FOREST LINKAGES TO DIVERSITY AND ABUNDANCE IN LOWLAND STREAM FISH COMMUNITIES

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Abstract—In 1999 we sampled fish and fish habitat in 79 stream reaches within watersheds of north-central Mississippi. Despite a program of successful reforestation and soil stabilization (Yazoo-Little Tallahatchie Project, 1949–1985), nearly all streams in the region are channelized or incised. In these sandy, upper Coastal Plain streams, we explored the relationships among in-stream wood, canopy cover, and stream fish assemblages and were particularly interested in how these relationships are affected by extensive channel modification. Minnows, sunfishes, darters, and catfishes, respectively, dominated the fauna. Total fish species, total fish abundance, minnow relative abundance, and canopy cover were related only to watershed size. Stream incision, as indicated by high banks and shallow water depths, showed negative associations with sunfish relative abundance, in-stream wood, and detritus. Flow and large in-stream wood were associated positively with relative abundances of darters and catfishes. Despite scarcity of wood and deep pools in these systems, we detected associations between fish assemblage composition and in-stream wood. Our analysis suggests even modest densities of in-stream wood can shift fish assemblage attributes from colonizing stages to intermediate or stable stages.

INTRODUCTION

Large-scale reforestation emphasizing riparian zones can dramatically affect fish communities of low-gradient Coastal Plain streams. Forested riparian zones provide multiple benefits to stream fishes (Angermeier and Karr 1984, Gregory and others 1991). Indirect benefits include reduction of sediment and nutrient inputs (Lowrance and others 1984), stabilization of stream banks, and moderation of water temperature extremes (Gregory and others 1991). These factors can affect fish productivity, physiology, reproduction, and community composition (Matthews 1987). More directly, organic matter input into streams as leaves and in-stream wood provides the primary energy source for aquatic macroinvertebrates (Wallace and others 1997), which form the food base for most stream fishes. In sandy Coastal Plain streams, debris dams and large wood greatly increase macroinvertebrate production (Benke and others 1984, Smock and others 1989), promote channel stability, and increase habitat complexity for fishes (Shields and Smith 1992).

From 1949 to 1985 the U.S. Department of Agriculture, Forest Service, and other Federal agencies led the Yazoo-Little Tallahatchie Project in the upper Coastal Plain of northern Mississippi (U.S. Department of Agriculture, Forest Service 1988). The program was designed to re-establish forests and stabilize soils in a region subjected to a sequence of massive erosion cycles from 1830 into the 1970s (Schumm and others 1984). Postsettlement alluvium from hillside erosion, reaching 5-m depths in valleys, exacerbated flooding and prompted the dredging and channelization of most streams in the region (Schumm and others 1984). Modification of stream channels induced cycles of stream incision or headcutting, an active geomorphic process on the landscape today (Shields and others 1994, 1998). Although not focused on riparian areas, the reforestation effort successfully stabilized hillslopes and dramatically increased forest cover of the region.

In 1999 we sampled fish and fish habitat in streams within the stabilized, reforested region. In these sandy, upper Coastal Plain streams, we explored the relationships among in-stream wood, canopy cover, and stream fish assemblages. We were particularly interested in how extensive channel modification affected these relationships. We examined whether multivariate relationships among canopy, in-stream wood, and fish community attributes were detectable, and if so, how they covaried across a range of watershed sizes and local habitat configurations.

STUDY REGION

The study region lies primarily within the Holly Springs National Forest located in Benton, Lafayette, Marshall, Tippah, and Union Counties in north-central Mississippi. The proclamation boundaries of potential Federal ownership include 153,000 ha, about 35 percent of which is national forest land. The ecoregion is classified as the Northern Loessial Hills Subsection, Coastal Plain Middle Section, Southeastern Mixed Forest Province (Keys and others 1995).

The study streams drain parts of four major river basins: the Little Tallahatchie and Yocona Rivers (both Yazoo River tributaries) and the Hatchie and Wolf Rivers (both direct Mississippi River tributaries). The topography consists of irregular low hills (200-m maximum relief) dissected by well-developed, dendritic drainage systems with flat, often broad, floodplains adjacent to large streams. Stream substrate is predominantly sand or silty sand with accumulations of finer material in depositional areas.

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The disturbance history of the area has profoundly modified stream systems through aggradation, channelization, and incision. The soils of the region are highly erodible, being derived from wind-deposited loess and Coastal Plain materials (Dendy and others 1979). Following European settlement, the land was deforested and cultivated. These actions accelerated hillside erosion, led to massive gully formation in uplands, and filled valleys with postsettlement alluvium (Cooper and Knight 1991, Schumm and others 1984, Shields and others 1994). All of these disturbances exacerbated flooding. Between about 1840 and 1930 individuals and local drainage districts attempted ineffectively to reclaim valley lands through channelization of streams and construction of drainage ditches (Shields and others 1994). From 1930 to 1970 in conjunction with reforestation and soil stabilization programs, Federal agencies led a second round of stream channelization and constructed many flood-control impoundments in headwater streams. Streams responded to changes in channel gradients, resulting in large part from channelization by undergoing incision. This process affects entire stream networks upstream to the smallest headwater channels. Incision is rapid, proceeding upstream at rates up to 500 m per year (Schumm and others 1984), often occurs episodically, and is widespread in the region (Shields and others 1998). First, streams eroded through the partially consolidated surface material; then, downcutting proceeded rapidly through underlying strata of unconsolidated sand and clay. Geologic controls in the resulting sand-bed channels are infrequent and mostly consist of outcrops of consolidated clay or cemented sand (Shields and others 1997). Despite successful reforestation and concomitant soil stabilization in the area, few streams have escaped channelization or incision. Massive bank failures from stream channel incision can contribute amounts of sediment to the region's stream systems comparable to amounts produced by deforestation at European settlement (Schumm and others 1984).

METHODS

We sampled fish and fish habitat at 79 wadeable stream reaches in the study region from May to September 1999 (appendix A). These reaches represent a range of watershed sizes, habitat types, and watershed conditions across the study region. When possible, we selected one or more extreme headwater, middle, and downstream reaches in each watershed and covered as many habitat types as possible within selected reaches, e.g., riffle, run, pool. We sampled a predetermined length of stream, such that sampling effort was approximately proportional to stream size (Angermeier and Smogor 1995, Lyons 1992, Paller 1995). Typically, reach lengths were 20 times the average width of the stream. Minimum reach length was 80 m for streams < 4 m in average width, and maximum reach length was 300 m for streams wider than 15 m. We subdivided each reach into four subreaches of equal length. We located the upstream and downstream termini of the reach and subreaches with a hip chain, tape, or range finder before sampling.

Fish Sampling

We employed two methods of fish sampling at each reach: (1) single-pass backpack electrofishing, and (2) seining. Combination of the two methods helped reduce bias and assured capture of most fishes representative of the reach assemblage. We standardized effort for both methods and sampled each subreach separately. For electrofishing, we calculated total sampling time as the reach length times 5 seconds and applied one-fourth the total effort to each subreach. For seining, we conducted 8 seine hauls (2 per subreach) for streams < 5 m in average width and 12 seine hauls (3 per subreach) for streams > 5 m in average width. One haul was either a sustained drag of the seine within a stream macrohabitat, such as a pool or one set-and-kick seine in a riffle (Jenkins and Burkhead 1994). Standardization of fishing times for electrofishing and effort for seining assured that streams of all sizes were sampled with effort proportional to their size. We kept fish samples from each subreach separately for both electrofishing and seining, but pooled all data within each reach for this analysis.

Physical Habitat Sampling

Subsequent to fish sampling, we sampled physical habitat. We established 12 equally spaced transects within each reach so that 3 transects occurred (one-fourth, one-half, and three-fourths of subreach length) within each subreach. At each transect, we recorded wetted width and estimated bank stability (eroding or stable); bank angle (steep, 90 degrees; moderately steep, > 45 degrees; gradual, > 45 degrees); bank height (nearest meter); and dominant bank vegetation. At equally spaced points along each transect, we measured water depth and velocity (at 0.6 depth). We visually categorized dominant substrate type as soft clay, hard clay, silt, sand, fine gravel (2 to 15 mm), coarse gravel (16 to 63 mm), cobble (64 to 256 mm), or bedrock. We also recorded presence or absence of detritus, small wood (< 10 cm in diameter or < 1.5 m in length), large wood (>10 cm in diameter, > 1.5 m in length), and aquatic vegetation within an area approximately 1 m^2 around each point. We estimated canopy cover at each point as 0, 25, 50, or 100 percent cover. We adjusted the number of points per transect for stream width. Transects > 10 m in width had points located at 2-m intervals; transects 5 to 10 m in width, at 1-m intervals; and transects < 5 m had a minimum of 5 equally placed points.

