Environmental Relationships to Wadeable Stream Fisheries Resources in Mississippi

John B. Alford and Donald C. Jackson

Wadeable streams in Mississippi do not garner the attention of most anglers or fishery managers; consequently, these streams hold an unmanaged recreational fishery. However, they can support quality sizes and abundances of largemouth bass (*Micropterus salmoides*), spotted bass (*Micropterus punctulatus*), and sunfishes. We used the U.S. Environmental Protection Agency's Wadeable Stream Assessment (WSA) to identify local and landscape-scale environmental features of Mississippi wadeable streams associated with relative abundances and size structure of catchable basses and sunfishes. In addition, we developed a testable regression model that can potentially be used as a rapid assessment tool to locate candidate streams in Mississippi that support a bass and sunfish fishery. Canonical correspondence analysis (CCA) suggested that increases in relative abundances of largemouth bass, longear sunfish (*Lepomis megalotis*), total bass combined and total sunfish combined were associated with small, meandering stream channels with residual pools, heavily forested watersheds and riparian canopy cover, and poor rapid habitat scores. Increases in relative abundances of spotted bass were associated with increasing stream size, flow and nitrogen concentration, decreases in channel incision height and sand substrates in favor of gravel and wood, as well as benthic macroinvertebrate assemblages with increasing proportions of scrapers and decreasing proportions of collector-gatherers and collector-filterers. These local-scale characteristics reflect forested riparian zones that minimize erosion and sedimentation from landscapes and supply woody debris for invertebrate colonization. In contrast, increases in bluegill (*L. macrochirus*) relative abundances were associated with more impacted systems, especially large, straight channels with open canopies, increased nutrient runoff, and landscapes with small to moderate increases in agricultural and urban cover (1-18% of watershed area). Our regression model suggests that, on average, as one proceeds towards the Mississippi Gulf Coast and 30 m wide riparian corridors are covered by increasing proportions of forest, then relative abundances and growth of age-1 of basses and sunfishes tend to increase. If this model can be validated, then fishery managers can use the model as a first-order assessment of wadeable streams in Mississippi with regard to their potential to support a recreational bass and sunfish fishery.

Keywords: Ecology, Recreation, Water Quality

Introduction

Wadeable streams support recreational fisheries throughout most of North America (Griffith 1999; Fisher and Burroughs 2003). The abundances and size structure of fisheries resources from these ecosystems tend to be related to local and landscape-scale environmental processes. For example, substrate size (Sowa and Rabeni 1995), water chemistry (Matthews 1987; Kwak and Waters 1997), woody debris inputs, (Angermeier and Karr 1984) and stable riparian corridors (Shields et al. 2000; Opperman and Merenlander 2004) are examples of local-scale processes that influence the abundances and size structure of fisheries resources from wadeable streams. However, landscape-scale attributes of wadeable streams typically influence local-scale processes, and they have been related to changes in abundance and biomass of trout (Jones et al. 1999; Kiffney et al. 2003; Wang et al. 2003; Kocovsky and Carline 2004), diatoms (Naymik et al. 2005) and aquatic insects (Nislow and Lowe 2006).

Clear-cutting of forest stands, row-crop agriculture, and pastoral activities on watersheds have lead to channel incision and sedimentation in wadeable streams (Roth et al 1996; Kauffman et al. 1997; Shields et al 2000; Dodds et al. 2004). Short-lived, small, fluvial generalists usually comprise fish assemblages from these streams (Schlosser 1982; Shields et al. 2003). Consequently, these wadeable streams typically do not support sport fisheries (Krueger and Waters 1983), especially for centrarchids (i.e., black basses, sunfishes and crappies) and salmonids (i.e., trout and salmon). In Mississippi, wadeable streams tend to be low-gradient, warmwater systems that support largemouth bass (*Micropterus salmoides*), spotted bass (*M. punctulatus*), and a variety of sunfishes (*Lepomis* spp.) (Robinson and Rich 1980; Robinson and Rich 1981; Robinson and Rich 1984). Compared to impoundments and large rivers (Jackson and Brown-Peterson 1995), local and landscape-scale processes that influence centrarchid fisheries resources in Mississippi wadeable streams are relatively unknown.

The goal of our research was to identify environmental influences on centrarchid fisheries resources in wadeable streams from Mississippi at two spatial scales. We define local-scale environmental features as those occurring at the riparian zone (0-300 m from channel edge) and the stream channel. Environmental features at the landscape-scale are those occurring throughout the entire upstream drainage area (i.e., watershed) of a reach. Our research had the following objectives: 1) identify local and landscape-scale environmental influences on abundance and size structure of centrarchid fisheries resources in wadeable streams from Mississippi and 2) develop a parsimonious and comprehensive model that can potentially predict centrarchid abundances and size structure from these systems.

