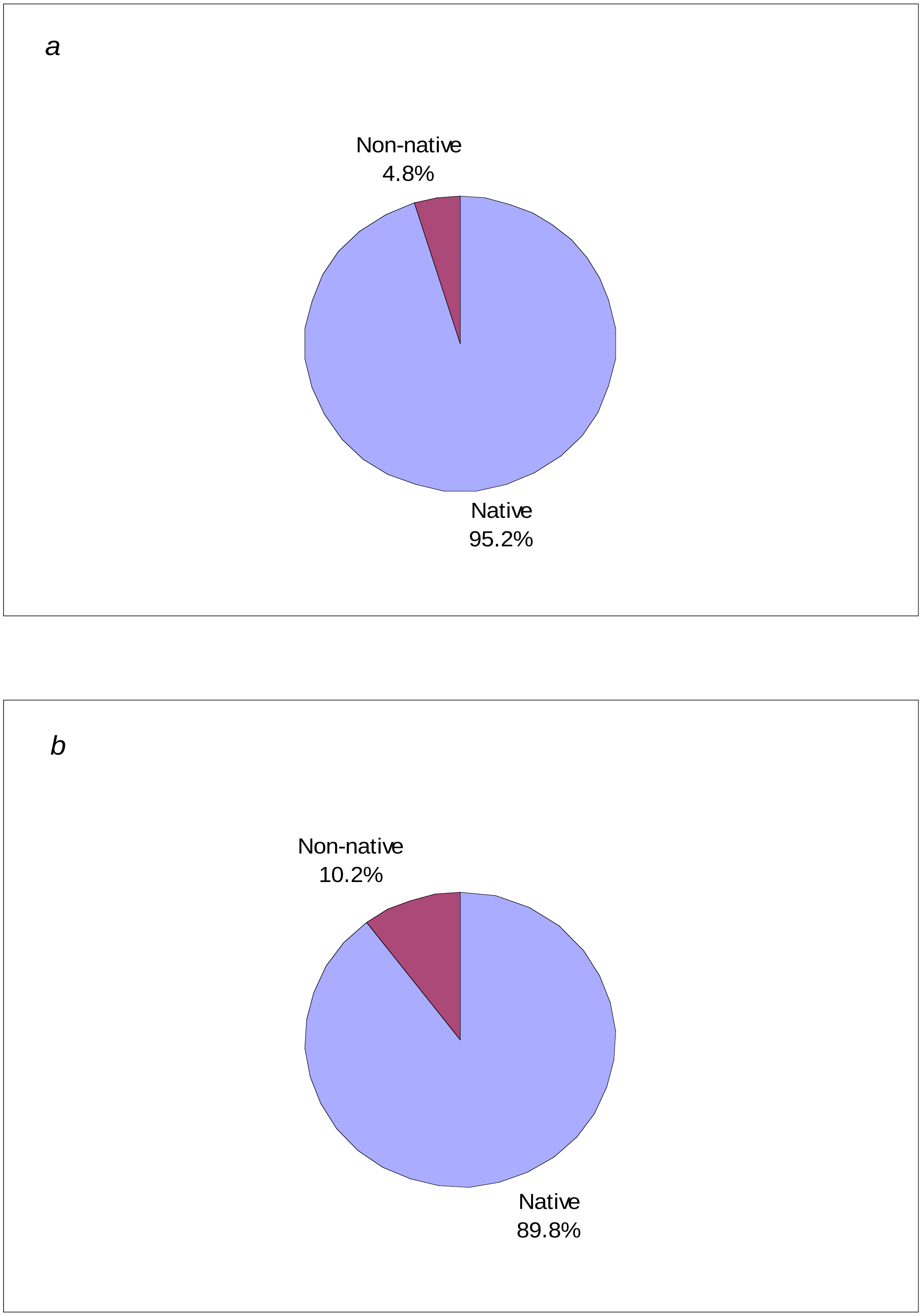

Fig. 9. Mean percentage of non-native individuals in reference sites (*a*) and treatment sites (*b*)

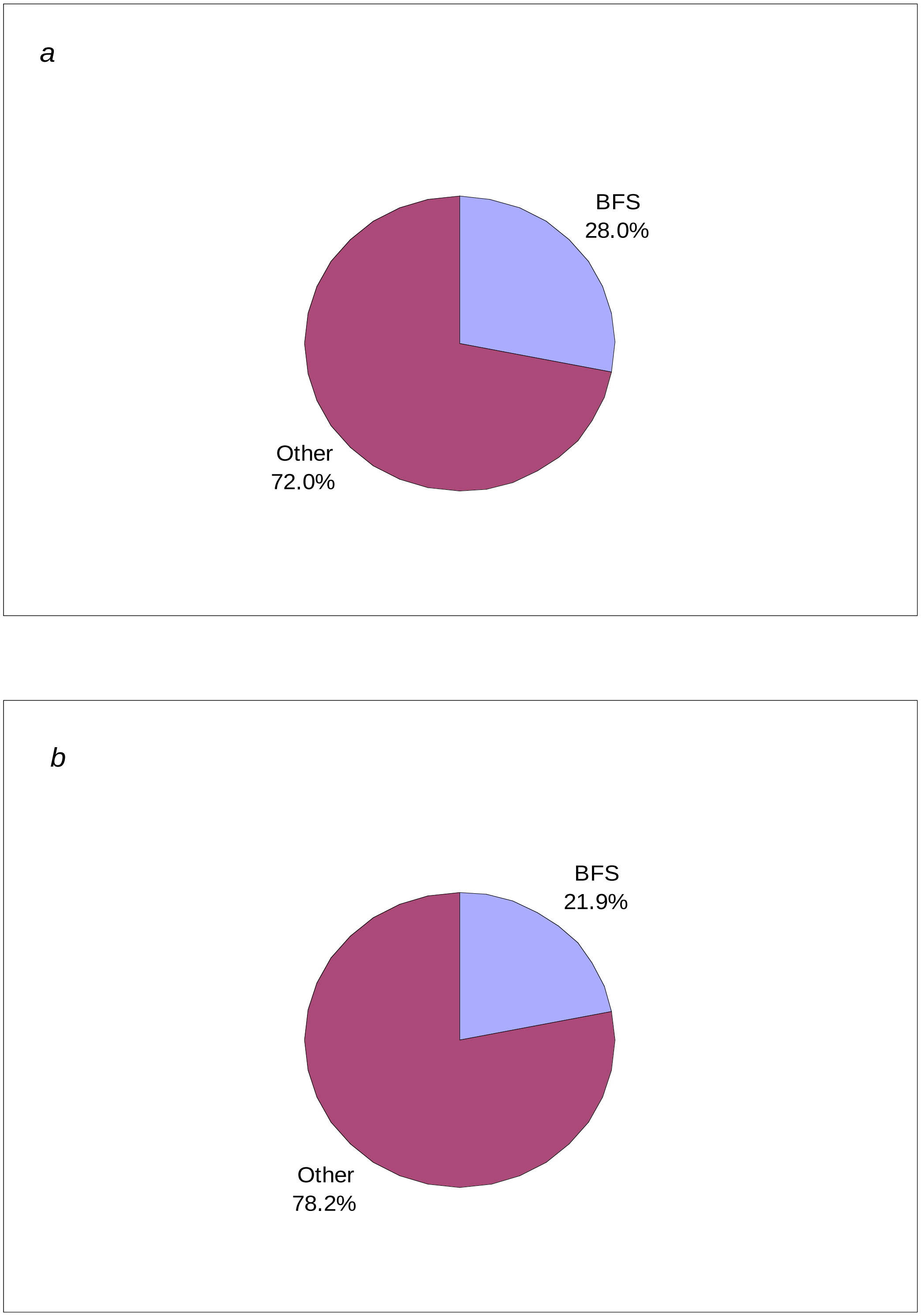

Fig. 10. Percentage of benthic fluvial specialist (BFS) species in (*a*) free-flowing and (*b*) dammed sites.

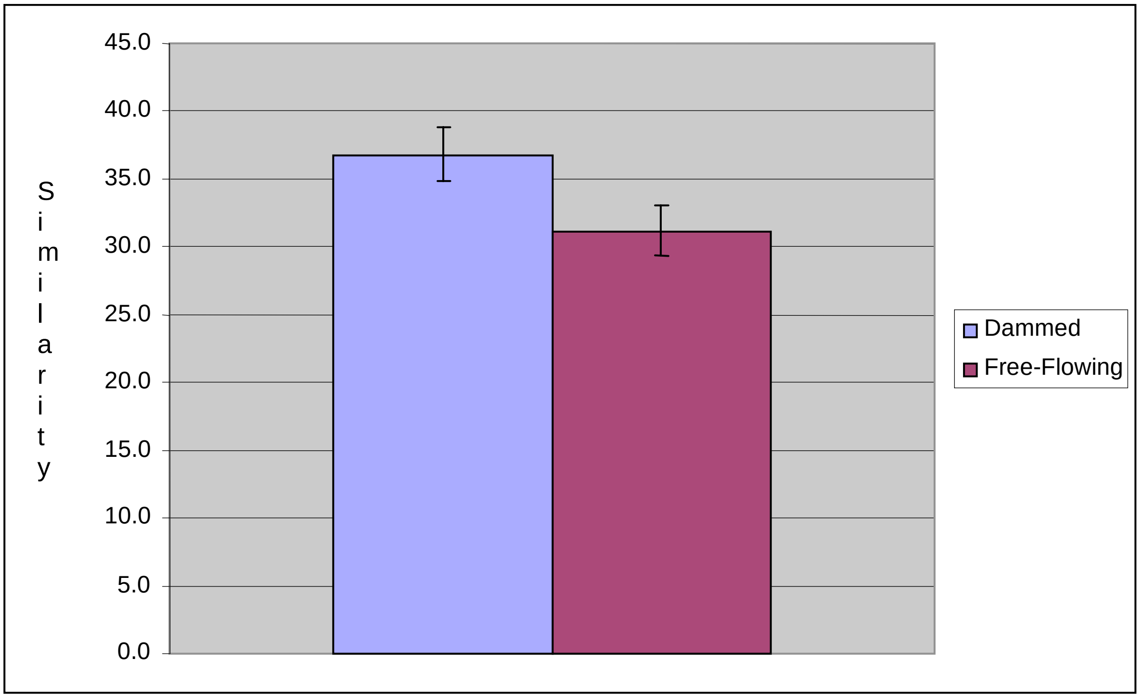

Fig. 11. Comparison of mean Bray-Curtis similarity within reference sites and within treatment sites. Similarity was 5.6 % higher within treatment sites (*P* = 0.040).

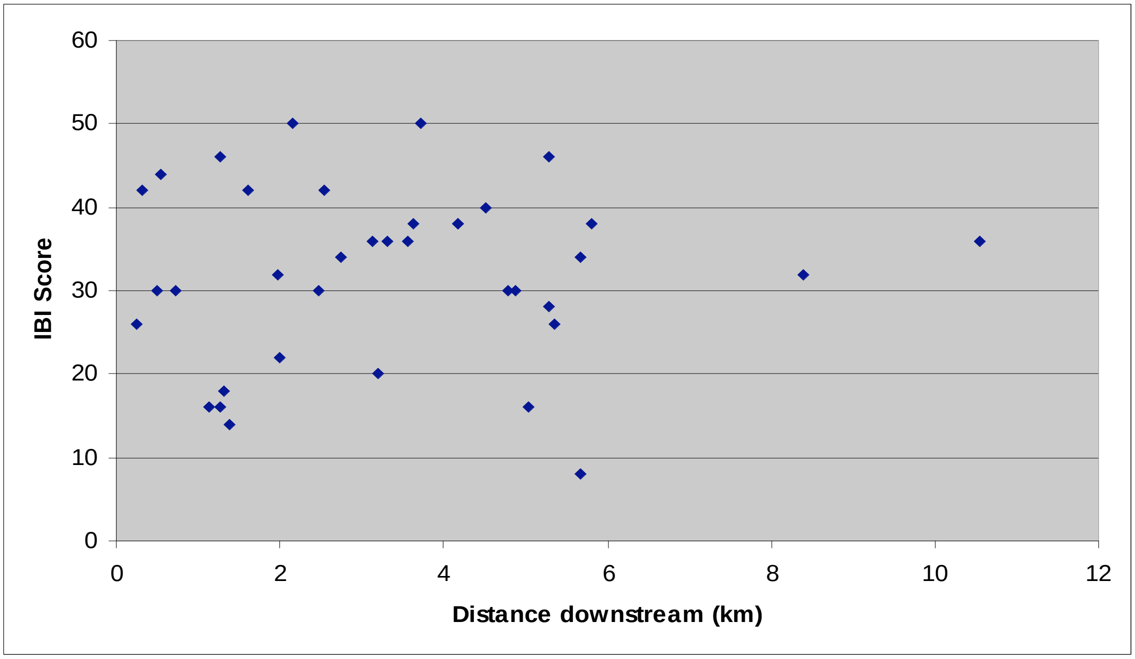

Fig. 12. Scatterplot showing IBI score against distance downstream of nearest dam ($r^2 = 0.001$, $P = 0.823$).