Data Analysis

We calculated the following measures of fish community composition for 66 of 79 reaches: total species, total abundance, and familial relative abundance. We eliminated 13 reaches from the analysis because physical data were incomplete, no fishes were captured, or visits in September 1999 revealed the sampled reach was located in an intermittent stream. Total species and total abundance at a reach were the total recorded number of fish species and individuals, respectively. Familial relative abundance was the proportional abundance of the four most abundant families across reaches: Centrarchidae, sunfishes; Cyprinidae, minnows; Percidae, darters (genera *Etheostoma* and *Percina*); and Ictaluridae, catfishes (mostly bullhead catfishes, *Ameiurus* spp., and madtom catfishes, *Noturus* spp.). Familial responses to physical habitat differences are ecological in origin, and within each family, fish species are reasonably similar in habitat requirements (Shields and others 1998).

For each reach, we derived mean values for a suite of physical and riparian characteristics. We calculated average depth (centimeter), velocity (meter per second), and bank height (meter) from transect points. We determined proportions of detritus, small in-stream wood, and large in-stream wood from the number of points at which each occurred divided by the number of points surveyed. For comparison with other studies, we also were interested in converting the large in-stream wood data into the number of pieces per unit length. Assuming that each transect point with large in-stream wood represented one piece of large wood, we calculated the number of pieces over the length of each reach and averaged across reaches. This rough data transformation to pieces of wood per unit length allows general comparison with other studies. We determined watershed area on 1:100,000-scale topographic maps in a Geographic Information System. We calculated stream order (Strahler 1957) and link magnitude (Osborne and Wiley 1992), including both intermittent and permanent channels on 1:24,000-scale topographic maps.

We used principal components analysis (PCA) as a first approximation to partition covariation of physical variables and fish community composition into one or more component axes and to ordinate reaches in physical variable-fish community space. The PCA contained geomorphic-related variables (watershed area, average velocity, average depth, and average bank height); riparian-related variables (proportions of canopy cover, large wood, small wood, and detritus); and fish community variables (total species, total abundance, and familial proportional abundance). We extracted principal components (SAS 1996) from the correlation matrix of the variables. We transformed watershed area, total species, average depth, and average velocity to logarithms (base 10) and proportional variables to arcsine square roots (Sokal and Rohlf 1995). We used the broken-stick model (Jackson 1993) to evaluate the interpretability of each principal component axis. Using this method, an axis has interpretive value if observed eigenvalues exceed eigenvalues generated by the model.

Table 1—Mean, standard error (SE), minimum, and maximum values for watershed area, physical habitat variables, canopy cover, and in-stream wood variables at 66 reaches in upper Coastal Plain streams of north-central Mississippi

Variable	Mean	SE	Min.	Max.
Watershed area (ha)	2543	457.4	43	15194
Depth (cm)	14.3	1.40	2	49
Velocity (m/s)	.17	.013	< .01	.53
Bank height (m)	2.7	.18	.9	7.8
Canopy cover (%)	71	3.3	6	100
Detritus (%)	16	2.0	0	95
Small wood (%)	27	2.2	0	68
Large wood (%)	7	.9	0	28

Table 2—Mean, standard error (SE), minimum, and maximum values for fish community variables at 66 reaches

Variable	Mean	SE	Min.	Max.
Total species	14.7	0.84	3	33
Total abundance (individuals)	154.2	18.94	7	1009
Minnow relative abundance (%)	41.7	3.41	0	100
Sunfish relative abundance (%)	21.0	2.50	0	100
Darter relative abundance (%)	13.3	1.80	0	73
Catfish relative abundance (%)	6.3	.99	0	32

RESULTS

The sampled reaches represented a range of physical stream conditions (table 1). Watershed area spanned 3 orders of magnitude; however, 55 of 66 reaches drained watersheds of 100 to 10 000 ha. Stream order ranged from first to fifth order and link magnitude from 1 to 314, but 82 percent of reaches were third order. Streams were generally shallow with low velocities. Only seven reaches had mean depths > 30 cm and only eight had velocities > 0.30 m per second. Stream incision as indicated by average bank height and percent shallow depths was a prominent feature across reaches. Most reaches (66 percent) had bank heights > 2 m, notwithstanding inclusion of many small streams. Most depths (61 percent) along transects were < 15 cm. Stream substrate was dominated by sand (71.4 percent of all transect points) with some silt (14.3 percent), hard clay (7.3 percent), and soft clay (5.1 percent); rocky substrates were rarely encountered (< 2.0 percent). Average canopy cover was high despite the range in watershed sizes. Three-fourths of reaches had 50 percent or greater canopy cover. The proportion of large wood was low (table 1), and for half the reaches, large wood occurred in < 5 percent of the sampled points. Large wood averaged 47 pieces per kilometer (SE = 5) and ranged from 0 to 213 pieces per kilometer.

The fish fauna was relatively diverse and abundant within most reaches, but highly variable among reaches (tables 2, 3). We captured 65 fish species representing 15 families (table 3), and only 16 reaches had fewer than 10 species. However, variability of total species among reaches was high with a coefficient of variation (CV) of 46.2 percent (table 2). Total abundance also showed high variability with CV of 99.8 percent. Catch per unit effort for electrofishing ranged from 0.02 to 0.71 individuals per second (mean = 0.21, SE = 0.016, CV = 62.4 percent). Capture rate on a reach-length basis ranged from 0.09 to 6.64 individuals per meter (mean = 1.47, SE = 0.138, CV = 76.4 percent). Density of fishes ranged from 0.04 to 1.7 individuals per square meter (mean = O.42, SE = 0.043, CV = 82.5 percent).

Table 3—Fish species frequency and proportional occurrence for 66 stream reaches in the upper Coastal Plain of north-central Mississippi

Family and species	Reaches Proportion	Reaches Frequency
Amiidae		
Bowfin (*Amia calva* Linnaeus)	.015	1
Aphredoderidae		
Pirate perch [*Aphredoderus sayanus* (Gilliams)]	.288	19
Atherinidae		
Brook silverside [*Labidesthes sicculus* (Cope)]	.121	8
Catostomidae		
Creek chubsucker [*Erimyzon oblongus* (Mitchill)]	.364	24
Northern hog sucker [*Hypentelium nigricans* (Lesueur)]	.212	14
Spotted sucker [*Minytrema melanops* (Rafinesque)]	.045	3
Blacktail redhorse (*Moxostoma poecilurum* Jordan)	.182	12
Centrarchidae		
Green sunfish (*Lepomis cyanellus* Rafinesque)	.606	40
Warmouth [*L. gulosus* (Cuvier)]	.273	18
Orangespotted sunfish [*L. humilis* (Girard)]	.030	2
Bluegill (*L. macrochirus* Rafinesque)	.758	50
Dollar sunfish [*L. marginatus* (Holbrook)]	.258	17
Longear sunfish [*L. megalotis* (Rafinesque)]	.545	36
Redear sunfish [*L. microlophus* (Gunther)]	.045	3
Redspotted sunfish [*L. miniatus* (Jordan)]	.121	8
Spotted bass [*Micropterus punctulatus* (Rafinesque)]	.288	19
Largemouth bass [*M. salmoides* (Lacepede)]	.303	20
White crappie (*Pomoxis annularis* Rafinesque)	.030	2
Clupeidae		
Gizzard shad [*Dorosoma cepedianum* (Lesueur)]	.015	1
Cyprinidae		
Bluntface shiner [*Cyprinella camura* (Jordan & Meek)]	.606	40
Blacktail shiner (*C. venusta* Girard)	.303	20

continued

Table 3—Fish species frequency and proportional occurrence for 66 stream reaches in the upper Coastal Plain of north-central Mississippi (continued)

Family and species	Reaches	
	Proportion	Frequency
Cyprinidae (continued)		
Common carp (*Cyprinus carpio* Linnaeus)	.015	1
Cypress minnow (*Hybognathus hayi* Jordan)	.015	1
Mississippi silvery minnow (*Hybognathus nuchalis* Agassiz)	.242	16
Striped shiner (*Luxilus chrysocephalus* Rafinesque)	.197	13
Ribbon shiner [*Lythrurus fumeus* (Evermann)]	.136	9
Redfin shiner [*L. umbratilis* (Girard)]	.409	27
Golden shiner [*Notemigonus crysoleucas* (Mitchill)]	.106	7
Orangefin shiner (*Notropis ammophilus* Suttkus & Boschung)	.030	2
Emerald shiner (*N. atherinoides* Rafinesque)	.288	19
Yazoo shiner (*N. rafinesquei* Suttkus)	.258	17
Mimic shiner [*Notropis volucellus* (Cope)]	.121	8
Pugnose minnow (*Opsopoeodus emiliae* Hay)	.045	3
Bluntnose minnow [*Pimephales notatus* (Rafinesque)]	.288	19
Bullhead minnow [*P. vigilax* (Baird & Girard)]	.061	4
Creek chub [*Semotilus atromaculatus* (Mitchill)]	.530	35
Esocidae		
Grass pickerel (*Esox americanus* Gmelin)	.121	8
Fundulidae		
Blackstripe topminnow [*Fundulus notatus* (Rafinesque)]	.561	37
Blackspotted topminnow [*F. olivaceous* (Storer)]	.845	56
Ictaluridae		
Yellow bullhead [*Ameiurus natalis* (Lesueur)]	.333	22
Brown bullhead [*A. nebulosus* (Lesueur)]	.030	2
Channel catfish [*Ictalurus punctatus* (Rafinesque)]	.159	11
Least madtom [*Noturus hildebrandi* (Bailey & Taylor)]	.015	1
Brindled madtom (*N. miurus* Jordan)	.121	8

continued

Table 3—Fish species frequency and proportional occurrence for 66 stream reaches in the upper Coastal Plain of north-central Mississippi (continued)