Study Area

In 2004, the U.S. Environmental Protection Agency (USEPA) conducted the National Wadeable Streams Assessment (WSA) (USEPA 2004). From this program, we included the sampling units (i.e., stream reaches) from Mississippi. Sampling units consisted of one reach within each of 12 wadeable streams (Figure 1). Wadeable streams were identified as stream orders 1 through 5 (Strahler 1964). Reaches that were accessible only by boat were not considered wadeable. Sampling occurred during low flow conditions of summer months. The sample reach length was 40 times the mean wetted width at the X-site, where the X-site is the mid-point of the randomly-determined reach (Figure 2). This reach length was chosen by the USEPA to capture most of the variability in physical characteristics and benthic macroinvertebrate assemblages within the streams (USEPA 2004).

Materials and Methods

Environmental and benthic macroinvertebrate sampling protocol

Environmental data and benthic macroinvertebrates were collected once during the summer of 2004. The environmental data were collected at local and landscape scales, and variables from four categories were measured. The categories included physical characteristics of the channel (Table 1), taxonomy and size structure of riparian vegetation, land use and land cover (LULC) characteristics of the upland watersheds (Table 2) and water chemistry. Sampling methods for each of these data followed the environmental monitoring and assessment protocol in the WSA (USEPA 2004).

Benthic macroinvertebrates were collected in 2004 with a 500 μm mesh D-frame kicknet at left, center or right portions of transects for a period of 30 seconds. Samples from each transect were

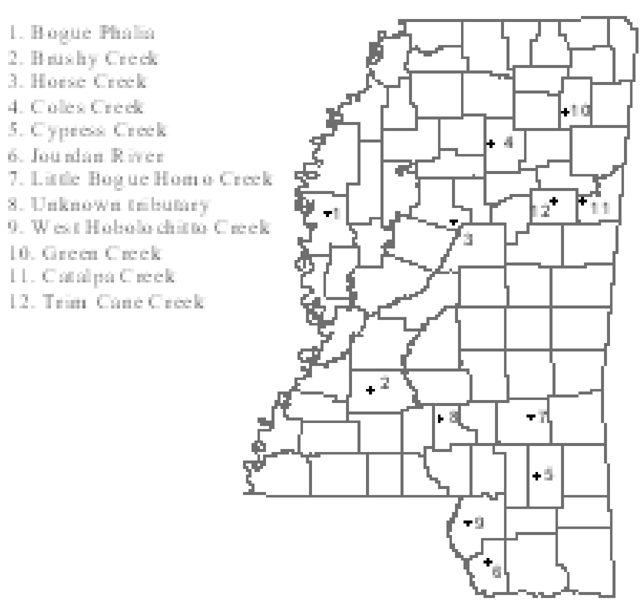

Figure 1. Locations of the 12 wadeable stream reaches in Mississippi that were sampled during the summers of 2004 and 2005.