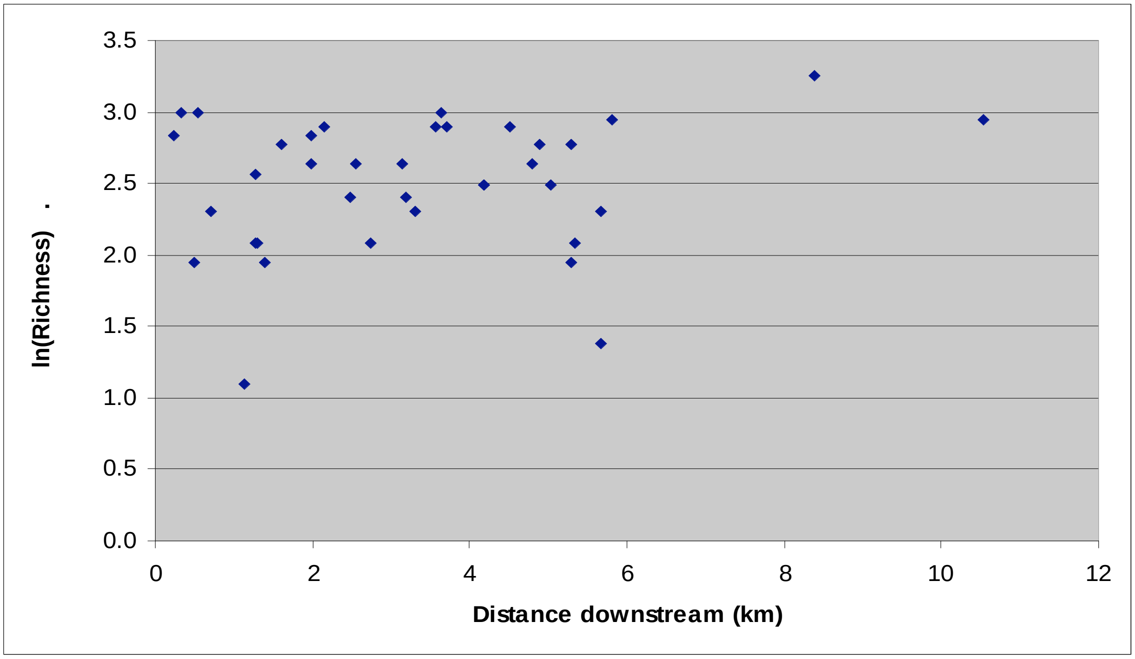

Fig. 13. Scatterplot showing ln(Native Species Richness) against distance downstream of nearest dam (r^2 = 0.040, P = 0.235)

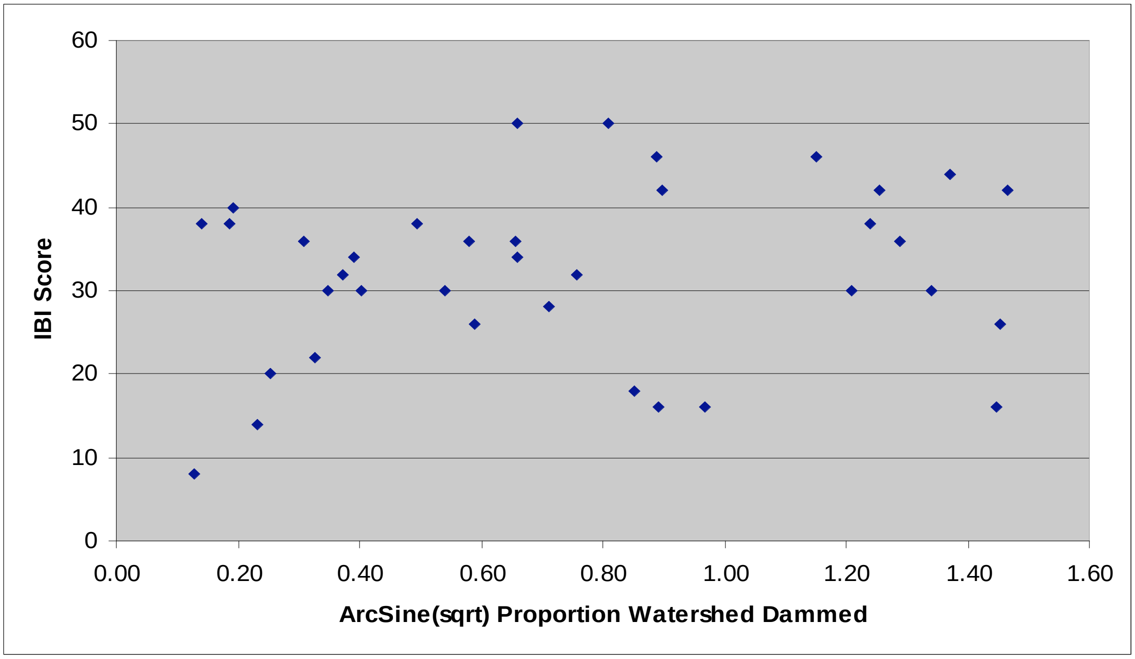

Fig. 14. Scatterplot showing IBI Score against ArcSine(SQRT) transformed Proportion of Watershed Dammed (r^2 = 0.033, P = 0.281)

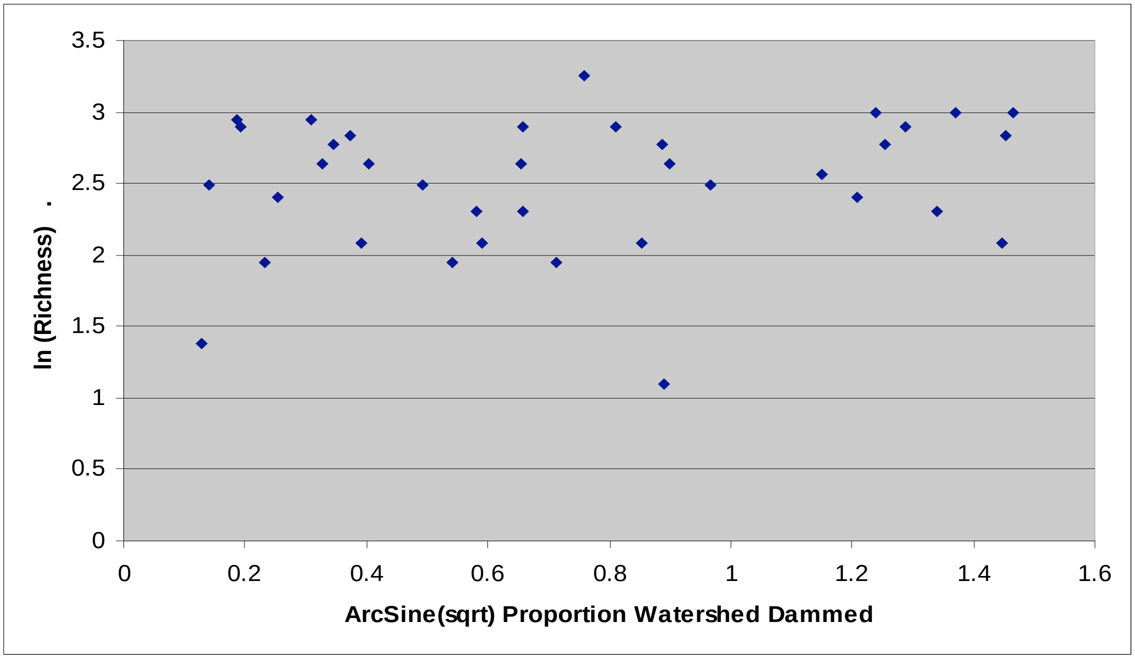

Fig. 15. Scatterplot showing ln(Native Species Richness) from ArcSine(sqrt) transformed Proportion of Watershed Dammed ($r^2 = 0.033$, $P = 0.281$)

Table 1. Study site distribution among physiographic regions (Ridge and Valley, Piedmont, and Coastal Plain), drainage basins (AL=Alabama River Drainage, AP=Apalachicola River Drainage, and AH=Altamaha River Drainage), stream orders (1-3), and site treatment (Dammed and Free-flowing). These sites were used in all comparisons requiring equal number of reference and treatment sites. Thirty-seven reference sites and thirty-seven treatment sites are shown.

		RIDGE AND VALLEY			PIEDMONT			COASTAL PLAIN		
Stream Order	Treatment	AL	AP	AH	AL	AP	AH	AL	AP	AH
1	Dammed	1	--	--	1	5	1	--	1	1
	Free-Flowing	1	--	--	1	5	1	--	1	1
2	Dammed	4	--	--	2	4	4	--	3	2
	Free-Flowing	4	--	--	2	4	4	--	3	2
3	Dammed	4	--	--	--	1	--	--	3	--
	Free-Flowing	4	--	--	--	1	--	--	3	--

Table 2. List of all species found in study sites across Georgia. Fishes are categorized in three ways. *Lepomis* and darters are categorized taxonomically. Benthic fluvial specialists (BFS) are identified in this study. Cyprinid Insectivores were classified by the Stream Survey and specific designations are not available (*see Methods*). An 'X' denotes a species that occured in study sites of a specific drainage (Alabama = AL, Apalachicola = AP, and Altamaha = AH) as a nonnative species.

Species	Taxonomic Group	BFS	Nonnative Species (by Drainage) AL	AP	AH
Acantharchus pomotis					
Ambloplites ariommus					
Ameiurus brunneus			X		
Ameiurus catus					
Ameiurus melas					
Ameiurus natalis					
Ameiurus nebulosus					
Amia calva					
Anguilla rostrata					
Aphredoderus sayanus					
Aplodinotus grunniens					
Campostoma oligolepis		BFS			
Campostoma pauciradii		BFS			
Centrarchus macropterus					
Cottus carolinae		BFS			
Cyprinella callisema					
Cyprinella callistia					
Cyprinella gibbsi					
Cyprinella lutrensis				X	
Cyprinella trichroistia					
Cyprinella venusta					
Cyprinus carpio			X		X
Dorsoma cepedianum					
Elassoma zonatum					
Ericymba buccata					
Erimyzon oblongus		BFS			
Erimyzon sucetta		BFS			
Esox americanus					
Esox niger					
Etheostoma brevirostrum	Darters	BFS			
Etheostoma coosae	Darters	BFS			
Etheostoma edwini	Darters	BFS			
Etheostoma fusiforme	Darters	BFS			
Etheostoma hopkinsi	Darters	BFS			
Etheostoma inscriptum	Darters	BFS			
Etheostoma jordani	Darters	BFS			

Etheostoma olmstedi	Darters	BFS			
Etheostoma scotti	Darters	BFS			
Etheostoma stigmaeum	Darters	BFS			
Etheostoma swaini	Darters	BFS			
Etheostoma tallapoosae	Darters	BFS			
Etheostoma trisella	Darters	BFS			
Fundulus chrysotus					
Fundulus escambiae					
Fundulus lineolatus					
Fundulus olivaceus					
Fundulus stellifer					
Gambusia affinis					
Gambusia holbrooki			X		
H. sp. cf. winchelli					
Hybognathus regius					
Hybopsis lineapunctata					
Hybopsis rubrifrons					
Hypentelium etowanum		BFS			
Hypentelium nigricans		BFS			
Ichthyomyzon gagei					
Ictalurus furcatus					
Ictalurus punctatus					X
Labidesthes sicculus					
Lepisosteus oculatus					
Lepomis auritus	*Lepomis*		X		
Lepomis cyanellus	*Lepomis*			X	X
Lepomis gulosus	*Lepomis*				
Lepomis macrochirus	*Lepomis*				
Lepomis marginatus	*Lepomis*				
Lepomis megalotis	*Lepomis*				
Lepomis microlophus	*Lepomis*				
Lepomis punctatus	*Lepomis*				
Luxilus chrysocephalus					
Luxilus zonistius			X		
Lythrurus atrapiculus					
Lythrurus lirus					
Micropterus cataractae					
Micropterus coosae					X
Micropterus punctulatus					
Micropterus salmoides					
Minytrema melanops		BFS			
Moxostoma duquesnei		BFS			
Moxostoma erythurum		BFS			
Moxostoma poecilurum		BFS			
Moxostoma sp. cf. poecilurum		BFS			
Nocomis leptocephalus		BFS			
Notemigonus crysoleucas					
Notropis asperifrons					

Notropis baileyi				X	
Notropis chrosomus					
Notropis cummingsae					
Notropis harperi					
Notropis hudsonius					X
Notropis hypsilepis					
Notropis longirostris					
Notropis lutipinnis			X	X	
Notropis maculatus					
Notropis petersoni					
Notropis stilbius					
Notropis texanus					
Notropis xaenocephalus					
Noturus funebris		BFS			
Noturus gyrinus		BFS			
Noturus insignis		BFS			
Noturus leptacanthus		BFS			
Oncorhynchus mykiss			X		
Opsopoeodus emiliae					
Perca flavescens				X	X
Percina (Alvordius) sp. cf. P. macrocephala (UDD)	Darters	BFS			
Percina kathae	Darters	BFS			
Percina nigrofasciata	Darters	BFS			
Percina palmaris	Darters	BFS			
Phenacobius catostomus					
Pimephales vigilax					
Polydictis olivaris					
Pomoxis nigromaculatus					
Pteronotropis euryzonus					
Pteronotropis hypselopterus					
Rhinichthys atratulus					
Scartomyzon lachneri		BFS			
Scartomyzon rupiscartes		BFS			
Semotilus atromaculatus					
Semotilus thoreauianus					