Family and species	Reaches	
	Proportion	Frequency
Ictaluridae (continued)		
Brown madtom (*N. phaeus* Taylor)	.667	44
Flathead catfish [*Pylodictis olivaris* (Rafinesque)]	.015	1
Lepisosteidae		
Spotted gar [*Lepisosteus oculatus* (Winchell)]	.076	5
Longnose gar [*L. osseus* (Linnaeus)]	.015	1
Percidae		
Bluntnose darter [*Etheostoma chlorosoma* (Hay)]	.045	3
Slough darter [*E. gracile* (Girard)]	.167	11
Harlequin darter (*E. histrio* Jordan & Gilbert)	.045	3
Brighteye darter [*E. lynceum* (Hay)]	.333	22
Johnny darter (*E. nigrum* Rafinesque)	.258	17
Goldstripe darter (*E. parvipinne* Gilbert & Swain)	.424	28
Cypress darter [*E. proeliare* (Hay)]	.106	7
Yazoo darter (*E. raneyi* Suttkus & Bart)	.409	27
Speckled darter [*E. stigmaeum* (Jordan)]	.303	2
Gulf darter [*E. swaini* (Jordan)]	.212	14
Redfin darter [*E. whipplei* (Girard)]	.242	16
Bandfin darter (*E. zonistium* Bailey & Etnier)	.015	1
Dusky darter [*Percina sciera* (Swain)]	.515	34
River darter [*P. shumardi* (Girard)]	.030	2
Petromyzontidae		
Ichthyomyzon sp.	.424	28
Poeciliidae		
Western mosquitofish [*Gambusia affinis* (Baird & Girard)]	.273	18
Sciaenidae		
Freshwater drum (*Aplodinotus grunniens* Rafinesque)	.061	4

Minnows, sunfishes, darters, and catfishes, respectively, dominated the fauna and on average accounted for about 82 percent of individuals captured (table 2). These four families were represented by at least one species in most reaches (table 3). Minnow and sunfish species each occurred in 65 reaches, darter species in 63, and catfish species in 55. Average relative abundance and number of species showed similar ranks among families. Minnows had the highest average relative abundance and the most species (17) and catfishes, the lowest abundance and 7 species (table 3). Sunfishes and darters were represented by 11 and 14 species, respectively. The 11 other families accounted for 16 species that ranged from relatively rare, e.g. bowfin, gizzard shad, to widespread, e.g., blackspotted and blackstripe topminnows (table 3).

Principal components analysis of physical and fish community variables across reaches produced eigenvalues exceeding those of the broken-stick model, providing support for interpretation of the first three axes (table 4). The first three axes accounted for 60 percent of the total variance (table 4). We considered variables with loadings > 0.20 (absolute value) as being associated with an axis; 52 percent of loadings across axes did not exceed this value. Because we were interested in interaction of stream geomorphic variables with in-stream wood and fish community variables, we named axes based on the geomorphic variable(s) with the highest absolute loading.

We interpreted the first principal component axis (PC–I) as a watershed size axis. Magnitudes and polarities of loadings (table 4) contrasted total species (fig. 1A), total abundance (fig. 1B), minnow relative abundance, watershed area, depth, and velocity, which all increased with watershed size, with canopy cover and detritus accumulations, which decreased with watershed size. Total species, total abundance, minnow relative abundance, and canopy cover were only associated with PC–I; absolute loadings on other axes were low. We detected no strong associations between canopy cover and these fish community variables except in the context of watershed size. The watershed size axis was only weakly associated with bank height, an indicator of stream incision.

Table 4—Loadings on the first three principal component axes of habitat, canopy, in-stream wood, and fish community variables for 66 stream reaches in the upper Coastal Plain of north-central Mississippi

Variable	PC–I	PC–II	PC–III
Watershed area	0.421	0.147	0.049
Depth	.304	.391	- .052
Velocity	.214	.158	.280
Bank height	.165	- .368	.066
Canopy cover	- .285	- .053	.066
Detritus	- .227	.282	- .243
Small wood	- .183	.484	.021
Large wood	- .030	.480	.222
Total species	.402	.173	- .024
Total abundance	.396	.037	- .062
Minnow relative abundance	.382	- .141	- .030
Sunfish relative abundance	- .075	.235	- .525
Darter relative abundance	- .068	.061	.543
Catfish relative abundance	- .122	.086	.471
Total variance (%)	29	17	14

We interpreted PC–II as a stream incision-depth axis. Magnitudes and polarities of loadings contrasted sunfish abundance, large and small in-stream wood, detritus, and depth (pool development) with bank height (table 4). The axis arrayed reaches along a gradient from shallow, deeply incised streams with low proportions of wood and sunfishes to deep streams with low banks and relatively high proportions of wood and sunfishes.

We interpreted PC–III as a stream velocity axis. The loadings indicate positive covariation between darter and catfish abundance, velocity, and large wood. Sunfish abundance and detritus covaried negatively with these variables. The axis arrayed reaches along a gradient from flowing, stream habitats having high proportions of large wood, darters, and catfishes and low proportions of detritus and sunfishes to slow or nonflowing habitats with low proportions of large wood, darters, and catfishes and high proportions of sunfishes. Importantly, the pattern of covariation indicates that the relative abundance of two largely rheophilic families, darters and catfishes, covaried positively with large wood in the context of flowing habitats.

DISCUSSION

We detected covariation among fish community measures, canopy, in-stream wood, detritus, and physical habitat configuration across a variety of watershed sizes and conditions. The watershed size axis essentially removed species-area effects from the analysis, such that remaining interpretable axes were independent of watershed size effects. Total species, minnow relative abundance, and total abundance were related positively, and percent canopy cover, negatively to watershed size. Surprisingly, little or no variability in minnow relative abundance, total species, or fish abundance was related to either the stream incision-depth or stream velocity axes, both of which were associated with in-stream wood and/or detritus. Large wood increases habitat heterogeneity (Shields and Smith 1992), and stable, deep, heterogeneous habitats typically yield increased fish species richness (Angermeier and Smogor 1995, Schlosser 1987) and show decreased dominance by minnows (Schlosser 1987). We expected that a high proportion of in-stream wood, especially large wood in pools, would be associated with increased diversity of fishes and decreased dominance of minnows after accounting for watershed size on PC–I. Given the increases in stream productivity associated with debris dams and large wood (Benke and others 1984, Smock and others 1989), we also expected total fish abundance to covary positively with in-stream wood. In contrast, we found no relationship between in-stream wood and total species, minnow relative abundance, or total abundance.

Influences of pool development and flow regimes on in-stream wood abundance might explain why total species, minnow relative abundance, and total abundance were not