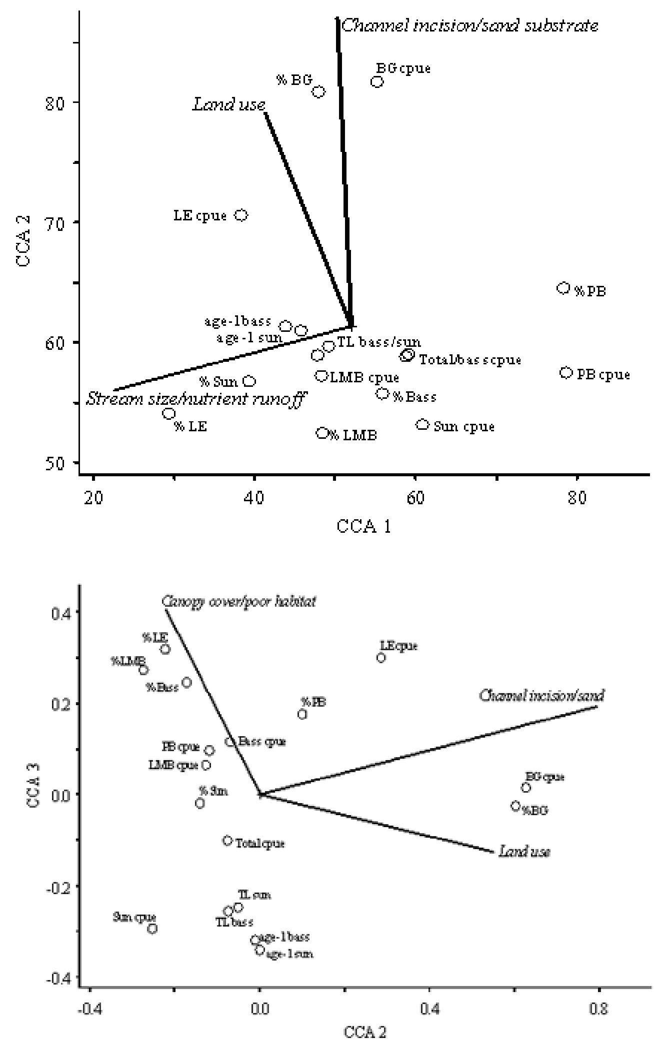

Figure 2.—Joint-plots describing a canonical correspondence analysis (CCA) ordination of centrarchid catch characteristics (circles). Environmental variables associated with catch characteristics are in italics. LMB=largemouth bass; PB=spotted bass; LE=longear sunfish; BG=bluegill sunfish; Total cpue=all fishes combined; Total bass=largemouth and spotted bass combined; Sun=all Lepomis spp. combined; TL=mean total length; age-1=mean length at age 1

Table 1. A summary of environmental data collected from reaches within 12 wadeable streams in Mississippi during summer 2004.

Environmental variables	Mean	Std. error
Channel		
CV of bank angle	73.0	8.16
Wetted width	9.2	1.79
Bankfull width	12.3	2.78
Bar width	2.2	1.36
Bankfull height	0.6	0.09
Incision height	2.8	0.27
CV of cross-sectional depth	104.4	5.19
Substrate size-class	2.6	0.36
% fines	29.2	9.26
% sand	42.1	8.58
% gravel	12.8	5.36
% wood	6.2	1.56
Total LWD units	36	10.94
Canopy cover (densiometer count: 0-17)	11.8	1.20
% water surfact slope	1.14	0.06
CV of bearing (i.e., sinuosity)	24.3	5.39
CV of thalweg depth	49.2	3.93
% of reach with bars	51.4	7.8
% of reach with soft sediment	64.2	10.11
% of reach with backwater	52.8	13.03
% of reach with residual pools	7.8	3.26
Discharge (m^3/s)	1.2	0.69
Rapid habitat assessment (0–180)	131.3	10.9
Intensity of beaver dams (0–3)	0.5	0.26
Riparian zone		
% deciduous vegetation	74.9	10.7
% mixed vegetation	25.1	10.7
Large tree cover class (0–4)	1.6	0.18
Small tree cover class (0–4)	2.5	0.17
Understory shrubs class (0–4)	2.8	0.15
Understory grasses class (0–4)	0.9	0.14
Ground shrubs class (0–4)	3.2	0.18
Ground grasses class (0–4)	2.3	0.27

Environmental variables	Mean	Std. error
Barren/dirt class (0–4)	1.3	0.12
Legacy tree dbh class (0–4)	2.3	0.30
Legacy tree distance from bank (m)	13.5	3.72
Total human disturbance score (0–6)	0.18	0.05
Aesthetic appeal (0–10)	6.8	1.08
Fish cover density (0–4)		
Small woody debris	1.5	0.33
Live trees/rootwads	0.5	0.08
Overhanging vegetation	2.3	0.34
Undercut banks	0.17	0.04
Watershed: physiographic features		
Stream order	3.3	0.30
Land area (km^2)	100.6	25.0
Latitude	32.5	0.38
Longitude	89.4	0.19
Land use/land cover		
Human impact score (0–26)	12.8	1.59
% forest	76.6	8.45
% non-forest	23.0	8.54
% deciduous vegetation	22.8	7.40
% conifer vegetation	37.3	10.18
% mixed vegetation	13.8	4.85
% agriculture	15.6	7.82
% pasture	4.5	1.54
% urban	3.8	1.42
Water chemistry		
pH	6.6	0.16
Temperature	25.9	0.76
Dissolved oxygen (mg/L)	4.4	0.50
Specific conductance (μS/cm)	179.8	80.98
Total alkalinity (mg/L $CaCO_3$)	43.1	10.67
Hardness (mg/L $CaCO_3$)	47.1	12.14
Turbidity (NTU's)	17.0	6.08
NH_3-N (mg/L)	0.58	0.13

Table 1. A summary of environmental data collected from reaches within 12 wadeable streams in Mississippi during summer 2004. (continued)

Environmental variables	Mean	Std. error
NO_3-N (mg/L)	0.10	0.02
Total nitrogen (mg/L)	0.33	0.05
Total phosphorus (µg/L)	40.2	9.13
Chlorine (mg/L)	11.9	2.12
Dissolved CO_2 (mg/L)	7.5	1.90
Dissolved organic carbon (mg/L)	4.3	0.68
Dissolved inorganic carbon (mg/L)	10.4	4.62
Total suspended solids (mg/L)	18.5	5.91

Table 2. Metrics describing benthic macroinvertebrates collected from 12 wadeable streams in Mississippi during summer 2004.[1]