Table 3. Assemblage data for treatment and reference sites showing IBI score, Native species richness (NATSPEC), and proportions of sunfishes (% *Lepomis*), cyprinid insectivores (% CYPINS), non-native species (% NONNAT), darters (% DART), and benthic fluvial specialists (%BFS)

COLLECTION	SITE_TYPE	IBI	NATSPEC	% *Lepomis*	% CYPINS	% NONNAT	% DART	% BFS
27	Reference	26	6	75	0	0.00	12.50	12.50
31	Reference	34	9	65	1.5	0.00	0.00	13.11
32	Reference	32	10	7.2	59.2	0.00	3.59	23.77
40	Reference	34	11	5.8	57.1	0.00	0.51	35.01
42	Reference	40	14	44.7	16.9	0.31	5.94	10.31
43	Reference	34	7	12.2	63.4	0.00	0.61	23.78
45	Reference	36	9	35.2	36.1	6.01	3.43	25.75
69	Reference	50	18	13.8	47.4	2.47	14.48	34.23
86	Reference	52	31	19.5	31.2	2.47	7.20	43.15
124	Reference	30	9	11.9	73.4	0.00	0.41	13.11
172	Reference	28	11	11.3	49.6	0.75	0.00	18.80
226	Reference	36	11	38	41.3	3.31	17.36	18.18
248	Reference	24	11	11.4	0	0.00	0.00	8.57
257	Reference	36	13	4.4	70.1	1.47	2.94	8.33
260	Reference	22	8	0	56.4	0.00	5.13	7.69
330	Reference	48	30	42.3	38.1	0.00	5.89	11.36
342	Reference	28	17	62.2	7.8	0.00	0.56	2.22
349	Reference	30	8	1.9	70.3	0.00	0.00	25.84
362	Reference	24	7	11.8	29.4	0.00	0.00	0.00
372	Reference	36	11	15.1	59.3	0.00	4.65	8.14
375	Reference	50	21	17.1	59.5	0.00	10.24	15.61
408	Reference	46	20	12.5	51.7	0.00	0.00	2.27
433	Reference	30	12	9.6	16.7	2.78	10.80	66.05
443	Reference	28	17	57.6	0	21.09	3.55	30.81
450	Reference	50	25	23.8	22.3	13.17	4.91	45.54
455	Reference	48	22	18.8	23.9	9.19	3.42	52.49
459	Reference	40	13	3.7	29.1	0.70	13.49	55.35
463	Reference	44	12	0	47.8	35.29	2.77	34.26
467	Reference	44	16	1.5	29.9	15.71	10.92	51.72
479	Reference	52	31	20.4	30.5	9.34	10.68	43.67
501	Reference	38	14	11.8	32.1	1.11	11.81	50.18
505	Reference	22	16	47.2	1.5	6.09	0.00	40.61
528	Reference	42	12	15.7	25.6	8.52	28.52	48.52
559	Reference	40	11	7.6	31.7	3.05	14.89	41.98
626	Reference	44	15	43.8	20.6	12.93	4.12	31.96
663	Reference	26	10	20.7	21.1	19.41	1.69	56.12
669	Reference	42	13	6.6	66.1	1.60	4.12	25.86
22	Treatment	30	7	3.6	72.2	71.13	2.06	2.06
50	Treatment	34	8	1.5	79.6	0.00	1.16	16.92
65	Treatment	22	14	76.7	0.3	1.32	0.00	5.03
73	Treatment	36	10	16.9	68.7	0.00	8.84	11.65

90	Treatment	42	14	13.2	28.9	0.76	13.42	53.92
159	Treatment	16	3	11.8	0	0.00	0.00	0.00
190	Treatment	46	13	4	84.7	13.16	7.02	10.35
196	Treatment	50	18	19.6	28.9	5.45	12.53	43.87
261	Treatment	8	4	55	0	45.00	0.00	5.00
275	Treatment	38	12	25.9	45.4	0.57	1.15	2.30
287	Treatment	20	11	60.9	0	0.00	0.00	0.00
300	Treatment	36	18	80.7	6.2	5.25	1.70	2.41
338	Treatment	16	8	64.9	0	0.00	0.00	0.00
346	Treatment	46	16	40.4	33.1	0.00	11.92	12.58
355	Treatment	42	20	73.2	16.4	0.00	5.23	5.57
361	Treatment	30	16	1.8	49.5	1.22	9.94	17.04
371	Treatment	30	11	11.5	66.7	0.00	1.15	4.60
409	Treatment	38	20	19.8	42.6	0.00	3.70	8.64
428	Treatment	30	14	13.5	15.5	7.90	8.61	66.55
430	Treatment	36	14	7.5	40.2	1.92	6.31	44.72
432	Treatment	44	20	35	23.7	13.16	13.16	38.68
438	Treatment	42	16	46.2	18.2	16.89	4.00	26.67
457	Treatment	26	17	76.2	0	7.31	0.38	13.08
469	Treatment	18	8	62.7	8.1	61.73	7.16	16.05
487	Treatment	36	19	16.7	18.5	2.74	1.30	59.58
503	Treatment	32	26	54	9.8	9.80	3.27	21.23
504	Treatment	32	17	64.6	0.5	6.84	7.31	30.19
508	Treatment	16	12	57.1	7.8	16.88	2.60	9.09
515	Treatment	34	10	20.5	58.4	12.43	3.24	9.73
536	Treatment	40	18	52.3	27.3	17.58	3.91	15.23
605	Treatment	38	12	40.4	14	3.82	0.00	28.34
617	Treatment	30	10	13.4	38.4	0.58	1.16	36.63
629	Treatment	14	7	78.3	0	13.04	8.70	10.87
650	Treatment	26	8	6.8	24	20.34	6.21	68.93
655	Treatment	38	19	12	37.5	11.26	1.69	41.09
667	Treatment	50	18	22	28.5	0.48	4.11	37.70
688	Treatment	28	7	41.1	25	8.93	2.38	32.14

*Table 4. Di*stribution of sites used to compare assemblage sensitivity to dams among drainage basins.

	Drainage		
Treatment	ALABAMA	APALACHICOLA	ALTAMAHA
Dammed	12	17	8
Free-Flowing	12	17	8

Table 5. Distribution of sites used to compare assemblage sensitivity to dams among physiographic regions.

	Physiographic Region		
Treatment	RIDGE AND VALLEY	PIEDMONT	COASTAL PLAIN
Dammed	9	18	10
Free-Flowing	9	18	10

Table 6. Distribution of sites used to compare assemblage sensitivity to dams among stream orders.

	Stream Order		
Treatment	1	2	3
Dammed	10	19	8
Free-Flowing	10	19	8

Table 7. Study sites included in analysis between the Ridge and Valley and Piedmont regions. These regions had only one drainage basin in common (Alabama) and two stream orders in common (1st and 2nd order). Cells containing (--) represent conditions which had no available sample sites.

Stream Order	Site Type	RIDGE AND VALLEY	PIEDMONT
1	Dammed	1	1
	Free-Flowing	1	1
2	Dammed	4	2
	Free-Flowing	4	2
3	Dammed	--	--
	Free-Flowing	--	--

Table 8. Study sites included in analysis between the Piedmont and Coastal Plain Regions. These regions shared two common drainage basins (Apalachicola and Altamaha) and three stream orders (1-3). Cells containing (--) represent conditions which had no available sample sites.

		PIEDMONT		COASTAL PLAIN	
Stream Order	Treatment	AP	AH	AP	AH
1	Dammed	5	1	1	1
	Free-Flowing	5	1	1	1
2	Dammed	4	4	3	2
	Free-Flowing	4	4	3	2
3	Dammed	1	--	3	--
	Free-Flowing	1	--	3	--

Table 9. Results of statistical analyses for fish assemblage comparisons between reference and treatment sites. TREAT = Treatment site, REF = Reference site, Diff (R-T) = Difference Between Reference and Treatment sites, and Diff SE = +/- the Standard Error for differences between Treatment and Reference sites. Significant findings are shown in bold.

Metric	REF	TREAT	Diff (R-T)	Diff SE	Test	Statistic	P-value (2-sided)
IBI Score	36.92	32.16	4.76	2.29	t-test	t = 2.08	**0.041**
Native Richness	14.35	13.38	0.97	1.38	t-test	t = 0.71	0.483
% Non-native	4.78	10.20	-5.42	2.98	Wilcoxon	W = 1228.0	0.080
% *Lepomis*	21.81	35.18	-13.37	5.39	Wilcoxon	W =1174.5	**0.022**
% CypIns	35.64	27.53	8.11	5.43	Wilcoxon	W =1550.5	0.079
% Darters	5.98	4.46	1.51	1.25	Wilcoxon	W =1448.5	0.512
% BFS	28.02	21.85	6.17	4.38	Wilcoxon	W =1534.5	0.113

Table 10. Results of statistical analyses for comparisons of habitat metrics between treatment and reference sites. TREAT = Treatment site, REF = Reference site, Diff (R-T) = Difference Between Reference and Treatment sites, and Diff SE = +/- the Standard Error for differences between Treatment and Reference sites. Significant findings are shown in bold.

Metric	REF	TREAT	Diff (R-T)	Diff SE	Test	Statistic	P-value (2-sided)
Total Habitat Score	97.44	90.53	6.92	6.09	t-test	t = 1.14	0.260
Embeddedness	7.64	6.46	1.18	1.31	Wilcoxon	W = 814.0	0.220
Sediment Deposition	8.07	6.48	1.59	1.06	Wilcoxon	W = 1516.0	0.166
Turbidity	12.03	11.37	0.66	1.87	t-test	t = -0.03	0.977

Table 11. Bray-Curtis similarity values between first order reference sites (11a), first order treatment sites (11b), second order reference sites (11c), and second order treatment sites (11d). Pariwise similarity was only calculated for sites of different drainage-physiographic units (ALRV = Alabama River Drainnage-Ridge and Valley, ALPD = Alabama River Drainage-Piedmont, APPD = Apalachicola River Drainage-Piedmont, APCP = Apalachicola River Drainage-Coastal Plain, AHPD = Altamaha River Drainage-Piedmont, and AHCP = Altamaha River Drainage-Coastal Plain). Sites of the same stream order were compared.

11a 1st Order Reference Sites	559	463	349	40	372	45
ALRV 559						
ALPD 463	0.46					
APPD 349	0.02	0.16				
APCP 40	0.05	0.10	0.30			
AHPD 372	0.00	0.01	0.04	0.00		
AHCP 45	0.05	0.24	0.22	0.16	0.12	

11b 1st Order Treatment Sites	504	515	90	371	605	338
ALRV 504						
ALPD 515	0.21					
APPD 90	0.23	0.20				
APCP 371	0.04	0.01	0.01			
AHPD 605	0.25	0.16	0.25	0.01		
AHCP 338	0.13	0.14	0.10	0.03	0.15	

Table 11 (*continued*).

11c 2nd Order Reference Sites	443	528	467	501	27	42	375	408	124	172	248	342
ALRV 443												
ALRV 528												
ALPD 467	0.27	0.18										
ALPD 501	0.34	0.34										
APPD 27	0.06	0.08	0.04	0.05								
APPD 42	0.30	0.08	0.15	0.13								
APCP 375	0.14	0.08	0.06	0.02	0.11	0.26						
APCP 408	0.10	0.06	0.09	0.03	0.13	0.23						
AHPD 124	0.08	0.04	0.04	0.20	0.08	0.13	0.10	0.20				
AHPD 172	0.06	0.04	0.05	0.14	0.12	0.11	0.07	0.12				
AHCP 248	0.01	0.00	0.00	0.00	0.08	0.06	0.06	0.10	0.00	0.05		
AHCP 342	0.21	0.10	0.04	0.03	0.13	0.26	0.21	0.18	0.07	0.10		

11d 2nd Order Treatment Sites	428	536	438	469	629	650	261	355	617	655	287	346
ALRV 428												
ALRV 536												
ALPD 438	0.09	0.31										
ALPD 469	0.15	0.34										
APPD 629	0.02	0.15	0.31	0.18								
APPD 650	0.03	0.07	0.16	0.15								
APCP 261	0.01	0.03	0.07	0.00	0.19	0.00						
APCP 355	0.10	0.31	0.43	0.32	0.20	0.13						
AHPD 617	0.04	0.12	0.29	0.19	0.13	0.55	0.02	0.11				
AHPD 655	0.03	0.12	0.23	0.16	0.12	0.41	0.02	0.18				
AHCP 287	0.05	0.15	0.16	0.11	0.22	0.10	0.07	0.33	0.17	0.09		
AHCP 346	0.06	0.17	0.15	0.16	0.16	0.13	0.00	0.33	0.16	0.11		

Table 12. Interaction effects of drainage, region, and stream order on fish assemblage sensitivity to dams as measured by IBI Score. This table shows results of three independent ANOVAs for each of the three factors.