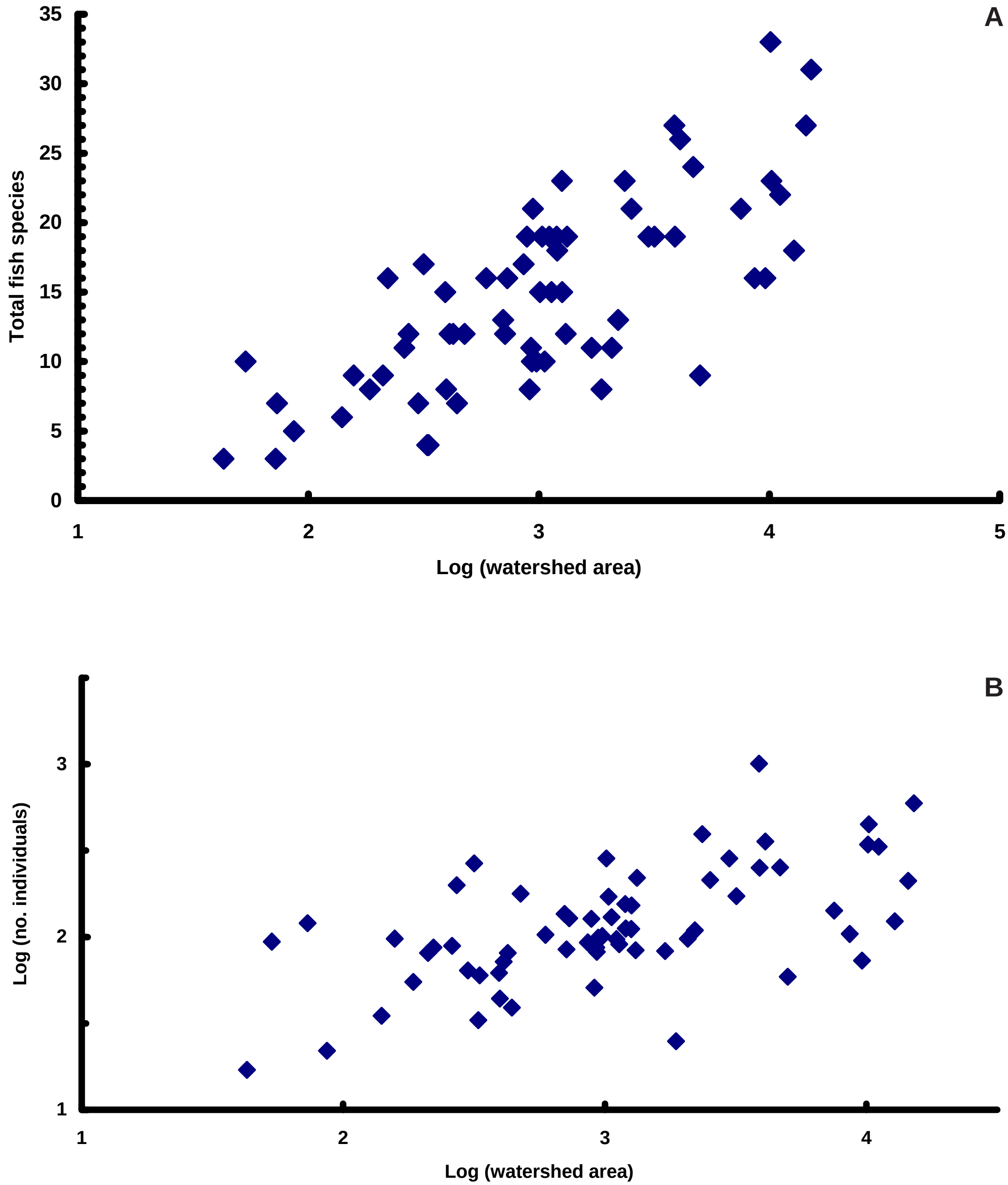

Figure 1—Scatterplots of watershed area and total number of fish species (A) and total number of fishes (B) in 66 stream reaches of the upper Coastal Plain of northern Mississippi.

associated strongly with in-stream wood. The overall amount of large wood in the sampled reaches appeared to be low, relative to conditions prevailing in streams within late successional forests. Large wood in Coastal Plain streams draining late successional forests is expected to approach about 200 pieces per kilometer (Smock and others 1989), and in eastern upland forests it can reach 400 to 500 pieces per kilometer (Hedman and others 1996, Hildebrand and others 1997). Our estimate of large wood across the study region is < 25 percent of the Coastal Plain expectation and only 6 reaches (9 percent) exceeded 100 pieces per kilometer. Shields and others (1995) also indicated scarcity of in-stream large wood in the study area. Maximum depth, an indicator of pool development, also was limited in the study reaches. Only 19 percent of our transect points exceeded 30 cm in depth, and only 6 percent exceeded 60 cm. Wide channels, shallow depths, and flashy flows in streams of the study region (Shields and others 1995, Wallerstein and others 1997) likely limit wood accumulation even in systems with relatively high wood recruitment. We believe the paucity of deep pools and large wood precluded detection of strong associations among total species, fish abundance, and in-stream wood after accounting for watershed size. Obversely, many of the minnow species represented in study reaches are adapted to the shallow, uniform, sandy habitats where they often occur in schools of hundreds to thousands of individuals. Ubiquity and extreme abundance of minnows, when treated as a single group, may explain their strong association with watershed size and lack of association with other axes. We believe analysis by species or habitat guilds within minnows may reveal associations beyond watershed size that were masked by examining the family as a group.

Stream incision strongly affects the interaction of in-stream wood with the quality of fish habitats and the composition of fish assemblages. Pairing Schlosser's (1987) conceptual stream framework for fishes and incised channel models (Schumm and others 1984, Simon 1989), three stages in fish community development for incising channels were hypothesized (Shields and others 1998). Colonizing fish assemblages are associated with shallow, uniform habitats with little debris. These are dominated by small species, such as minnows. In relatively undisturbed watersheds, these assemblages are found in small, headwater streams, but channelization and incision produce colonizing assemblages even in large streams. Intermediate assemblages typify streams with some increase in pool volume and begin to be comprised of larger fishes, such as sunfishes (Shields and others 1998). In both colonizing and intermediate stages, in-stream wood density may be depressed in response to changes in channel geometry (Shields and others 1998). As pool depth and volume increase further, stable assemblages develop with fewer, but larger, piscivores. Abundance of small invertivores and omnivores decreases as predation and resulting competition for refugia among prey species increases (Schlosser 1987, Shields and other 1998). At this stage, shallow riffle areas between pools provide important habitat, e.g., refuge from predators, for benthic invertivores, e.g., darters, madtom catfishes. Channelization and cycles of channel incision produce colonizing to intermediate fish assemblages (Shields and others 1998), but stable assemblage attributes may develop between disturbance events because of channel and adjoining floodplain dynamics.

We detected positive associations between the relative abundance of a dominant family, the sunfishes, and woody, deep habitats, a response attenuated by stream incision. These results are congruent with Schlosser's (1987) conceptual framework for small stream fish communities, in which deep, woody habitat was a key factor, and with fish assemblage changes observed after habitat manipulation in incised streams (Shields and others 1998). Addition of relatively deep, stable pools to incised streams shifted fish assemblages from colonizing stages to those more representative of intermediate stages, a change principally involving sunfishes (Shields and others 1998). Deep, woody pools increase habitat (pool volume), temporal stability, and forage availability, which influence fish community structure through shifts in fish age and size structure, species composition, and trophic composition. Wood in the deepest habitats in a stream may be especially critical to sunfishes during summer low flows, when total habitat area is reduced, and pools become relatively accessible to bird and mammal predators (Angermeier and Karr 1984). In Coastal Plain rivers sunfishes, especially *Lepomis* spp., obtain a large proportion of their food intake from invertebrates produced on wood, forming a distinct trophic pathway from in-stream wood to sunfishes (Benke and others 1985). Despite incision, poor pool development, and scarcity of large wood, the results from the stream incision-depth axis indicate that even modest increases in in-stream wood and pool development can play a strong role in structuring fish assemblages.

On the stream velocity axis, we discovered further evidence of the association of large wood and fish assemblage composition but in the context of water velocity, not pool development. The fish assemblage showed increased darter and catfish relative abundances and decreased sunfish relative abundance as large wood and velocities increased. Notably, this assemblage pattern emerged after watershed size and incision-related variation was removed, suggesting relatively small changes in habitat configuration improved conditions for species in both families. Although pool development is important in fish assemblage composition (Schlosser 1987), we suggest this pattern reflects the importance of large wood in providing cover for darters and catfishes irrespective of watershed size, incision, or the relatively shallow depths and low flows observed in study reaches. We attribute the trend in sunfish relative abundance on this axis, at least in part, to their affinity for low velocities, but realize other more complex factors, e.g., predation, may be involved. During field sampling we noticed that the majority of darters and catfishes (particularly madtoms) showed high affinity for cover, rarely occurring in open, uniformly sand-bottom habitats. Large wood generally formed primary cover in flowing habitats and is likely critical to the persistence of many darters and madtom catfishes (Chan and Parsons 2000, Monzyk and others 1997) in the study area. In sum, our results indicated large wood increases habitat quality for these two dominant and diverse families.

Fish species occurring in the region are those that have persisted through extensive historical and ongoing modifications to stream channels. We believe for most stream reaches surveyed that the number of species was at or near saturation because the available local species pool lacks potential new colonists regardless of the availability of stable, heterogeneous habitats. We did discover fish assemblage patterns associated with in-stream wood, but the legacy of channelization and incision limits the amount and thus the influence of wood on fish habitats. The results on the watershed size axis suggest that most reaches, regardless of watershed size, showed attributes of colonizing assemblages, particularly dominance by minnows. Minnows dominated 61 percent of our reaches. Minnows predictably dominate uniform shallow reaches (Schlosser 1987) and are conspicuously abundant in incised or channelized streams (Shields and others 1998). In contrast, covariation on the stream incision-depth axis indicates some reaches show characteristics of intermediate assemblages with increased representation of sunfishes. Incision apparently limits sunfishes by creating unstable shallow habitats that do not retain wood for cover or pool formation. The higher relative abundances of darters and catfishes on the stream velocity axis suggests that colonizing assemblages, predominated by minnows, may develop stable attributes if large wood and flow are present in sufficient quantity.

We did not examine some important aspects of stream fish assemblages, such as size structure or trophic relationships. Other assemblage attributes might show stronger associations with amounts of in-stream wood, canopy cover, or other aspects of habitat configuration. We plan to examine the data set to discern further assemblage patterns in the context of ecological guilds and watershed conditions.

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APPENDIX A

Localities for 79 stream reaches surveyed for fish and fish habitat in north-central Mississippi. An asterisk indicates the site was not used in the analyses because physical data were incomplete, no fishes were captured, or visits in September 1999 revealed the sampled reach was located in an intermittent stream. Abbreviations: trib. = tributary; CR = county road; FS = Forest Service road; quad. = U.S. Geological Survey 1:24,000 scale topographic map; DMS = degrees, minutes, and seconds; Lat. = latitude; Long. = longitude; DD = decimal degrees; T = township; R = range; S = section; and Q = quarter.

HATCHIE RIVER DRAINAGE

Unnamed trib. N. Br. Hurricane Creek, Muddy Creek trib., Tippah Co. Date: 7/26/99. CR 324 end, 3 km SE Camp Hill, 21 km NE Ashland. Walnut quad. Lat. (DMS): N34-56-14.2 Long. (DMS): W88-59-41.0 Lat. (DD): 34.9357 Long. (DD): -88.990167 T-2S, R-3E, S-4, Q-SW. Stream order: 2. Link magnitude: 4.

Unnamed trib. N. Br. Hurricane Creek, Muddy Creek trib., Tippah Co. Date: 7/26/99. FS 644A end, 3 km SE Camp Hill, 20 km NE Ashland. Walnut quad. Lat. (DMS): N34-55-41.8 Long. (DMS): W88-59-35.1 Lat. (DD): 34.923633 Long. (DD): -88.989183 T-2S, R-3E, S-9, Q-NW. Stream order: 3. Link magnitude: 14.

S. Br. Hurricane Creek, Muddy Creek trib., Tippah Co. Date: 7/27/99. CR 300 bridge, 8 km NNW Falkner, 7 km SE Camp Hill. Walnut quad. Lat. (DMS): N34-54-18.5 Long. (DMS): W88-57-51.4 Lat. (DD): 34.903083 Long. (DD): -88.958567 T-2S, R-3E, S-14, Q-SW. Stream order: 4. Link magnitude: 81.

West Prong Muddy Creek, Muddy Creek trib., Tippah Co. Date: 7/16/99. CR 414 bridge, 17.6 km E Ashland, 8.6 km NNW Ripley. Falkner quad. Lat. (DMS): N34-49-28.0 Long. (DMS): W88-58-59.0 Lat. (DD): 34.821333 Long. (DD): -88.9765 T-3S, R-3E, S-16, Q-NE. Stream order: 4. Link magnitude: 27.

*Unnamed trib. West Prong Muddy Creek, Muddy Creek trib., Tippah Co. Date: 7/16/99. CR 346, 15 km E Ashland, 14 km NNW Ripley. Whitten Town quad. Lat. (DMS): N34-50-55.6 Long. (DMS): W89-01-08.3 Lat. (DD): 34.8426 Long. (DD): -89.01805 T-3S, R-3E, S-6, Q-SE. Stream order: 1. Link magnitude: 1.

LITTLE TALLAHATCHIE RIVER DRAINAGE

*Bagley Creek, Lafayette Co. Date: 6/7/99. CR 244 (Riverside Rd.), 8 km E Abbeville, 19 km SW Potts Camp. Malone quad. Lat. (DMS): N34-30-08.3 Long. (DMS): W89-24-48.1 Lat. (DD): 34.501383 Long. (DD): -89.408017 T-7S, R-2W, S-4, Q-S. Stream order: 4. Link magnitude: 17.

Bagley Creek, Lafayette Co. Date: 6/7/99. Bagley Lake outflow, 8.7 km ESE Abbeville, 20.7 km SSW Potts Camp. Bagley quad. Lat. (DMS): N34-28-50.7 Long. (DMS): W89-24-19.5 Lat. (DD): 34.475117 Long. (DD): -89.40325 T-7S, R-2W, S-9, Q-SE. Stream order: 3. Link magnitude: 10.

Cypress Creek, Lafayette Co. Date: 6/1/99. CR 251 bridge, 6 km WNW Pleasantdale Church, 4 km SE Union Hill Church. Puskus quad. Lat. (DMS): N34-23-36.7 Long. (DMS): W89-17-12.9 Lat. (DD): 34.38945 Long. (DD): -89.285483 T-7S, R-1W, S-15, Q-NE. Stream order: 3. Link magnitude: 11.

Cypress Creek, Lafayette Co. Date: 6/4/99. 1.6 km upstream Goolsby Lake, 20.7 km E Oxford, 5.8 km NNW Lafayette Springs. Denmark quad. Lat. (DMS): N34-21-35.4 Long. (DMS): W89-18-15.3 Lat. (DD): 34.3559 Long. (DD): -89.30255 T-8S, R-1W, S-28, Q-N. Stream order: 2. Link magnitude: 2.

Cypress Creek, Lafayette Co. Date: 6/4/99. CR 252 bridge, 8 km NNW Lafayette Springs, 23.2 km E Oxford. Puskus quad. Lat. (DMS): N34-22-56.4 Long. (DMS): W89-17-54.3 Lat. (DD): 34.376067 Long. (DD): -89.292383 T-8S, R-1W, S-15, Q-SW. Stream order: 2. Link magnitude: 4.

Cypress Creek, Lafayette Co. Date: 5/28/99. CR 244 bridge, 3.6 km WNW Etta, 6.8 km S Cornersville. Puskus quad. Lat. (DMS): N34-28-37.7 Long. (DMS): W89-15-45.1 Lat. (DD): 34.47295 Long. (DD): -89.257517 T-6S, R-1W, S-13, Q-E. Stream order: 5. Link magnitude: 108.

West Cypress Creek, Cypress Creek trib., Lafayette Co. Date: 6/4/99. CR 251, 21.9 ENE Oxford, 12.1 km NNE Denmark. Puskus quad. Lat. (DMS): N34-24-31.5 Long. (DMS): W89-17-34.1 Lat. (DD): 34.40525 Long. (DD): -89.289017 T-8S, R-1W, S-3/10, Q-SW/NW. Stream order: 3. Link magnitude: 16.

West Cypress Creek, Cypress Creek trib., Lafayette Co. Date: 6/1/99. FS 844C, 18.4 km ENE Oxford, 9.2 km N Denmark. Puskus quad. Lat. (DMS): N34-23-29.2 Long. (DMS): W89-19-36.8 Lat. (DD): 34.3882 Long. (DD): -89.3228 T-8S, R-1W, S-17, Q-NW. Stream order: 3. Link magnitude: 8.

*West Cypress Creek, Cypress Creek trib., Lafayette Co. Date: 6/1/99. CR 252, 7.7 km N Denmark, 14.8 km E Oxford. Puskus quad. Lat. (DMS): N34-23-04.8 Long. (DMS): W89-20-06.7 Lat. (DD): 34.384133 Long. (DD): -89.33445 T-8S, R-1W, S-18, Q-SE. Stream order: 2. Link magnitude: 12.

*Unnamed trib. West Cypress Creek, Cypress Creek trib., Lafayette Co. Date: 6/3/99. FS 837E, 18.4 km ENE Oxford, 10.4 km N Denmark. Puskus quad. Lat. (DMS): N34-24-29.1 Long. (DMS): W89-20-11.3 Lat. (DD): 34.40485 Long. (DD): -89.335217 T-8S, R-1W, S-7, Q-NE. Stream order: 2. Link magnitude: 3.

Unnamed northern trib. W. Cypress Creek, Cypress Creek trib., Lafayette Co. Date: 6/3/99. FS 837E, 2.3 km E Keel, 10.9 km N Denmark. Puskus quad. Lat. (DMS): N34-24-27.4 Long. (DMS): W89-20-13.7 Lat. (DD): 34.404567 Long. (DD): -89.335617 T-8S, R-1W, S-6, Q-SE. Stream order: 1. Link magnitude: 1.

Puskus Creek, Cypress Creek trib., Lafayette Co. Date: 6/2/99. CR 237 (FS 830), 14.4 km ENE Oxford, 9.8 km NNW Denmark. Puskus quad. Lat. (DMS): N34-23-43.2 Long. (DMS): W89-22-20.7 Lat. (DD): 34.390533 Long. (DD): -89.370117 T-8S, R-2W, S-11, Q-SE. Stream order: 2. Link magnitude: 3.

Puskus Creek, Cypress Creek trib., Lafayette Co. Date: 6/2/99. CR 237 (FS 830), 14.4 km ENE Oxford, 9.8 km NNW Denmark. Puskus quad. Lat. (DMS): N34-23-43.7 Long. (DMS): W89-22-18.3 Lat. (DD): 34.390617 Long. (DD): -89.369717 T-8S, R-2W, S-11, Q-SE. Stream order: 3. Link magnitude: 7.

Puskus Creek, Cypress Creek trib., Lafayette Co. Date: 7/28/99. CR 245, 17 km NE Oxford, 15 km N Denmark. Puskus quad. Lat. (DMS): N34-26-46.7 Long. (DMS): W89-19-58.3 Lat. (DD): 34.441117 Long. (DD): -89.326383 T-7S, R-1W, S-29, Q-NW. Stream order: 4. Link magnitude: 37.

Puskus Creek, Cypress Creek trib., Lafayette Co. Date: 8/3/99. FS 832-C, 0.8 km downstream Puskus Lake, 16.2 km NNE Oxford, 14 km SSW Cornersville. Puskus quad. Lat. (DMS): N34-26-41.0 Long. (DMS): W89-20-14.8 Lat. (DD): 34.440167 Long. (DD): -89.3358 T-7S, R-1W, S-30, Q-SE. Stream order: 4. Link magnitude: 34.