Interaction	F-Value	P-Value
Drainage*Treatment	1.09	0.341
Region*Treatment	0.11	0.897
Order*Treatment	1.82	0.171

Table 13. Interaction effects of region and stream order on fish assemblage sensitivity to dams as measured by IBI Score. Only sites in the Alabama River Drainage were used in this ANOVA

Interaction	F-Value	P-Value
Region*Treatment	1.07	0.378
Order*Treatment	0.28	0.758

Table 14. Interaction effects of drainage, region, stream order, and drainage-physiographic unit on fish assemblage sensitivity to dams as measured by IBI Score. Only sites in the Apalachicola and Altamaha River Drainages were included in this ANOVA.

Interaction	F-Value	P-Value
Drainage*Treatment	0.62	0.544
Region*Treatment	0.79	0.461
Order*Treatment	0.36	0.702
Drainage*Region*Treatment	0.85	0.439

APPENDICES

APPENDIX A

STUDY SITE CLASSIFICATION AND LOCALITY INFORMATION

Appendix A. Locality information, site classification, and collection date for all study sites (COL# = Collection Number, DR = Drainage, PHYS = Physiographic Region, AH = Altamaha River, AL = Alabama River, AP = Apalachicola River, CP = Coastal Plain, PD= Piedmont, and RV = Ridge and Valley).

SITE_TYPE	DR	PHYS	ORDER	COL #	STREAM NAME	DATE	LONG	LAT
Reference	AH	CP	1	349	Tiger Creek	7/18/2000	-82.9881	33.0950
Reference	AH	CP	2	248	Ochwalkee Creek	4/11/2000	-82.8706	32.3055
Reference	AH	CP	2	342	Ockwalkee Creek	7/12/2000	-82.6465	32.1893
Reference	AH	PD	1	40	Tussahaw Creek	7/21/1999	-84.0875	33.3890
Reference	AH	PD	2	124	Redbud Creek	7/1/1998	-83.9870	33.0922
Reference	AH	PD	2	172	Tobesfokee Creek	7/13/1998	-84.1234	33.0424
Reference	AH	PD	2	626	Rocky Creek	6/10/2003	-83.7594	34.0437
Reference	AH	PD	2	669	Mulberry Creek	8/27/2003	-83.8790	34.1470
Reference	AL	PD	1	463	Camp Creek	7/12/2001	-84.0289	34.4924
Reference	AL	PD	2	467	Burt Creek	7/30/2002	-84.1278	34.4321
Reference	AL	PD	2	501	Walton Creek	8/16/2001	-85.2721	33.6969
Reference	AL	RV	1	559	Perry Creek trib	6/4/2002	-84.7342	34.9605
Reference	AL	RV	2	443	Nancy Creek	6/21/2001	-84.8275	34.1843
Reference	AL	RV	2	459	Kenyon Creek	6/28/2001	-84.9595	34.8942
Reference	AL	RV	2	505	Noblet Creek	8/21/2001	-84.7908	34.5892
Reference	AL	RV	2	528	Sumac Creek trib	4/30/2002	-84.8002	34.8951
Reference	AL	RV	3	433	Conesenna Creek	5/3/2001	-84.9558	34.2796
Reference	AL	RV	3	450	East Armuchee Creek	7/19/2001	-85.1200	34.6531
Reference	AL	RV	3	455	Swamp Creek	6/27/2001	-85.0017	34.6443
Reference	AL	RV	3	479	West Armuchee Creek	7/19/2001	-85.1613	34.5699
Reference	AP	CP	1	372	Ty Ty Creek	8/29/2000	-84.4110	31.9614
Reference	AP	CP	2	260	Little Pine Creek	4/24/2000	-84.6961	32.4209
Reference	AP	CP	2	375	Camp Creek	8/30/2000	-84.1308	32.2483
Reference	AP	CP	2	408	Smithee Jack Creek	9/12/2000	-84.9827	31.8417
Reference	AP	CP	3	257	Colochee/Frog Branch	4/25/2000	-84.8429	32.1083
Reference	AP	CP	3	330	Chickasawhatche	6/26/2000	-84.4820	31.3512
Reference	AP	CP	3	362	Day Creek	7/24/2000	-84.8664	32.0058
Reference	AP	PD	1	31	Flat Shoals Creek	5/18/1999	-84.7624	33.0126
Reference	AP	PD	1	43	Panther Creek	5/20/1999	-84.9411	33.0090
Reference	AP	PD	1	45	Big Branch	6/9/1999	-85.0992	32.8789
Reference	AP	PD	1	69	Gum Creek	7/16/1999	-85.1642	33.4019
Reference	AP	PD	1	86	Hillabahatchee Creek	9/1/1999	-85.1877	33.3112
Reference	AP	PD	2	27	Ollie Branch	5/17/1999	-84.8045	33.1034
Reference	AP	PD	2	32	Beech Creek	5/17/1999	-84.8155	33.0369
Reference	AP	PD	2	42	Long Cane Creek	6/9/1999	-84.9425	33.0253
Reference	AP	PD	2	663	Ivy Creek	8/7/2003	-83.9722	34.0709
Reference	AP	PD	3	226	Blue John Creek	4/8/1998	-85.0514	32.9997
Treatment	AH	CP	1	338	Crooked Creek	7/12/2000	-83.2487	32.0146
Treatment	AH	CP	2	287	Limestone Creek	5/11/2000	-83.6374	32.4117
Treatment	AH	CP	2	346	South Sandy Creek	7/18/2000	-83.0319	32.7021
Treatment	AH	PD	1	605	Barber Creek	5/5/2003	-83.6122	33.9487
Treatment	AH	PD	2	50	Peeksville Cree	6/1/1999	-84.0253	33.4087

Treatment	AH	PD	2	617	Briar Creek	5/28/2003	-83.3782	33.6209
Treatment	AH	PD	2	655	Rose Creek	7/30/2003	-83.3241	33.7684
Treatment	AH	PD	2	667	Cedar Creek	8/14/2003	-83.7132	34.0295
Treatment	AL	PD	1	515	Possum Creek	10/8/2001	-84.7909	33.9912
Treatment	AL	PD	2	438	Board Tree Creek	6/18/2001	-84.2742	34.2892
Treatment	AL	PD	2	469	Settingdown Creek	7/10/2001	-84.1382	34.2937
Treatment	AL	RV	1	504	Lynn Cree	8/22/2001	-84.9345	34.4337
Treatment	AL	RV	2	428	Mud Creek	5/2/2001	-84.8660	34.2703
Treatment	AL	RV	2	430	Clear Creek	5/14/2001	-84.8721	34.2739
Treatment	AL	RV	2	432	Rocky Creek	5/2/2001	-84.7751	34.3742
Treatment	AL	RV	2	536	Dry Creek	5/14/2002	-84.7548	34.5574
Treatment	AL	RV	3	457	Haig Mill	6/28/2001	-84.9825	34.8000
Treatment	AL	RV	3	487	Taliaferr Creek	8/1/2001	-85.3941	34.3775
Treatment	AL	RV	3	503	Mill Creek	8/22/2001	-84.9163	34.7787
Treatment	AL	RV	3	508	Lick Creek	8/21/2001	-84.8071	34.5388
Treatment	AP	CP	1	371	Pessell Creek	8/29/2000	-84.3763	31.9362
Treatment	AP	CP	2	261	Tiger Creek	4/24/2000	-84.8924	32.4196
Treatment	AP	CP	2	300	Sandy Mount Cre	6/2/2000	-83.8359	32.1123
Treatment	AP	CP	2	355	Little Muckalee	7/27/2000	-84.3274	32.1906
Treatment	AP	CP	3	275	Sawhatchee Cree	5/16/2000	-85.0052	31.3200
Treatment	AP	CP	3	361	Hitchitee Creek	7/24/2000	-84.8464	32.2263
Treatment	AP	CP	3	409	Holanna Creek	9/13/2000	-84.9342	31.7940
Treatment	AP	PD	1	22	Lewis Creek	5/4/1999	-84.3670	33.1354
Treatment	AP	PD	1	90	Snake Creek	8/19/1998	-84.9569	33.5986
Treatment	AP	PD	1	159	Long Branch	6/15/1998	-84.9280	33.3232
Treatment	AP	PD	1	190	Kendall Creek	8/29/1998	-84.7083	32.9925
Treatment	AP	PD	1	688	Pea Creek	10/14/2003	-84.7015	33.6103
Treatment	AP	PD	2	73	Polecat Creek	8/11/1999	-84.8988	32.9104
Treatment	AP	PD	2	196	Whooping Creek	8/21/1998	-85.0433	33.5188
Treatment	AP	PD	2	629	Ward Creek	6/12/2003	-84.6178	33.9167
Treatment	AP	PD	2	650	Turner Creek	7/22/2003	-83.7900	34.6143
Treatment	AP	PD	3	65	Long Cane Creek	7/22/1999	-85.0247	32.9729

APPENDIX B.

SPECIES ABUNDANCE LISTED BY DRAINAGE, REGION, AND SITE TYPE

Appendix B Table 1. Species abundance in reference sites of the Alabama River Drainage and Ridge and Valley region.

	Collection Number								
Species name	559	443	459	505	528	433	450	455	479
Acantharchus pomotis	0	0	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0	1	2	11
Ameiurus brunneus	0	0	0	1	0	0	0	0	0
Ameiurus catus	0	0	0	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0	0	0	0
Ameiurus natalis	0	0	0	1	0	0	0	0	1
Ameiurus nebulosus	0	0	0	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	0	0	0
Aphredoderus sayanus	0	0	0	0	0	0	0	0	0
Aplodinotus grunniens	0	0	0	0	0	0	0	0	1
Campostoma oligolepis	35	15	74	59	38	84	297	612	187
Campostoma pauciradii	0	0	0	0	0	0	0	0	0
Centrarchus macropterus	0	0	0	0	0	0	0	0	0
Cottus carolinae	31	60	75	0	21	81	6	279	66
Cyprinella callisema	0	0	0	0	0	0	0	0	0
Cyprinella callistia	0	0	0	0	0	0	0	0	7
Cyprinella gibbsi	0	0	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	31	330	179
Cyprinella venusta	0	0	0	1	0	0	0	0	2
Cyprinus carpio	0	1	0	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	0	0	14	0	0
Elassoma zonatum	0	0	0	0	0	0	0	0	0
Ericymba buccata	0	0	0	0	0	0	0	0	0
Erimyzon oblongus	0	0	0	0	0	0	0	0	0
Erimyzon sucetta	0	0	0	0	0	0	0	0	0
Esox americanus	0	0	0	0	0	0	0	0	0
Esox niger	0	0	0	0	0	2	0	0	0
Etheostoma brevirostrum	0	0	0	0	0	0	0	0	0
Etheostoma coosae	39	10	58	0	87	35	26	57	16
Etheostoma edwini	0	0	0	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0	0	0
Etheostoma inscriptum	0	0	0	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0	0	6	53
Etheostoma olmstedi	0	0	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0	3	0	11
Etheostoma swaini	0	0	0	0	0	0	0	0	0
Etheostoma tallapoosae	0	0	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0	0	0	0
Fundulus escambiae	0	0	0	0	0	0	0	0	0

Fundulus lineolatus	0	0	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	1	0	0	0	0	0
Fundulus stellifer	0	0	0	0	0	0	34	20	4
Gambusia affinis	0	9	0	5	0	0	0	0	6
Gambusia holbrooki	0	0	0	0	20	0	0	0	0
H. sp. cf. winchelli	0	0	0	0	0	0	0	0	0
Hybognathus regius	0	0	0	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0	0	0	0
Hypentelium etowanum	5	40	31	10	2	14	25	13	15
Hypentelium nigricans	0	0	0	0	0	0	0	0	0
Ichthyomyzon gagei	3	0	1	0	0	0	0	0	0
Ictalurus furcatus	0	1	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0	0	0	0
Labidesthes sicculus	0	0	0	0	0	0	0	0	0
Lepisosteus oculatus	0	0	0	0	0	0	0	0	0
Lepomis auritus	8	88	3	11	6	7	118	172	90
Lepomis cyanellus	8	68	3	16	2	15	25	25	30
Lepomis gulosus	0	6	0	10	0	0	2	0	0
Lepomis macrochirus	4	28	9	5	4	4	6	80	4
Lepomis marginatus	0	0	0	0	0	0	0	0	0
Lepomis megalotis	0	3	1	51	23	0	50	67	56
Lepomis microlophus	0	8	0	0	0	0	0	1	0
Lepomis punctatus	0	42	0	0	13	6	12	4	17
Luxilus chrysocephalus	0	0	12	2	61	0	116	32	15
Luxilus zonistius	0	0	0	0	0	0	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	16	0	18	0	6
Micropterus cataractae	0	0	0	0	0	0	0	0	0
Micropterus coosae	9	20	11	0	0	7	21	66	13
Micropterus punctulatus	0	0	0	0	0	0	0	0	4
Micropterus salmoides	0	7	0	11	0	0	3	1	1
Minytrema melanops	0	0	0	6	0	0	0	0	0
Moxostoma duquesnei	0	0	0	0	0	0	18	11	31
Moxostoma erythurum	0	0	0	5	0	0	15	0	19
Moxostoma poecilurum	0	0	0	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0	0	0	0
Nocomis leptocephalus	0	0	0	0	0	0	0	0	0
Notemigonus crysoleucas	0	1	0	0	0	0	0	0	0
Notropis asperifrons	0	0	0	0	0	0	0	27	0
Notropis baileyi	0	0	0	0	0	0	0	0	0
Notropis chrosomus	40	0	44	0	1	32	5	19	42
Notropis cummingsae	0	0	0	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	0	0	0	0
Notropis hudsonius	0	0	0	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0	0	0	0
Notropis longirostris	0	0	0	0	0	0	0	0	0
Notropis lutipinnis	0	0	0	0	0	0	0	0	0
Notropis maculatus	0	0	0	0	0	0	0	0	0

Notropis petersoni	0	0	0	0	0	0	0	0	0
Notropis stilbius	0	0	0	0	0	0	0	0	3
Notropis texanus	0	0	0	0	0	0	0	0	0
Notropis xaenocephalus	43	0	69	0	0	22	30	40	0
Noturus funebris	0	0	0	0	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0	0	0	0
Noturus leptacanthus	0	0	0	0	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0	2	0	0	0
Opsopoeodus emiliae	0	0	0	0	0	0	0	0	0
Perca flavescens	0	0	0	0	0	0	0	0	0
*Percina (*Alvordius*)sp.cf. P. macrocephala*	0	0	0	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0	3	4	5
Percina nigrofasciata	0	5	0	0	0	0	15	0	18
Percina palmaris	0	0	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	0	1	0	0	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	0	0	0	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	0	0	0	0
Scartomyzon rupiscartes	0	0	0	0	0	0	0	0	0
Semotilus atromaculatus	37	10	39	0	0	14	2	0	2
Semotilus thoreauianus	0	0	0	0	0	0	0	0	0

Appendix B Table 2. Species abundance in treatment sites of the Alabama River Drainage and Ridge and Valley region.