Bay Springs Branch, Puskus Creek trib., Lafayette Co. Date: 9/14/99. University Mississippi Field Station, 10.2 km NE Oxford, 12 km SE Abbeville. Bagley quad. Lat. (DMS): N34-25-34.1 Long. (DMS): W89-23-44.3 Lat. (DD): 34.42235 Long. (DD): -89.390717 T-7S, R-2W, S-34, Q-SW. Stream order: 1. Link magnitude: 1.

Unnamed trib. Puskus Creek, Cypress Creek trib., Lafayette Co. Date: 7/28/99. CR 832, 1 km N Puskus Lake, 16 km N Denmark. Puskus quad. Lat. (DMS): N34-27-02.6 Long. (DMS): W89-21-00.2 Lat. (DD): 34.450433 Long. (DD): -89.350033 T-7S, R-1W, S-30, Q-NW. Stream order: 2. Link magnitude: 2.

*Little Tallahatchie Canal, Marshall-Lafayette Co. Date: 8/10/99. Riverside recreation site, 5.8 km SSW Bethlehem, 10.7 km SW Cornersville, Bethlehem quad. Lat. (DMS): N34-31-45.6 Long. (DMS): W89-21-58.7 Lat. (DD): 34.524267 Long. (DD): -89.359783 T-6S, R-2W, S-25, Q-SW. Stream order: ND. Link magnitude: ND.

*Little Tallahatchie Canal, Union Co. Date: 8/9/99. downstream Hwy 30 bridge at Etta. Etta quad. Lat. (DMS):

N34-28-55.2 Long. (DMS): W89-13-29.5 Lat. (DD): 34.475867 Long. (DD): -89.221583 T-7S, R-1E, S-8, Q-SW. Stream order: ND. Link magnitude: ND.

*Little Tallahatchie R., Lafayette Co. Date: 8/12/99. Old channel at Riverside Recreation Area, 6.5 km SSW Bethlehem, 10.7 km SW Cornersville. Bethlehem quad. Lat. (DMS): N34-31-11.3 Long. (DMS): W89-21-48.3 Lat. (DD): 34.51855 Long. (DD): -89.35805 T-6S, R-2W, S-36, Q-NW. Stream order: ND. Link magnitude: ND.

*Little Tallahatchie R., Lafayette Co. Date: 9/15/99. 1.2 km downstream Bakers Field boat ramp, 10.8 km ESE Malone, 10.8 km ENE Abbeville. Malone quad. Lat. (DMS): N34-31-11.2 Long. (DMS): W89-22-56.2 Lat. (DD): 34.518533 Long. (DD): -89.376033 T-6S, R-2W, S-35/34, Q-NW/NE. Stream order: ND. Link magnitude: ND.

*Little Tallahatchie R., Lafayette Co. Date: 9/17/99. Old channel, north ‘Hudson’s Deer Camp’, 7 m downstream trail crossing, 8.8 km SSE Bethlehem, 4 km SSW Cornersville. Bethlehem quad. Lat. (DMS): N34-30-20.5 Long. (DMS): W89-16-16.7 Lat. (DD): 34.503417 Long. (DD): -89.26945 T-7S, R-1W, S-2, Q-N. Stream order: ND. Link magnitude: ND.

Lee Creek, Lafayette Co. Date: 8/5/99. 40 m upstream and downstream CR 210 bridge, 14.5 km SSW Bethlehem, 6 km SE Abbeville. Bagley quad. Lat. (DMS): N34-28-25.2 Long. (DMS): W89-26-46.1 Lat. (DD): 34.470867 Long. (DD): -89.441017 T-7S, R-2W, S-18, Q-E. Stream order: 4. Link magnitude: 34.

Lee Creek, Lafayette Co. Date: 8/5/99. 10 m upstream CR 291 bridge, 2.8 km E Abbeville, 14 km SSW Bethlehem. Bagley quad. Lat. (DMS): N34-29-52.1 Long. (DMS): W89-27-26.0 Lat. (DD): 34.492017 Long. (DD): -89.454333 T-7S, R-2W, S-6, Q-SW. Stream order: 4. Link magnitude: 48.

Mitchell Creek, Union Co. Date: 8/2/99. 5 m upstream Hwy 30 bridge, 7.9 km SSW Cornersville, 6.1 km NW Enterprise. Etta quad. Lat. (DMS): N34-28/56.9 Long. (DMS): W89-12-09.7 Lat. (DD): 34.47615 Long. (DD): -89.201617 T-7S, R-1E, S-9, Q-SE. Stream order: 4. Link magnitude: 87.

Mitchell Creek, Union Co. Date: 8/2/99. 5 m upstream CR 12 bridge, 27 km ENE Abbeville, 9.1 km SSW Myrtle. Hickory Flat quad. Lat. (DMS): N34-31-14.1 Long. (DMS): W89-12-09.7 Lat. (DD): 34.519017 Long. (DD): -89.201617 T-6S, R-1E, S-33, Q-Center. Stream order: 3. Link magnitude: 8.

TIPPAH RIVER DRAINAGE

Big Snow Creek, Benton Co. Date: 7/13/99. 10 m upstream CR 607 bridge, 10 km SW Ashland, 17.8 km E Holly Springs. Holly Springs SE quad. Lat. (DMS): N34-46-22.4 Long. (DMS): W89-15-08.3 Lat. (DD): 34.7704 Long. (DD): -89.251383 T-3S, R-1W, S-36, Q-SE. Stream order: 5. Link magnitude: 67.

Big Snow Creek, Benton Co. Date: 7/19/99. End FS Rd. 657-D, 20.3 km ESE Holly Springs, 13.7 km NNW Hickory Flat. Chilli Creek quad. Lat. (DMS): N34-43-51.6 Long. (DMS): W89-14-13.3 Lat. (DD): 34.725267 Long. (DD): -89.23555 T-4S, R-1E, S-18, Q-SE. Stream order: 5. Link magnitude: 95.

Wagner Creek, Big Snow Creek trib., Benton Co. Date: 7/12/99. 5 m downstream CR 652 bridge, 6.4 km SSW Ashland, 21.6 km ENE Holly Springs. Ashland quad. Lat. (DMS): N34-47-26.5 Long. (DMS): W89-12-53.6 Lat. (DD): 34.78775 Long. (DD): -89.208933 T-3S, R-1E, S-29, Q-SE. Stream order: 4. Link magnitude: 11.

Wagner Creek, Big Snow Creek trib., Benton Co. Date: 7/12/99. 15 m upstream CR 607 bridge, 8.9 km SSW Ashland, 20.1 km ESE Holly Springs. Ashland quad. Lat. (DMS): N34-46-05.5 Long. (DMS): W89-13-46.1 Lat. (DD): 34.767583 Long. (DD): -89.22435 T-4S, R-1E, S-6/5, Q-NE/NW. Stream order: 4. Link magnitude: 41.

Big Spring Creek, Marshall Co. Date: 7/29/99. 40 m upstream CR 633 bridge, 8.5 km WSW Potts Camp, 14.5 km SSE Holly Springs. Waterford quad. Lat. (DMS): N34-37-58.2 Long. (DMS): W89-23-49.0 Lat. (DD): 34.626367 Long. (DD): -89.3915 T-5S, R-2W, S-22, Q-NW. Stream order: 5. Link magnitude: 206.

Big Spring Creek, Marshall Co. Date: 8/3/99. Upstream CR 694 bridge, channel runs parallel to road, 8.3 km NNE Abbeville, 9.9 km WSW Bethlehem. Malone quad. Lat. (DMS): N34-33-28.3 Long. (DMS): W89-25-49.6 Lat. (DD): 34.554717 Long. (DD): -89.424933 T-6S, R-W, S-17, Q-SE. Stream order: 5. Link magnitude: 314.

Unnamed trib. Big Spring Creek, Marshall Co. Date: 7/30/99. Musgray Rd off CR 633, upstream and downstream bridge, 9.3 km ENE Potts Camp, 11 km S Holly Springs. Waterford quad. Lat. (DMS): N34-39-48.4 Long. (DMS): W89-24-46.1 Lat. (DD): 34.658067 Long. (DD): -89.407683 T-5S, R-2W, S-9, Q-NW. Stream order: 4. Link magnitude: 71.

Chilli Creek, Benton Co. Date: 7/1/99. 10 m upstream CR 625 bridge, 15 km SSW Ashland, 9.7 km NNW Hickory Flat. Chilli Creek quad. Lat. (DMS): N34-42-10.2 Long. (DMS): W89-12-08.3 Lat. (DD): 34.7017 Long. (DD): -89.201383 T-4S, R-1E, S-28, Q-S. Stream order: 5. Link magnitude: 91.

Chewalla Creek, Marshall Co. Date: 6/16/99. 25 m upstream Hwy 4 bridge, 5 km S Hudsonville, 8.9 km NE Holly Springs. Holly Springs SE quad. Lat. (DMS): N34-41-46.8 Long. (DMS): W89-22-03.4 Lat. (DD): 34.691133 Long. (DD): -89.367233 T-3S, R-2W, S-24/13, Q-NW/SW. Stream order: 3. Link magnitude: 10.