	Collection Number								
Species name	504	428	430	432	536	457	487	503	508
Acantharchus pomotis	0	0	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0	0	0	0
Ameiurus brunneus	0	0	0	0	0	0	0	0	0
Ameiurus catus	0	0	0	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0	0	0	0
Ameiurus natalis	0	0	0	0	0	0	0	0	0
Ameiurus nebulosus	0	0	0	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	0	0	0
Aphredoderus sayanus	0	0	0	0	0	0	0	0	0
Aplodinotus grunniens	0	0	0	0	0	0	0	0	0
Campostoma oligolepis	36	796	173	22	23	36	147	27	0
Campostoma pauciradii	0	0	0	0	0	0	0	0	0
Centrarchus macropterus	0	0	0	0	0	0	0	0	0
Cottus carolinae	48	14	63	21	0	3	257	0	0
Cyprinella callisema	0	0	0	0	0	0	0	0	0
Cyprinella callistia	0	0	0	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	0	0	0
Cyprinella venusta	0	0	0	5	12	0	0	52	6
Cyprinus carpio	0	0	0	0	0	2	0	0	0
Dorsoma cepedianum	0	0	0	0	0	5	0	67	8
Elassoma zonatum	0	0	0	0	0	0	0	0	0
Ericymba buccata	0	0	0	0	0	0	0	0	0
Erimyzon oblongus	0	0	0	0	0	0	0	0	0
Erimyzon sucetta	0	0	0	0	0	0	0	0	0
Esox americanus	0	0	0	0	0	0	0	0	0
Esox niger	0	0	0	0	0	0	0	0	0
Etheostoma brevirostrum	0	0	0	0	0	0	0	0	0
Etheostoma coosae	26	114	44	39	4	0	8	1	0
Etheostoma edwini	0	0	0	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0	0	0
Etheostoma inscriptum	0	0	0	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	8	2	0	9	0	0	6	0
Etheostoma swaini	0	0	0	0	0	0	0	0	0
Etheostoma tallapoosae	0	0	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	2	0	0	1	0
Fundulus chrysotus	0	0	0	0	0	0	0	0	0

Fundulus escambiae	0	0	0	0	0	0	0	0	0
Fundulus lineolatus	0	0	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	0	5	0	0	1	0
Fundulus stellifer	0	45	5	0	5	0	0	0	0
Gambusia affinis	1	0	0	0	0	0	0	5	3
Gambusia holbrooki	0	0	0	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	0	0	0	0	0	0
Hybognathus regius	0	0	0	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0	0	0	0
Hypentelium etowanum	13	11	44	18	14	1	40	59	0
Hypentelium nigricans	0	0	0	0	0	0	0	0	0
Ichthyomyzon gagei	0	0	0	0	0	0	1	0	0
Ictalurus furcatus	0	0	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	1	0	19	0
Labidesthes sicculus	0	0	0	0	0	0	0	0	0
Lepisosteus oculatus	0	0	0	0	0	0	0	0	0
Lepomis auritus	29	112	14	50	90	17	15	78	13
Lepomis cyanellus	9	57	18	1	59	8	73	228	7
Lepomis gulosus	2	0	0	0	0	1	2	9	2
Lepomis macrochirus	131	0	5	10	28	138	26	20	17
Lepomis marginatus	0	0	0	0	0	0	0	0	0
Lepomis megalotis	34	8	2	68	73	12	0	95	0
Lepomis microlophus	49	0	0	0	0	12	1	0	0
Lepomis punctatus	20	14	16	4	18	9	10	0	1
Luxilus chrysocephalus	0	56	48	73	126	0	0	0	0
Luxilus zonistius	0	0	0	0	0	0	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	2	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0	0	0	0
Micropterus coosae	7	15	32	8	0	0	14	2	0
Micropterus punctulatus	0	0	0	0	0	0	2	12	0
Micropterus salmoides	7	0	0	1	0	16	0	2	6
Minytrema melanops	0	0	0	1	7	3	1	2	0
Moxostoma duquesnei	0	0	0	8	0	0	0	0	0
Moxostoma erythurum	0	0	0	27	14	0	2	2	2
Moxostoma poecilurum	0	0	0	0	0	0	0	15	3
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0	0	0	0
Nocomis leptocephalus	0	0	0	0	0	0	0	0	0
Notemigonus crysoleucas	0	0	0	0	0	0	0	0	0
Notropis asperifrons	0	0	0	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0	0	0	0
Notropis chrosomus	0	49	70	10	0	0	89	0	0
Notropis cummingsae	0	0	0	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	0	0	0	0
Notropis hudsonius	0	0	0	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0	0	0	0
Notropis longirostris	0	0	0	0	0	0	0	0	0
Notropis lutipinnis	0	0	0	0	0	0	0	0	0
Notropis maculatus	0	0	0	0	0	0	0	0	0
Notropis petersoni	0	0	0	0	0	0	0	0	0

Notropis stilbius	0	0	0	0	0	0	0	24	0
Notropis texanus	0	0	0	0	0	0	0	0	0
Notropis xaenocephalus	2	114	223	2	0	0	53	0	0
Noturus funebris	0	0	0	0	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0	0	0	0
Noturus leptacanthus	0	0	0	0	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0	0	6	0	0
Opsopoeodus emiliae	0	0	0	0	0	0	0	0	0
Perca flavescens	0	0	0	0	0	0	0	0	0
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0	0	0	0
Percina kathae	0	0	0	2	0	0	2	0	2
Percina nigrofasciata	5	0	0	9	5	1	0	18	0
Percina palmaris	0	0	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0	2	0
Pimephales vigilax	0	0	0	0	0	0	0	38	0
Polydictis olivaris	0	0	0	0	0	1	0	1	0
Pomoxis nigromaculatus	3	0	0	0	0	3	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	0	0	0	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	0	0	0	0
Scartomyzon rupiscartes	0	0	0	0	0	0	0	0	0
Semotilus atromaculatus	2	6	18	1	16	0	17	1	0
Semotilus thoreauianus	0	0	0	0	0	0	0	0	0

Appendix B Table 3. Species abundance in reference and treatment sites of the Alabama River Drainage and Piedmont region.

	Collection Number					
	Reference			Treatment		
Species name	463	467	501	515	438	469
Acantharchus pomotis	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0
Ameiurus brunneus	0	0	0	0	1	19
Ameiurus catus	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0
Ameiurus natalis	0	0	0	0	0	0
Ameiurus nebulosus	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0
Aphredoderus sayanus	0	0	0	0	0	0
Aplodinotus grunniens	0	0	0	0	0	0
Campostoma oligolepis	15	97	27	0	23	8
Campostoma pauciradii	0	0	0	0	0	0
Centrarchus macropterus	0	0	0	0	0	0
Cottus carolinae	51	29	16	7	1	0
Cyprinella callisema	0	0	0	0	0	0
Cyprinella callistia	1	48	0	24	0	33
Cyprinella gibbsi	0	0	14	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0
Cyprinella trichroistia	0	41	0	0	0	0
Cyprinella venusta	0	0	0	0	0	0
Cyprinus carpio	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	0	0
Elassoma zonatum	0	0	0	0	0	0
Ericymba buccata	0	0	0	0	0	0
Erimyzon oblongus	0	0	0	0	0	0
Erimyzon sucetta	0	0	0	0	0	0
Esox americanus	0	0	0	0	0	0
Esox niger	0	0	0	0	0	0
Etheostoma brevirostrum	7	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0
Etheostoma edwini	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0
Etheostoma inscriptum	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0
Etheostoma scotti	0	7	0	0	0	0
Etheostoma stigmaeum	0	0	16	0	5	0
Etheostoma swaini	0	0	0	0	0	0
Etheostoma tallapoosae	0	0	16	0	0	0
Etheostoma trisella	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0

Fundulus escambiae	0	0	0	0	0	0
Fundulus lineolatus	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	0	0	0
Fundulus stellifer	0	0	0	7	0	0
Gambusia affinis	0	0	0	0	0	0
Gambusia holbrooki	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	0	0	0
Hybognathus regius	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	29	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0
Hypentelium etowanum	19	83	28	5	22	18
Hypentelium nigricans	0	0	0	0	0	0
Ichthyomyzon gagei	6	0	0	0	1	0
Ictalurus furcatus	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0
Labidesthes sicculus	0	0	0	0	0	0
Lepisosteus oculatus	0	0	0	0	0	0
Lepomis auritus	0	11	3	23	22	231
Lepomis cyanellus	0	4	2	0	8	1
Lepomis gulosus	0	0	0	0	0	0
Lepomis macrochirus	0	2	27	15	74	22
Lepomis marginatus	0	0	0	0	0	0
Lepomis megalotis	0	0	0	0	0	0
Lepomis microlophus	0	0	0	0	0	0
Lepomis punctatus	0	0	0	0	0	0
Luxilus chrysocephalus	0	0	44	0	0	0
Luxilus zonistius	67	71	0	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0
Micropterus coosae	1	6	23	5	1	0
Micropterus punctulatus	0	0	0	0	0	0
Micropterus salmoides	0	0	0	0	5	11
Minytrema melanops	0	0	0	0	0	0
Moxostoma duquesnei	0	3	0	0	1	0
Moxostoma erythurum	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0
Nocomis leptocephalus	6	1	32	0	4	10
Notemigonus crysoleucas	0	0	0	0	0	0
Notropis asperifrons	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0
Notropis chrosomus	32	3	0	0	0	0
Notropis cummingsae	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	0
Notropis hudsonius	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0
Notropis longirostris	0	0	0	18	25	0
Notropis lutipinnis	35	0	0	0	15	0

Notropis maculatus	0	0	0	0	0	0
Notropis petersoni	0	0	0	0	0	0
Notropis stilbius	0	0	0	0	1	0
Notropis texanus	0	0	0	0	0	0
Notropis xaenocephalus	3	17	0	66	0	0
Noturus funebris	0	0	1	0	0	0
Noturus gyrinus	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0
Noturus leptacanthus	0	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	0	0	0
Perca flavescens	0	0	0	0	0	0
Percina (Alvordius) *sp. cf. P. macrocephala*	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0
Percina nigrofasciata	1	10	0	6	3	29
Percina palmaris	0	40	0	0	1	0
Phenacobius catostomus	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	0	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	0
Rhinichthys atratulus	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	0
Scartomyzon rupiscartes	0	0	0	0	0	0
Semotilus atromaculatus	45	13	9	9	12	23
Semotilus thoreauianus	0	0	0	0	0	0

Appendix B Table 4. Species abundance in reference sites of the Apalachicola River Drainage and Piedmont region.