Chewalla Creek, Marshall Co. Date: 6/17/99. 15 m upstream bridge Lacy Ivy Rd. bridge, 3.9 km SE Lake Center, 4.5 km NNW Potts Camp. Potts Camp quad. Lat. (DMS): N34-40-44.0 Long. (DMS): W89-19-56.3 Lat. (DD): 34.674 Long. (DD): -89.32605 T-5S, R-1W, S-5, Q-NW. Stream order: 5. Link magnitude: 189.

Chewalla Creek, Marshall Co. Date: 6/21/99. FS Rd. 661-A end, upstream and downstream, 3.8 km W Lake Center, 6.8 km NNW Potts Camp. Potts Camp quad. Lat. (DMS): N34-41-52.5 Long. (DMS): W89-19-49.0 Lat. (DD): 34.692083 Long. (DD): -89.324833 T-4S, R-1W, S-29/32, Q-SW/NW. Stream order: 5. Link magnitude: 150.

Chewalla Creek, Marshall Co. Date: 6/14/99. 100 m downstream Chewalla Lake outflow, 8.8 km NNW Potts

Camp, 10.6 km SE Holly Springs. Potts Camp quad. Lat. (DMS): N34-43-23.3 Long. (DMS): W89-20-27.8 Lat. (DD): 34.72055 Long. (DD): -89.337967 T-4S, R-1W, S-19, Q-NE. Stream order: 4. Link magnitude: 90.

Unnamed trib. Chewalla Creek, Marshall Co. Date: 7/8/99. 10 m upstream CR 611, 13.9 km ESE Holly Springs, 16.8 km NW Hickory Flat. Potts Camp quad. Lat. (DMS): N34-43-58.8 Long. (DMS): W89-18-12.1 Lat. (DD): 34.726467 Long. (DD): -89.302017 T-4S, R-1W, S-16, Q-SE. Stream order: 3. Link magnitude: 11.

Chilli Creek, Benton Co. Date: 6/30/99. 30 m downstream North Chilli Lake outflow. Chilli Creek quad. Lat. (DMS): N34-42-00.5 Long. (DMS): W89-08-23.2 Lat. (DD): 34.700083 Long. (DD): -89.1372 T-4S, R-2E, S-30, Q-SW. Stream order: 3. Link magnitude: 8.

East Chilli Creek, Chilli Creek trib., Benton Co. Date: 6/30/99. CR 626E downstream Chilli Lake, 40 m upstream confluence southern trib. Chilli Creek quad. Lat. (DMS): N34-41-46.0 Long. (DMS): W89-08-52.4 Lat. (DD): 34.691 Long. (DD): -89.142067 T-4S, R-1E, S-36, Q-NE. Stream order: 3. Link magnitude: 12.

Curtis Creek, Benton Co. Date: 7/22/99. FS Rd. 609A, 30 m downstream Curtis Lake outflow, 8.5 km SE Ashland, 7 km S Yellow Rabbit Lake. Whitten Town quad. Lat. (DMS): N34-46-44.5 Long. (DMS): W89-06-38.1 Lat. (DD): 34.774083 Long. (DD): -89.10635 T-3S, R-2E, S-32, Q-NE. Stream order: 3. Link magnitude: 2.

Oaklimeter Creek, Benton Co. Date: 6/29/99. 40 m downstream Wood Duck Lake outflow, 7.8 km SSE Bethel, 18 km E Potts Camp. Blue Mountain quad. Lat. (DMS): N34-39-59.0 Long. (DMS): W89-06-19.4 Lat. (DD): 34.659833 Long. (DD): -89.103233 T-5S, R-2E, S-8/9, Q-NE/NW. Stream order: 3. Link magnitude: 12.

Oaklimeter Creek, Benton Co. Date: 6/29/99. 15 m upstream CR 626 bridge, 7.1 km SSE Bethel, 18 km E Potts Camp. Blue Mountain quad. Lat. (DMS): N34-39-39.8 Long. (DMS): W89-06-28.1 Lat. (DD): 34.656633 Long. (DD): -89.104683 T-5S, R-2E, S-8, Q-SE. Stream order: 4. Link magnitude: 21.

Oaklimeter Creek, Benton Co. Date: 7/6/99. 15 m upstream CR 640 bridge, 8.1 km WNW Hickory Flat, 3.7 km SE Potts Camp. Potts Camp quad. Lat. (DMS): N34-37-42.5 Long. (DMS): W89-16-27.3 Lat. (DD): 34.62375 Long. (DD): -89.271217 T-5S, R-1W, S-23, Q-S. Stream order: 5. Link magnitude: 277.

Pechahallee Creek, Oaklimeter Creek trib., Benton Co. Date: 6/23/99. 12 m upstream FS 692 bridge, 5 km W Hickory Flat, 6.5 km SE Potts Camp. Hickory Flat. quad. Lat. (DMS): N34-37-12.1 Long. (DMS): W89-14-24.8 Lat. (DD): 34.618683 Long. (DD): -89.237467 T-5S, R-1E, S-30, Q-NW. Stream order: 4. Link magnitude: 31.

*Pechahallee Creek, Oaklimeter Creek trib., Benton Co. Date: 6/25/99. 30 m downstream Hwy 5 bridge, 4.8 km N Hickory Flat, 8 km SSE Bethel. Chilli Creek quad. Lat. (DMS): N34-39-39.1 Long. (DMS): W89-11-03.5 Lat. (DD): 34.656517 Long. (DD): -89.183917 T-5S, R-1E, S-10, Q-S. Stream order: 1. Link magnitude: 1.

Pechahallee Creek, Oaklimeter Creek trib., Benton Co. Date: 7/2/99. 15 m upstream CR 625 bridge, 4 km NW Hickory Flat, 8.3 km E Potts Camp. Chilli Creek quad. Lat. (DMS): N34-38-21.2 Long. (DMS): W89-13-05.3 Lat. (DD): 34.636867 Long. (DD): -89.21755 T-5S, R-1E, S-20, Q-NE. Stream order: 4. Link magnitude: 21.

Unnamed trib. Oaklimeter Creek, Benton Co. Date: 6/25/99. 10 m upstream box culvert opening on north side Hwy 78, 9.3 km ESE Potts Camp, 2.5 km NNW Hickory Flat. Chilli Creek quad. Lat. (DMS): N34-37-43.9 Long. (DMS): W89-12-29.4 Lat. (DD): 34.623983 Long. (DD): -89.2049 T-5S, R-1E, S-21, Q-SW. Stream order: 2. Link magnitude: 3.

*Unnamed trib. Oaklimeter Creek, Benton Co. Date: 7/7/99. 75 m upstream CR 662, 4.3 km E Potts Camp, 7.4 km WNW Hickory Flat. Potts Camp quad. Lat. (DMS): N34-38-20.9 Long. (DMS): W89-15-45.6 Lat. (DD): 34.636817 Long. (DD): -89.2576 T-5S, R-1W, S-24, Q-NW. Stream order: 1. Link magnitude: 1.

*Potts Creek, Benton Co. Date: 6/22/99. 3 m downstream CR 638, downstream Brents Lake, 6.4 km NNW Cornersville, 7 km SSE Potts Camp. Bethlehem quad. Lat. (DMS): N34-35-13.2 Long. (DMS): W89-16-46.1 Lat. (DD): 34.585533 Long. (DD): -89.27435 T-6S, R-1W, S-2, Q-SW. Stream order: 4. Link magnitude: 40.

Potts Creek, Marshall Co. Date: 6/23/99. 15 m downstream Mills Rd. bridge, 2.5 km NNW Bethlehem, 7 km SSW Potts Camp. Bethlehem quad. Lat. (DMS): N34-35-30.6 Long. (DMS): W89-20-32.5 Lat. (DD): 34.588433 Long. (DD): -89.33875 T-6S, R-1W, S-6, Q-NW. Stream order: 5. Link magnitude: 142.

Unnamed trib. Potts Creek, Benton Co. Date: 6/22/99. 7 m upstream 347 bridge, 4.4 km NE Bethlehem, 10 km W Hickory Flat. Bethlehem quad. Lat. (DMS): N34-36-13.2 Long. (DMS): W89-18-55.6 Lat. (DD): 34.6022 Long. (DD): -89.309267 T-5S, R-1W, S-33, Q-SW. Stream order: 4. Link magnitude: 21.

Unnamed trib. Tippah R., Benton Co. Date: 6/17/99. 20 m downstream CR 657 bridge, 7.2 km NNE Potts Camp, 10.8 km W Bethel. Potts Camp quad. Lat. (DMS): N34-42-32.7 Long. (DMS): W89-15-16.5 Lat. (DD): 34.70545 Long. (DD): -89.25275 T-4S, R-1W, S-25, Q-NE. Stream order: 4. Link magnitude: 26.