	Collection Number									
Species name	31	43	45	69	86	27	32	42	663	226
Acantharchus pomotis	0	0	0	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0	0	0	0	0
Ameiurus brunneus	0	0	0	3	56	0	0	0	0	0
Ameiurus catus	0	0	0	0	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0	0	0	0	0
Ameiurus natalis	1	0	0	2	0	1	0	0	0	1
Ameiurus nebulosus	0	0	0	0	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	0	0	0	0
Aphredoderus sayanus	0	0	0	0	0	0	0	0	0	0
Aplodinotus grunniens	0	0	0	0	0	0	0	0	0	0
Campostoma oligolepis	0	0	0	0	0	0	0	0	0	0
Campostoma pauciradii	0	15	3	36	593	0	0	2	0	1
Centrarchus macropterus	0	0	0	0	0	0	0	0	0	0
Cottus carolinae	0	0	0	0	3	0	0	0	0	0
Cyprinella callisema	0	0	0	0	0	0	0	0	0	0
Cyprinella callistia	0	0	0	0	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	0	0	0	0
Cyprinella venusta	0	0	0	2	236	0	0	0	0	0
Cyprinus carpio	0	0	0	0	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	8	0	0	0	0	0
Elassoma zonatum	0	0	0	0	0	0	0	0	0	0
Ericymba buccata	0	0	10	30	177	0	0	0	0	10
Erimyzon oblongus	27	0	0	1	16	0	0	3	0	0
Erimyzon sucetta	0	0	0	0	0	0	0	0	0	0
Esox americanus	0	0	0	0	0	0	1	3	0	0
Esox niger	1	0	0	0	0	1	0	0	0	0
Etheostoma brevirostrum	0	0	0	0	0	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0	0	0	0	0
Etheostoma edwini	0	0	0	0	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0	0	0	0

Etheostoma inscriptum	0	0	0	0	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0	0	0	0	0
Etheostoma swaini	0	0	0	0	0	0	0	0	0	0
Etheostoma tallapoosae	0	0	0	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0	0	0	0	0
Fundulus escambiae	0	0	0	0	0	0	0	0	0	0
Fundulus lineolatus	0	0	0	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	0	0	0	0	0	0	0
Fundulus stellifer	0	0	0	15	35	1	0	0	0	0
Gambusia affinis	0	0	0	0	0	0	0	0	0	1
Gambusia holbrooki	0	0	0	0	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	14	97	0	0	0	0	0
Hybognathus regius	0	0	0	0	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	0	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0	0	0	0	0
Hypentelium etowanum	0	0	0	17	128	0	1	0	10	0
Hypentelium nigricans	0	0	0	0	0	0	0	0	0	0
Ichthyomyzon gagei	0	0	0	6	0	0	16	87	0	0
Ictalurus furcatus	0	0	0	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0	0	0	0	0
Labidesthes sicculus	0	0	0	0	4	0	0	0	0	0
Lepisosteus oculatus	0	0	0	0	0	0	0	0	0	0
Lepomis auritus	81	16	76	101	474	5	13	35	20	17
Lepomis cyanellus	0	0	1	22	35	0	0	1	19	4
Lepomis gulosus	43	12	0	0	3	0	0	1	0	1
Lepomis macrochirus	0	3	5	0	66	4	2	32	10	14
Lepomis marginatus	0	0	0	0	0	0	0	5	0	0
Lepomis megalotis	0	0	0	0	0	0	0	0	0	0
Lepomis microlophus	0	0	0	0	2	0	0	0	0	0
Lepomis punctatus	10	1	0	0	5	3	1	69	0	10
Luxilus chrysocephalus	0	0	0	0	0	0	0	0	0	0

Luxilus zonistius	0	104	54	374	421	0	132	35	23	0
Lythrurus atrapiculus	0	0	0	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0	0	0	0	0
Micropterus coosae	0	0	0	12	35	0	0	0	0	0
Micropterus punctulatus	0	0	0	0	0	0	0	0	0	0
Micropterus salmoides	0	0	0	0	6	0	0	0	2	1
Minytrema melanops	0	0	0	1	2	0	0	0	0	0
Moxostoma duquesnei	0	0	0	0	0	0	0	0	0	0
Moxostoma erythurum	0	0	0	0	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	3	0	0	0	0	0
Nocomis leptocephalus	0	23	49	99	270	0	44	9	117	0
Notemigonus crysoleucas	40	0	0	0	1	0	0	0	1	0
Notropis asperifrons	0	0	0	0	0	0	0	0	0	0
Notropis baileyi	0	0	13	0	0	0	0	0	0	0
Notropis chrosomus	0	0	0	0	0	0	0	0	0	0
Notropis cummingsae	0	0	0	0	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	0	0	0	0	0
Notropis hudsonius	0	0	0	0	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	2	0	0	0	12	0	0
Notropis longirostris	0	0	7	0	2	0	0	7	0	40
Notropis lutipinnis	0	0	0	0	0	0	0	0	27	0
Notropis maculatus	0	0	0	0	0	0	0	0	0	0
Notropis petersoni	0	0	0	0	0	0	0	0	0	0
Notropis stilbius	0	0	0	0	0	0	0	0	0	0
Notropis texanus	2	0	0	0	4	0	0	0	0	0
Notropis xaenocephalus	0	0	0	0	0	0	0	0	0	0
Noturus funebris	0	0	0	22	7	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0	0	0	0	0
Noturus leptacanthus	0	0	0	0	10	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	0	0	0	0	0	0	0
Perca flavescens	0	0	0	0	39	0	0	0	0	0
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0	0	0	0	0

Percina nigrofasciata	0	1	8	129	216	2	8	19	4	21
Percina palmaris	0	0	0	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	1	0	13	0	0	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	0	0	0	0	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	46	0	0	0	0	0
Scartomyzon rupiscartes	0	0	0	0	0	0	0	0	2	0
Semotilus atromaculatus	0	0	0	0	0	0	0	0	2	0
Semotilus thoreauianus	0	0	0	0	0	0	5	0	0	0

Appendix B Table 5. Species abundance in treatment sites of the Apalachicola River Drainage and Piedmont region.

	Collection Number									
Species name	22	90	159	190	688	73	196	629	650	65
Acantharchus pomotis	0	0	0	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0	0	0	0	0
Ameiurus brunneus	0	3	0	0	0	0	3	3	0	0
Ameiurus catus	0	0	0	0	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0	0	0	0	0
Ameiurus natalis	0	0	1	2	0	4	1	0	0	0
Ameiurus nebulosus	0	0	0	0	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0	0	0	0	5
Anguilla rostrata	0	0	0	0	0	0	0	0	0	0
Aphredoderus sayanus	0	0	0	0	0	0	0	0	0	0
Aplodinotus grunniens	0	0	0	0	0	0	0	0	0	0
Campostoma oligolepis	0	0	0	0	0	0	0	0	0	0
Campostoma pauciradii	0	47	0	0	0	0	23	0	126	0
Centrarchus macropterus	0	0	0	0	0	0	0	0	0	0
Cottus carolinae	0	16	0	0	0	0	0	0	0	0
Cyprinella callisema	0	0	0	0	0	0	0	0	0	0
Cyprinella callistia	0	0	0	0	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	1	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	0	0	0	0
Cyprinella venusta	0	0	0	0	0	0	0	0	0	0
Cyprinus carpio	0	0	0	0	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	0	0	0	0	0	0
Elassoma zonatum	0	0	0	0	0	0	0	0	0	0
Ericymba buccata	2	0	0	185	0	25	21	0	0	0
Erimyzon oblongus	0	0	0	0	0	0	0	0	0	0
Erimyzon sucetta	0	0	0	0	0	0	0	0	0	0
Esox americanus	0	0	0	0	0	0	0	0	0	2
Esox niger	6	0	0	0	0	0	0	0	0	0
Etheostoma brevirostrum	0	0	0	0	0	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0	0	0	0	0
Etheostoma	0	0	0	0	0	0	0	0	0	0

edwini										
Etheostoma fusiforme	0	0	0	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0	0	0	0
Etheostoma inscriptum	0	0	0	0	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0	0	0	0	0
Etheostoma swaini	0	0	0	0	0	0	0	0	0	0
Etheostoma tallapoosae	0	0	0	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0	0	0	0	0
Fundulus escambiae	0	0	0	0	0	0	0	0	0	0
Fundulus lineolatus	0	0	0	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	0	0	0	0	0	0	0
Fundulus stellifer	0	0	0	0	0	0	0	0	0	0
Gambusia affinis	0	0	0	0	0	0	0	0	0	12
Gambusia holbrooki	0	0	0	0	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	10	0	0	11	0	0	1
Hybognathus regius	0	0	0	0	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	0	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0	0	0	0	0
Hypentelium etowanum	0	53	0	0	28	0	36	2	0	0
Hypentelium nigricans	0	0	0	0	0	0	0	0	0	0
Ichthyomyzon gagei	0	0	0	2	0	0	0	0	0	10
Ictalurus furcatus	0	0	0	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0	1	0	0	0
Labidesthes sicculus	0	0	0	0	0	0	0	0	0	12
Lepisosteus oculatus	0	0	0	0	0	0	0	0	0	0
Lepomis auritus	2	17	0	14	0	37	42	10	24	119
Lepomis cyanellus	0	3	0	0	10	0	20	6	0	1
Lepomis gulosus	0	0	0	1	0	0	0	1	0	13
Lepomis macrochirus	5	32	4	6	59	5	10	19	0	84
Lepomis marginatus	0	0	0	0	0	0	0	0	0	5
Lepomis	0	0	0	0	0	0	0	0	0	0

megalotis										
Lepomis microlophus	0	0	0	0	0	0	0	0	0	52
Lepomis punctatus	0	0	0	2	0	0	0	0	0	16
Luxilus chrysocephalus	0	0	0	0	0	0	0	0	0	0
Luxilus zonistius	0	110	0	0	25	142	74	0	13	0
Lythrurus atrapiculus	0	0	0	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0	0	0	0	0
Micropterus coosae	0	12	0	0	0	0	0	0	0	0
Micropterus punctulatus	0	0	0	0	0	0	0	0	0	0
Micropterus salmoides	0	1	0	1	0	1	3	0	1	23
Minytrema melanops	0	1	0	0	0	0	6	0	1	19
Moxostoma duquesnei	0	0	0	0	0	0	0	0	0	0
Moxostoma erythurum	0	0	0	0	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0	0	0	0	0
Nocomis leptocephalus	0	33	0	13	22	7	46	1	85	0
Notemigonus crysoleucas	0	0	0	0	0	0	0	0	0	0
Notropis asperifrons	0	0	0	0	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0	0	0	0	0
Notropis chrosomus	0	0	0	0	0	0	0	0	0	0
Notropis cummingsae	0	0	0	0	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	0	0	0	0	0
Notropis hudsonius	0	0	0	0	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0	0	0	0	0
Notropis longirostris	0	4	0	213	2	4	0	0	0	0
Notropis lutipinnis	138	0	0	75	15	0	0	0	72	0
Notropis maculatus	0	0	0	0	0	0	0	0	0	0
Notropis petersoni	0	0	0	0	0	0	0	0	0	0
Notropis stilbius	0	0	0	0	0	0	0	0	0	0
Notropis texanus	0	0	0	0	0	0	0	0	0	0
Notropis xaenocephalus	0	0	0	0	0	0	0	0	0	0
Noturus funebris	0	0	0	0	0	0	2	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0	0	0	0	0

Noturus leptacanthus	0	0	0	6	0	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	0	0	0	0	0	0	0
Perca flavescens	0	0	0	0	0	0	0	0	0	4
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0	0	0	0	0
Percina nigrofasciata	4	53	0	40	4	22	46	4	22	0
Percina palmaris	0	0	0	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	0	0	0	0	0	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	0	0	0	0	0	0	0	0	0	0
Scartomyzon lachneri	0	10	0	0	0	0	2	0	10	0
Scartomyzon rupiscartes	0	0	0	0	0	0	0	0	0	0
Semotilus atromaculatus	0	0	0	0	0	0	0	0	0	0
Semotilus thoreauianus	0	0	29	0	0	2	4	0	0	0

Appendix B Table 6. Species abundance in reference sites of the Apalachicola River Drainage and Coastal Plain region.

	Collection Number						
Species name	372	260	375	408	257	330	362
Acantharchus pomotis	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	1	0	0	0	0
Ameiurus brunneus	0	0	0	0	1	1	0
Ameiurus catus	0	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0	0
Ameiurus natalis	1	3	1	2	1	0	0
Ameiurus nebulosus	0	0	0	0	0	0	0
Amia calva	0	0	0	0	0	1	0
Anguilla rostrata	0	0	0	0	0	1	0
Aphredoderus sayanus	3	2	5	4	0	75	0
Aplodinotus grunniens	0	0	0	0	0	0	0
Campostoma oligolepis	0	0	0	0	0	0	0
Campostoma pauciradii	0	0	0	0	0	0	0
Centrarchus macropterus	0	0	0	0	0	0	0
Cottus carolinae	0	0	0	0	0	0	0
Cyprinella callisema	0	0	0	0	0	0	0
Cyprinella callistia	0	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	0
Cyprinella venusta	0	0	25	0	34	21	0
Cyprinus carpio	0	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	0	0	0
Elassoma zonatum	0	0	0	0	0	0	0
Ericymba buccata	11	0	10	28	46	0	0
Erimyzon oblongus	0	1	0	2	0	0	0
Erimyzon sucetta	0	0	0	0	0	0	0
Esox americanus	2	3	1	3	0	0	2
Esox niger	0	0	0	0	0	1	0
Etheostoma brevirostrum	0	0	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0	0
Etheostoma edwini	0	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0
Etheostoma inscriptum	0	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0	0
Etheostoma swaini	0	0	0	0	0	11	0
Etheostoma tallapoosae	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0	0

Fundulus chrysotus	0	0	0	0	0	1	0
Fundulus escambiae	0	0	0	0	0	1	0
Fundulus lineolatus	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	2	0	0	0
Fundulus stellifer	0	0	0	0	0	0	0
Gambusia affinis	1	0	1	8	0	1	0
Gambusia holbrooki	0	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	1	0	0	1	0
Hybognathus regius	0	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0	0
Hypentelium etowanum	0	0	0	0	0	0	0
Hypentelium nigricans	0	0	0	0	0	0	0
Ichthyomyzon gagei	0	4	7	5	0	0	18
Ictalurus furcatus	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0	0
Labidesthes sicculus	0	0	0	0	0	5	0
Lepisosteus oculatus	0	0	0	0	0	1	0
Lepomis auritus	0	0	9	12	1	358	1
Lepomis cyanellus	0	0	0	0	3	0	0
Lepomis gulosus	0	0	1	0	2	9	0
Lepomis macrochirus	0	0	2	5	3	25	0
Lepomis marginatus	0	0	4	1	0	1	0
Lepomis megalotis	0	0	0	0	0	0	0
Lepomis microlophus	0	0	0	0	0	17	0
Lepomis punctatus	13	0	19	4	0	93	3
Luxilus chrysocephalus	0	0	0	0	0	0	0
Luxilus zonistius	0	0	0	17	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	1	0
Micropterus coosae	0	0	0	0	0	0	0
Micropterus punctulatus	0	0	0	0	0	0	0
Micropterus salmoides	0	0	9	1	0	8	0
Minytrema melanops	0	0	9	1	0	19	0
Moxostoma duquesnei	0	0	0	0	0	0	0
Moxostoma erythurum	0	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0	0
Nocomis leptocephalus	0	0	0	0	0	0	0
Notemigonus crysoleucas	0	0	0	1	2	0	0
Notropis asperifrons	0	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0	0
Notropis chrosomus	0	0	0	0	0	0	0
Notropis cummingsae	0	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	50	0
Notropis hudsonius	0	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0	0
Notropis longirostris	4	0	7	11	62	0	2

Notropis lutipinnis	0	0	0	0	0	0	0
Notropis maculatus	0	0	0	0	0	0	0
Notropis petersoni	0	0	0	0	0	163	0
Notropis stilbius	0	0	0	0	0	0	0
Notropis texanus	0	0	25	30	0	131	5
Notropis xaenocephalus	0	0	0	0	0	0	0
Noturus funebris	0	0	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0	0
Noturus leptacanthus	3	0	2	1	11	10	0
Oncorhynchus mykiss	0	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	1	0	0	2	0
Perca flavescens	0	0	0	0	0	0	0
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0	0
Percina nigrofasciata	4	2	21	0	6	59	0
Percina palmaris	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	0	0	0	0	0
Pteronotropis euryzonus	0	22	0	5	1	0	3
Pteronotropis hypselopterus	36	0	53	0	0	85	0
Rhinichthys atratulus	0	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	36	0
Scartomyzon rupiscartes	0	0	0	0	0	0	0
Semotilus atromaculatus	0	0	0	0	0	0	0
Semotilus thoreauianus	8	2	0	34	31	0	0

Appendix B Table 7. Species abundance in treatment sites of the Apalachicola River Drainage and Coastal Plain region.

	Collection Number						
Species name	371	261	300	355	275	361	409
Acantharchus pomotis	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0	0
Ameiurus brunneus	0	0	0	0	0	3	0
Ameiurus catus	0	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0	0
Ameiurus natalis	0	4	0	1	0	1	0
Ameiurus nebulosus	0	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	1	0	0
Aphredoderus sayanus	3	0	14	1	25	11	14
Aplodinotus grunniens	0	0	0	0	0	0	0
Campostoma oligolepis	0	0	0	0	0	0	0
Campostoma pauciradii	0	0	0	0	0	0	0
Centrarchus macropterus	0	0	0	0	0	0	0
Cottus carolinae	0	0	0	0	0	0	0
Cyprinella callisema	0	0	0	0	0	0	0
Cyprinella callistia	0	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	0
Cyprinella venusta	9	0	0	0	0	61	4
Cyprinus carpio	0	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	0	0	0
Elassoma zonatum	0	0	0	0	0	0	0
Ericymba buccata	2	0	0	0	0	0	12
Erimyzon oblongus	0	1	0	0	0	0	0
Erimyzon sucetta	0	0	0	0	0	0	0
Esox americanus	7	0	6	1	0	1	1
Esox niger	0	0	0	0	0	0	1
Etheostoma brevirostrum	0	0	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0	0
Etheostoma edwini	0	0	0	0	0	0	2
Etheostoma fusiforme	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0
Etheostoma inscriptum	0	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0	0
Etheostoma swaini	0	0	1	0	0	0	1
Etheostoma tallapoosae	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0	0

Fundulus escambiae	0	0	0	0	0	0	0
Fundulus lineolatus	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	0	0	0	0
Fundulus stellifer	0	0	0	0	0	0	0
Gambusia affinis	0	4	33	3	20	32	1
Gambusia holbrooki	0	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	3	0	43	7
Hybognathus regius	0	0	0	0	0	0	0
Hybopsis lineapunctata	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0	0
Hypentelium etowanum	0	0	0	0	0	0	0
Hypentelium nigricans	0	0	0	0	0	0	0
Ichthyomyzon gagei	5	0	1	1	0	0	23
Ictalurus furcatus	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0	0
Labidesthes sicculus	0	0	2	1	0	0	0
Lepisosteus oculatus	0	0	0	3	0	0	0
Lepomis auritus	1	0	48	71	8	2	21
Lepomis cyanellus	0	9	26	0	1	6	0
Lepomis gulosus	0	0	37	6	1	0	0
Lepomis macrochirus	0	0	321	101	2	0	0
Lepomis marginatus	0	0	0	7	0	0	3
Lepomis megalotis	0	0	0	0	0	0	0
Lepomis microlophus	0	0	22	0	0	0	0
Lepomis punctatus	9	0	115	25	33	1	8
Luxilus chrysocephalus	0	0	0	0	0	0	0
Luxilus zonistius	0	0	0	0	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0	0
Micropterus coosae	0	0	0	0	0	0	0
Micropterus punctulatus	0	0	0	0	0	0	0
Micropterus salmoides	0	0	3	3	0	1	0
Minytrema melanops	0	0	6	1	1	0	0
Moxostoma duquesnei	0	0	0	0	0	0	0
Moxostoma erythurum	0	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0	0
Nocomis leptocephalus	0	0	0	0	0	0	0
Notemigonus crysoleucas	0	0	1	0	0	0	0
Notropis asperifrons	0	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0	0
Notropis chrosomus	0	0	0	0	0	0	0
Notropis cummingsae	0	0	0	0	0	0	0
Notropis harperi	0	0	18	0	34	0	0
Notropis hudsonius	0	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0	0
Notropis longirostris	0	0	0	7	0	130	3
Notropis lutipinnis	0	0	0	0	0	0	0
Notropis maculatus	0	0	0	0	0	0	0
Notropis petersoni	0	0	0	4	0	0	0

Notropis stilbius	0	0	0	0	0	0	0
Notropis texanus	7	0	0	27	0	0	29
Notropis xaenocephalus	0	0	0	0	0	0	0
Noturus funebris	0	0	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0	0
Noturus leptacanthus	3	0	0	0	1	28	8
Oncorhynchus mykiss	0	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	6	0	0	1
Perca flavescens	0	0	11	0	0	0	0
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0	0
Percina nigrofasciata	1	0	10	15	2	49	3
Percina palmaris	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	4	0	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	10	13
Pteronotropis hypselopterus	40	0	26	0	45	0	0
Rhinichthys atratulus	0	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	7	0
Scartomyzon rupiscartes	0	0	0	0	0	0	0
Semotilus atromaculatus	0	0	0	0	0	0	0
Semotilus thoreauianus	0	0	0	0	0	107	7

Appendix B Table 8. Species abundance in reference and treatment sites of the Altamaha River Drainage and Piedmont region.

	Collection Number									
	Reference					Treatment				
Species name	40	124	172	626	669	605	50	617	655	667
Acantharchus pomotis	0	0	0	0	0	0	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0	0	0	0	0
Ameiurus brunneus	0	3	15	4	1	0	0	0	1	92
Ameiurus catus	0	0	0	0	0	0	0	0	1	0
Ameiurus melas	0	0	0	0	0	0	0	0	0	0
Ameiurus natalis	1	0	9	0	0	0	0	0	5	0
Ameiurus nebulosus	0	0	0	15	0	5	0	0	0	7
Amia calva	0	0	0	0	0	0	0	0	0	0
Anguilla rostrata	0	1	0	0	0	0	0	0	0	0
Aphredoderus sayanus	0	0	0	0	0	0	0	0	0	0
Aplodinotus grunniens	0	0	0	0	0	0	0	0	0	0
Campostoma oligolepis	0	0	0	0	0	0	0	0	0	0
Campostoma pauciradii	26	0	0	0	3	0	3	0	0	0
Centrarchus macropterus	0	0	0	0	0	0	0	0	0	0
Cottus carolinae	0	0	0	0	0	0	0	0	0	0
Cyprinella callisema	0	0	0	0	0	0	0	0	0	64
Cyprinella callistia	0	0	0	0	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0	0	0	0	0
Cyprinella venusta	0	0	0	0	0	0	0	0	0	0
Cyprinus carpio	0	0	0	0	0	0	0	0	3	0
Dorsoma cepedianum	0	0	0	0	0	0	0	0	0	0
Elassoma zonatum	0	0	0	0	0	0	0	0	0	0
Ericymba buccata	1	36	0	0	0	0	48	0	0	0
Erimyzon oblongus	0	0	1	9	0	0	0	4	1	0
Erimyzon sucetta	0	0	0	0	0	0	0	0	0	0
Esox americanus	0	0	0	0	0	0	0	0	2	0
Esox niger	0	0	0	0	0	0	0	0	0	0
Etheostoma brevirostrum	0	0	0	0	0	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0	0	0	0	0
Etheostoma edwini	0	0	0	0	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	0	0	0	0	0	1	0	0
Etheostoma inscriptum	4	0	0	29	18	0	7	0	0	40
Etheostoma jordani	0	0	0	0	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	0	0	0	0	0
Etheostoma scotti	0	0	0	0	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0	0	0	0	0
Etheostoma swaini	0	0	0	0	0	0	0	0	0	0

Etheostoma tallapoosae	0	0	0	0	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0	0	0	0	0
Fundulus escambiae	0	0	0	0	0	0	0	0	0	0
Fundulus lineolatus	0	0	0	0	0	0	0	0	0	0
Fundulus olivaceus	0	0	0	0	0	0	0	0	0	0
Fundulus stellifer	0	0	0	0	0	0	0	0	0	0
Gambusia affinis	0	0	0	0	0	0	0	0	0	0
Gambusia holbrooki	0	0	0	0	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	0	0	0	0	0	0	0
Hybognathus regius	0	0	0	0	0	0	0	0	1	0
Hybopsis lineapunctata	0	0	0	0	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	66	101	2	0	0	17	77
Hypentelium etowanum	0	0	0	0	0	0	0	0	0	0
Hypentelium nigricans	0	0	0	0	1	0	0	0	0	28
Ichthyomyzon gagei	0	0	0	0	0	0	0	0	0	0
Ictalurus furcatus	0	0	0	0	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0	0	0	55	0
Labidesthes sicculus	0	0	0	0	0	0	0	0	0	0
Lepisosteus oculatus	0	0	0	0	0	0	0	0	0	0
Lepomis auritus	23	9	11	58	17	68	9	21	28	56
Lepomis cyanellus	0	0	0	91	7	1	0	1	0	5
Lepomis gulosus	0	0	1	2	0	2	0	0	1	7
Lepomis macrochirus	22	18	3	155	5	56	0	1	35	156
Lepomis marginatus	0	0	0	0	0	0	0	0	0	0
Lepomis megalotis	0	0	0	0	0	0	0	0	0	0
Lepomis microlophus	0	0	0	2	0	0	0	0	0	6
Lepomis punctatus	0	0	0	0	0	0	0	0	0	0
Luxilus chrysocephalus	0	0	0	0	0	0	0	0	0	0
Luxilus zonistius	0	0	0	0	0	0	0	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0	0	0	0	0
Micropterus coosae	0	0	1	0	0	0	0	0	1	0
Micropterus punctulatus	0	0	0	0	0	0	0	0	0	0
Micropterus salmoides	2	0	0	6	1	1	0	3	4	7
Minytrema melanops	0	0	0	0	0	0	0	0	0	0
Moxostoma duquesnei	0	0	0	0	0	0	0	0	0	0
Moxostoma erythurum	0	0	0	0	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0	0	0	0	0
Nocomis leptocephalus	220	31	23	161	80	80	90	55	194	216
Notemigonus crysoleucas	0	0	2	0	0	13	0	0	0	12
Notropis asperifrons	0	0	0	0	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0	0	0	0	0
Notropis chrosomus	0	0	0	0	0	0	0	0	0	0
Notropis cummingsae	0	0	0	0	0	0	0	0	0	0
Notropis harperi	0	0	0	0	0	0	0	0	0	0
Notropis hudsonius	0	0	7	0	0	11	0	0	17	12

Notropis hypsilepis	0	0	0	0	0	0	0	0	0	0
Notropis longirostris	0	0	0	0	0	0	0	0	0	0
Notropis lutipinnis	443	143	59	79	188	31	432	66	171	145
Notropis maculatus	0	0	0	0	0	0	0	0	0	0
Notropis petersoni	0	0	0	0	0	0	0	0	0	0
Notropis stilbius	0	0	0	0	0	0	0	0	0	0
Notropis texanus	0	0	0	0	0	0	0	0	0	0
Notropis xaenocephalus	0	0	0	0	0	0	0	0	0	0
Noturus funebris	0	0	0	0	0	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0	0	0	0	0
Noturus insignis	0	0	0	1	4	1	0	0	2	0
Noturus leptacanthus	0	0	0	0	0	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	0	0	0	0	0	0	0
Perca flavescens	0	0	0	0	0	0	0	0	1	0
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0	0	0	0	0
Percina nigrofasciata	0	1	0	0	0	0	0	1	9	3
Percina palmaris	0	0	0	0	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	0	0	0	0	0	0	3	0
Pteronotropis euryzonus	0	0	0	0	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	0	0	0	0	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	0	0	0	0	0
Scartomyzon rupiscartes	22	0	1	25	7	8	2	2	13	107
Semotilus atromaculatus	13	0	0	1	4	0	12	17	5	5
Semotilus thoreauianus	0	0	0	0	0	0	0	0	0	0

Appendix B Table 9. Species abundance in reference and treatment sites of the Altamaha River Drainage and Coastal Plain region.