Unnamed trib. Tippah R., Benton Co. Date: 6/17/99. 110 m upstream CR 606, Gandy Property, 4.4 km NNE Potts Camp, 7.3 km E Pine Grove. Potts Camp quad. Lat. (DMS): N34-40-50.6 Long. (DMS): W89-16-48.3 Lat. (DD): 34.6751 Long. (DD): -89.274717 T-5S, R-1W, S-2, Q-NE. Stream order: 4. Link magnitude: 36.

*Unnamed trib. Tippah R., Benton Co. Date: 7/9/99. 8 m upstream trail crossing and upstream confluence, unnumbered FS rd., 1.7 km NE Potts Camp. Potts Camp quad. Lat. (DMS): N34-39-35.4 Long. (DMS): W89-17-08.3

Lat. (DD): 34.6559 Long. (DD): -89.284717 T-5S, R-1W, S-10, Q-SE. Stream order: 3. Link magnitude: 4.

Unnamed trib. Tippah R., Benton Co. Date: 7/9/99. 5 m downstream confluence, 1.7 km NE Potts Camp. Potts Camp quad. Lat. (DMS): N34-39-36.5 Long. (DMS): W89-17-10.9 Lat. (DD): 34.656083 Long. (DD): -89.28515 T-5S, R-1W, S-10, Q-SE. Stream order: 3. Link magnitude: 7.

Unnamed trib. Tippah R., Benton Co. Date: 7/7/99. FS Rd. 606-L, 30 m downstream Cox Lake outflow, 5.3 km NE Potts Camp, 17.1 km SE Holly Springs. Potts Camp quad. Lat. (DMS): N34-41-28.3 Long. (DMS): W89-17-24.5 Lat. (DD): 34.68805 Long. (DD): -89.287417 T-4S, R-1W, S-34, Q-S. Stream order: 3. Link magnitude: 25.

Yellow Rabbit Creek, Benton Co. Date: 7/21/99. 3 m downstream CR 649 bridge, 6.3 km ESE Ashland, 16.4 km WNW Ripley. Whitten Town quad. Lat. (DMS): N34-49.09.3 Long. (DMS): W89-06-19.0 Lat. (DD): 34.818217 Long. (DD): -89.103167 T-3S, R-2E, S-17/16, Q-SE/SW. Stream order: 3. Link magnitude: 8.

Yellow Rabbit Creek, Benton Co. Date: 7/22/99. 80 m upstream CR 648 bridge, 7 km SSE Ashland, 15 km WNW Ripley. Ashland quad. Lat. (DMS): N34-46-25.8 Long. (DMS): W89-08-41.7 Lat. (DD): 34.770967 Long. (DD): -89.140283 T-3S, R-1E, S-36, Q-SE. Stream order: 4. Link magnitude: 38.

WOLF RIVER DRAINAGE

Indian Creek, Benton Co. Date: 7/14/99. 5 m downstream CR 646 (Blackjack Rd.), 9 km NE Sahland, 5.5 km NNE Yellow Rabbit Lake. Whitten Town quad. Lat. (DMS): N34-51-46.2 Long. (DMS): W89-05-08.0 Lat. (DD): 34.8577 Long. (DD): -89.084667 T-2S, R-2E, S-34, Q-SW. Stream order: 3. Link magnitude: 9.

Sourwood Creek, Benton Co. Date: 7/15/99. 10 m upstream CR 647 bridge, 9.3 km SSE Canaan, 17.8 km NW Benton. Camp Hill quad. Lat. (DMS): N34-52-39.4 Long. (DMS): W89-04-11.3 Lat. (DD): 34.873233 Long. (DD): -89.06855 T-2S, R-2E, S-27/26, Q-SE/SW. Stream order: 3. Link magnitude: 7.

Sourwood Creek, Benton Co. Date: 7/15/99. 8 m downstream CR 646 bridge, 7.3 km SE Canaan, 19.3 km NNW Ripley. Camp Hill quad. Lat. (DMS): N34-53-17.1 Long. (DMS): W89-04-49.4 Lat. (DD): 34.886183 Long. (DD): -89.0749 T-2S, R-2E, S-22/27, Q-NE. Stream order: 3. Link magnitude: 17.

Turkey Creek, Benton Co. Date: 8/11/99. Blackburn Rd off CR 647, 2 m upstream bridge, 12.5 km NNE Ashland, 19.2 km NNW Ripley. Camp Hill quad. Lat. (DMS): N34-53-47.0 Long. (DMS): W89-03-36.6 Lat. (DD): 34.891167 Long. (DD): -89.0561 T-2S, R-2E, S-23, Q-NE. Stream order: 3. Link magnitude: 30.

YOCONA RIVER DRAINAGE

Kettle Creek, Lafayette Co. Date: 6/10/99. 80 m downstream Drewery Lake outflow, 17.3 km E Oxford, 4 km N Denmark. Denmark quad. Lat. (DMS): N34-20-41.8 Long. (DMS): W89-20-12.3 Lat. (DD): 34.3403 Long. (DD): -89.335383 T-8S, R-1W, S-31, Q-NE. Stream order: 2. Link magnitude: 2.

Kettle Creek, Lafayette Co. Date: 6/10/99. 120 m upstream CR 277 bridge, 18.1 km ESE Oxford, 4 km ENE Denmark. Denmark quad. Lat. (DMS): N34-20-07.1 Long. (DMS): W89-19-53.5 Lat. (DD): 34.334517 Long. (DD): -89.325583 T-8S, R-1W, S-32, Q-SW. Stream order: 3. Link magnitude: 4.

Kettle Creek, Lafayette Co. Date: 6/8/99. 10 m upstream Hwy 6 bridge, 18.4 km ESE Oxford, 1.7 km ENE Denmark. Denmark quad. Lat. (DMS): N34-18-48.6 Long. (DMS): W89-19-42.1 Lat. (DD): 34.3081 Long. (DD): -89.323683 T-9S, R-1W, S-8, Q-NW. Stream order: 3. Link magnitude: 9.

Pumpkin Creek, Lafayette Co. Date: 6/11/99. 10 m upstream Hwy 6 bridge, 12 km ESE Oxford, 5.7 km NNE Yocona. Yocona quad. Lat. (DMS): N34-19-37.5 Long. (DMS): W89-23-51.3 Lat. (DD): 34.322917 Long. (DD): -89.391883 T-9S, R-2W, S-3, Q-NW. Stream order: 3. Link magnitude: 11.

Pumpkin Creek, Lafayette Co. Date: 6/11/99. Past end CR 266, 2.2 km upstream Hwy 6 bridge, 7.4 km ESE Oxford, 7.4 km N Yocona. Yocona quad. Lat. (DMS): N34-20-20.8 Long. (DMS): W89-23-02.2 Lat. (DD): 34.3368 Long. (DD): -89.3837 T-8S, R-2W, S-35, Q-NW. Stream order: 3. Link magnitude: 6.

Yellow Leaf Creek, Lafayette Co. Date: 6/8/99. 40 m upstream CR 225, 6.7 km ESE Oxford, 10.4 km NNW Yocona. Yocona quad. Lat. (DMS): N34-22-04.4 Long. (DMS): W89-25-44.1 Lat. (DD): 34.3674 Long. (DD): -89.424017 T-8S, R-2W, S-20, Q-SE. Stream order: 3. Link magnitude: 9.

Yellow Leaf Creek, Lafayette Co. Date: 6/9/99. Deloach property, 10 m upstream from trib. confluence, 8.2 km E Oxford, 16.3 km SE Abbeville. Bagley quad. Lat. (DMS): N34-22-32 Long. (DMS): W89-25-17 Lat. (DD): 34.372 Long. (DD): -89.4195 T-8S, R-2W, S-20/21, Q-NE/NW. Stream order: 2. Link magnitude: 2.

Yellow Leaf Creek, Lafayette Co. Date: 6/9/99. Deloach property, 100 m downstream from trib confluence, 8.2 km E Oxford, 16.2 km SE Abbeville. Yocona quad. Lat. (DMS): N34-22-27 Long. (DMS): W89-25-17 Lat. (DD): 34.371167 Long. (DD): -89.4195 T-8S, R-2W, S-20/21, Q-NE/NW. Stream order: 3. Link magnitude: 8.

Yellow Leaf Creek, Lafayette Co. Date: 6/9/99. Deloach property, 1.2 km upstream from trib. confluence, 8.7 km E Oxford, 16.3 km SE Abbeville. Bagley quad. Lat. (DMS): N34-22-48 Long. (DMS): W89-24-38 Lat. (DD): 34.374667 Long. (DD): -89.406333 T-8S, R-2W, S-16, Q-SE. Stream order: 3. Link magnitude: 6.

Yellow Leaf Creek, Lafayette Co. Date: 7/21/99. FS 849E, 5 m downstream confluence, 17.8 km SW Etta, 17 km SE Abbeville. Bagley quad. Lat. (DMS): N34-23-01.1 Long. (DMS): W89-24-06.9 Lat. (DD): 34.383517 Long. (DD): -89.40115 T-8S, R-2W, S-15, Q-W. Stream order: 2. Link magnitude: 2.