	Collection Number					
	Reference			Treatment		
Species name	349	248	342	338	287	346
Acantharchus pomotis	0	1	0	0	0	0
Ambloplites ariommus	0	0	0	0	0	0
Ameiurus brunneus	0	0	0	0	0	0
Ameiurus catus	0	0	0	0	0	0
Ameiurus melas	0	0	0	0	0	0
Ameiurus natalis	1	2	0	0	0	0
Ameiurus nebulosus	0	0	0	0	0	0
Amia calva	0	0	0	0	0	0
Anguilla rostrata	0	0	4	0	0	5
Aphredoderus sayanus	3	1	14	0	2	7
Aplodinotus grunniens	0	0	0	0	0	0
Campostoma oligolepis	0	0	0	0	0	0
Campostoma pauciradii	0	0	0	0	0	0
Centrarchus macropterus	0	1	1	0	0	0
Cottus carolinae	0	0	0	0	0	0
Cyprinella callisema	0	0	0	0	0	2
Cyprinella callistia	0	0	0	0	0	0
Cyprinella gibbsi	0	0	0	0	0	0
Cyprinella lutrensis	0	0	0	0	0	0
Cyprinella trichroistia	0	0	0	0	0	0
Cyprinella venusta	0	0	0	0	0	0
Cyprinus carpio	0	0	0	0	0	0
Dorsoma cepedianum	0	0	0	0	0	0
Elassoma zonatum	0	1	0	0	1	0
Ericymba buccata	0	0	0	0	0	0
Erimyzon oblongus	7	3	3	0	0	0
Erimyzon sucetta	0	0	0	0	0	0
Esox americanus	0	6	17	1	5	6
Esox niger	0	14	3	0	0	0
Etheostoma brevirostrum	0	0	0	0	0	0
Etheostoma coosae	0	0	0	0	0	0
Etheostoma edwini	0	0	0	0	0	0
Etheostoma fusiforme	0	0	0	0	0	0
Etheostoma hopkinsi	0	0	1	0	0	5
Etheostoma inscriptum	0	0	0	0	0	0
Etheostoma jordani	0	0	0	0	0	0
Etheostoma olmstedi	0	0	0	0	0	7
Etheostoma scotti	0	0	0	0	0	0
Etheostoma stigmaeum	0	0	0	0	0	0
Etheostoma swaini	0	0	0	0	0	0
Etheostoma tallapoosae	0	0	0	0	0	0
Etheostoma trisella	0	0	0	0	0	0
Fundulus chrysotus	0	0	0	0	0	0
Fundulus escambiae	0	0	0	0	0	0

Fundulus lineolatus	0	0	5	0	0	0
Fundulus olivaceus	0	0	0	0	0	0
Fundulus stellifer	0	0	0	0	0	0
Gambusia affinis	0	2	2	3	20	0
Gambusia holbrooki	0	0	0	0	0	0
H. sp. cf. winchelli	0	0	0	0	0	0
Hybognathus regius	0	0	0	0	0	2
Hybopsis lineapunctata	0	0	0	0	0	0
Hybopsis rubrifrons	0	0	0	0	0	0
Hypentelium etowanum	0	0	0	0	0	0
Hypentelium nigricans	0	0	0	0	0	0
Ichthyomyzon gagei	0	0	0	0	0	0
Ictalurus furcatus	0	0	0	0	0	0
Ictalurus punctatus	0	0	0	0	0	0
Labidesthes sicculus	0	0	4	1	4	0
Lepisosteus oculatus	0	0	0	0	0	0
Lepomis auritus	4	0	27	0	23	37
Lepomis cyanellus	0	0	0	0	0	0
Lepomis gulosus	0	1	7	1	6	0
Lepomis macrochirus	0	0	5	21	4	0
Lepomis marginatus	0	3	50	1	5	11
Lepomis megalotis	0	0	0	0	0	0
Lepomis microlophus	0	0	1	0	0	0
Lepomis punctatus	0	0	22	1	18	13
Luxilus chrysocephalus	0	0	0	0	0	0
Luxilus zonistius	0	0	0	0	0	0
Lythrurus atrapiculus	0	0	0	0	0	0
Lythrurus lirus	0	0	0	0	0	0
Micropterus cataractae	0	0	0	0	0	0
Micropterus coosae	0	0	0	0	0	0
Micropterus punctulatus	0	0	0	0	0	0
Micropterus salmoides	0	0	0	8	0	1
Minytrema melanops	0	0	0	0	0	0
Moxostoma duquesnei	0	0	0	0	0	0
Moxostoma erythurum	0	0	0	0	0	0
Moxostoma poecilurum	0	0	0	0	0	0
Moxostoma sp. cf. poecilurum	0	0	0	0	0	0
Nocomis leptocephalus	45	0	0	0	0	0
Notemigonus crysoleucas	0	0	0	0	4	0
Notropis asperifrons	0	0	0	0	0	0
Notropis baileyi	0	0	0	0	0	0
Notropis chrosomus	0	0	0	0	0	0
Notropis cummingsae	50	0	14	0	0	0
Notropis harperi	0	0	0	0	0	0
Notropis hudsonius	0	0	0	0	0	0
Notropis hypsilepis	0	0	0	0	0	0
Notropis longirostris	0	0	0	0	0	0
Notropis lutipinnis	97	0	0	0	0	0
Notropis maculatus	0	0	0	0	0	0

Notropis petersoni	0	0	0	0	0	18
Notropis stilbius	0	0	0	0	0	0
Notropis texanus	0	0	0	0	0	0
Notropis xaenocephalus	0	0	0	0	0	0
Noturus funebris	0	0	0	0	0	0
Noturus gyrinus	0	0	0	0	0	0
Noturus insignis	0	0	0	0	0	0
Noturus leptacanthus	2	0	0	0	0	1
Oncorhynchus mykiss	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	0	0	0
Perca flavescens	0	0	0	0	0	0
*Percina (*Alvordius*) sp. cf. P. macrocephala*	0	0	0	0	0	0
Percina kathae	0	0	0	0	0	0
Percina nigrofasciata	0	0	0	0	0	6
Percina palmaris	0	0	0	0	0	0
Phenacobius catostomus	0	0	0	0	0	0
Pimephales vigilax	0	0	0	0	0	0
Polydictis olivaris	0	0	0	0	0	0
Pomoxis nigromaculatus	0	0	0	0	0	0
Pteronotropis euryzonus	0	0	0	0	0	0
Pteronotropis hypselopterus	0	0	0	0	0	12
Rhinichthys atratulus	0	0	0	0	0	0
Scartomyzon lachneri	0	0	0	0	0	0
Scartomyzon rupiscartes	0	0	0	0	0	0
Semotilus atromaculatus	0	0	0	0	0	0
Semotilus thoreauianus	0	0	0	0	0	0

APPENDICE C

STUDY SITE HABITAT DATA

Appendix C. Habitat data for study sites including embeddedness (EMBED), sediment deposition (SEDIMENT), total habitat score (TOTALHAB), distance from nearest upstream dam (Distance), and percentage of upstream watershed dammed-off (% Dammed).

COLLECTION	TREATMENT	EMBED	SEDIMENT	TOTALHAB	Distance (km)	% Dammed
22	Treatment	3.1	2.3	84.3	0.50	26.60
50	Treatment	2.1	0.8	59.1	2.74	14.61
65	Treatment	1.4	5.2	69.3	1.99	10.37
73	Treatment	4.3	3.8	76.1	3.31	30.17
90	Treatment	11.7	14.0	106.4	2.54	61.28
159	Treatment	1.0	1.3	36.3	1.14	60.42
190	Treatment	1.3	2.3	55.3	1.28	83.29
196	Treatment	12.0	11.0	112.3	2.16	37.50
261	Treatment	0.0	3.7	73.2	5.66	1.66
275	Treatment	0.0	9.3	95.0	4.18	22.48
287	Treatment	0.0	4.4	116.6	3.19	6.26
300	Treatment	0.0	12.1	115.6	3.57	92.28
338	Treatment	0.0	10.0	105.7	1.28	98.45
346	Treatment	0.0	7.7	104.1	5.28	60.21
355	Treatment	0.0	6.0	80.1	0.32	98.89
361	Treatment	0.0	0.3	76.6	4.88	11.55
371	Treatment	0.0	5.0	114.0	2.47	87.42
409	Treatment	0.0	11.3	121.0	3.64	89.35
428	Treatment	10.2	11.3	85.2	4.79	15.43
430	Treatment	12.5	10.3	116.5	3.14	37.14
432	Treatment	10.5	13.2	117.2	0.55	96.01
438	Treatment	10.2	7.0	105.9	1.61	90.31
457	Treatment	9.6	10.8	109.0	0.24	98.63
469	Treatment	3.1	2.8	58.8	1.31	56.68
487	Treatment	13.4	13.5	127.2	10.54	9.25
503	Treatment	5.2	3.0	70.3	8.39	47.20
504	Treatment	12.6	11.3	96.5	1.98	13.34
508	Treatment	2.8	3.3	64.5	5.03	67.81
515	Treatment	2.7	2.4	95.0	5.67	37.42
536	Treatment	11.5	5.8	93.6	4.52	3.69
605	Treatment	11.4	9.2	108.9	4.18	1.96
617	Treatment	1.2	1.4	59.9	0.72	94.72
629	Treatment	0.5	3.7	58.0	1.39	5.32
650	Treatment	5.0	7.2	84.3	5.35	30.91
655	Treatment	1.7	1.6	72.6	5.81	3.41
667	Treatment	12.6	9.3	139.7	3.72	52.43
688	Treatment	0.8	2.2	85.4	5.28	42.67
27	Reference	4.0	7.1	84.5	NA	NA
31	Reference	2.2	5.0	78.0	NA	NA
32	Reference	5.5	6.2	65.4	NA	NA
40	Reference	5.3	4.4	81.1	NA	NA
42	Reference	2.1	3.4	68.9	NA	NA
43	Reference	3.9	5.6	89.7	NA	NA

45	Reference	4.7	3.2	82.4	NA	NA
69	Reference	7.9	9.9	121.5	NA	NA
86	Reference	15.0	15.2	149.9	NA	NA
124	Reference	1.3	1.3	45.0	NA	NA
172	Reference	3.7	5.0	80.0	NA	NA
226	Reference	2.0	1.7	60.0	NA	NA
248	Reference	0.0	14.6	152.4	NA	NA
257	Reference	0.0	12.3	85.8	NA	NA
260	Reference	0.0	18.5	142.8	NA	NA
330	Reference	0.0	13.8	117.3	NA	NA
342	Reference	0.0	6.3	94.2	NA	NA
349	Reference	0.0	10.3	88.3	NA	NA
362	Reference	0.0	0.3	78.1	NA	NA
372	Reference	0.0	5.0	109.2	NA	NA
375	Reference	0.0	5.3	87.5	NA	NA
408	Reference	0.0	0.3	76.0	NA	NA
433	Reference	12.9	13.2	135.9	NA	NA
443	Reference	6.5	6.8	106.0	NA	NA
450	Reference	8.1	10.3	110.0	NA	NA
455	Reference	15.8	16.9	138.8	NA	NA
459	Reference	14.4	10.7	108.6	NA	NA
463	Reference	9.2	7.5	114.6	NA	NA
467	Reference	12.0	10.6	130.2	NA	NA
479	Reference	9.6	10.5	110.8	NA	NA
501	Reference	12.4	10.8	109.1	NA	NA
505	Reference	11.9	11.9	90.7	NA	NA
528	Reference	5.3	6.0	52.3	NA	NA
559	Reference	12.7	14.0	110.4	NA	NA
626	Reference	14.3	11.3	124.4	NA	NA
663	Reference	0.0	0.3	53.3	NA	NA
669	Reference	3.5	3.0	72.3	NA	NA