Metrics	Mean	Std. error
Functional feeding groups		
% collectors (filterers + gatherers)	51.2	4.53
% shredders	15.5	3.18
% predators	19.2	3.46
% scrapers	9.5	2.83
Habit-types		
% burrowers	22.8	4.74
% climbers	18.6	3.28
% clingers	28.3	4.98
% miners	3.2	2.12
% sprawlers	20.6	4.80
% swimmers	1.8	0.91
Size structure and abundance		
Total length (mm)	3.4	0.54
% large individuals (>15 mm TL)	2.9	0.41
Abundance (individuals/m^2)	5,802	1,202

[1]Functional feeding and habit-type groups follow Merritt and Cummins (1996)

combined into one jar and preserved in 70-80% ethanol at the site. The reach-wide sample was then brought back to the fish research laboratory at Mississippi State University, where the invertebrates were sorted and identified. All benthic macroinvertebrates were measured (TL, mm), identified to genus using dichotomous keys and assigned to functional feeding and behavioral groups (e.g., collector-gatherer or burrower) (Merritt and Cummins 1996). The samples then were sent to Rithron Associates, Inc. (Billings, Montana) for taxonomic verification (a QA/QC procedure).

Fish sampling protocol

Centrarchid fisheries resources were sampled by angling with ultra-light fishing gear (spinning reels with 1.8 kg test line and 1.7 m rod). We chose this sampling technique because it focused the sampling effort on the species of interest in Mississippi's wadeable streams (i.e., catchable centrarchids). Angling is an important sampling technique for fisheries resources in streams, because it applies directly to management of recreational fisheries in these systems (Hudgins 1984). In addition, angling has been a valuable sampling technique for small stream fish stocks in Alaska (Hetrick and Bromaghin 2006) and catfish stocks in South Dakota streams (Arterburn and Berry 2002), especially when other gear types were ineffective at sampling certain sizes or species of fish.

Beetlespin lures were used to fish all reaches and consisted of yellow grub bodies (5.1cm long), 3.5 g yellow jig heads and #0 nickel spinner blades. Two anglers entered a reach at its downstream end and fished in an upstream direction for three hours. To address temporal variation in angling, reaches were fished on three separate occasions from June through September 2004-2005. Upon capture, fish were measured (TL in mm), and scales were removed for age analysis. Mean length-at-age was determined by back-calculation regressions following the procedures of Gulland (1969). All fish were released back into the stream at their point of capture.

Statistical analyses

We used canonical correspondence analysis (CCA) to identify environmental influences on centrarchid fisheries resources in wadeable streams from Mississippi. A CCA is essentially a multivariate linear regression analysis. Unlike multiple linear regressions (MLR), which use only one dependent variable, CCA uses multiple dependent variables and accounts for multicollinearity between the dependent variables. In our analyses, CCA simultaneously ordinated reaches and centrarchid catch characteristics while running a multiple linear regression on the fish matrix and the environmental and benthic macroinvertebrate data.

As the number of independent variables approaches the number of samples units (i.e., reaches), CCA results become increasingly unreliable. Therefore, we ran a principal component analysis (PCA)

on the original environmental matrix (67 variables) and the original benthic macroinvertebrate matrix (13 metrics). We reduced the dimensionality of these original datasets to ≤6 principal components for each matrix. These new independent variables (i.e., the components) were used in subsequent CCA with the original fish matrix (17 catch characteristics). To improve univariate normality, we arcsine-square root-transformed proportion data and log-transformed non-proportion data before any analyses occurred. All multivariate analyses were conducted with PC-ORD version 4.1 (McCune and Mefford 1999).
To develop a testable model, we used MLR to describe the relationships between centrarchid fisheries resources and environmental features of wadeable stream ecosystems in Mississippi. First, we performed a PCA on the centrarchid catch matrix to reduce the dimensionality of the original fish matrix and define gradients in abundance and size structure. Then, we selected candidate environmental variables that reflected the results of the CCA. The independent variables in the MLR included latitude, longitude and drainage area (km^2), an unnatural watershed vegetation index (e.g., agriculture or timber plantations), percent of the 0, 30 and 300 m wide riparian corridors forested and percent of the 0, 30 and 300 m wide riparian zones with human activities (e.g., parking lots, golf courses, residences). At α=0.10, we used backward elimination and best-subsets regression (Draper and Smith 1998) to select a parsimonious (i.e., simple) MLR model with the best fit. Finally, we checked the assumptions regarding constant variance, independence and normality of the errors by inspecting studentized residual plots and normal probability plots of the studentized residuals (Draper and Smith 1998). Regression analyses were conducted with SAS version 9.1 (SAS Institute Inc., Cary, NC).

Results

Description of environmental characteristics

The reaches in this study (Table 1) occurred primarily in forested landscapes (mean forest cover 76.6%). They were low-gradient (mean water surface slope 1.14%), warm-water (mean temperature 25.9°C) systems with unstable substrates (fines and sand 29.2% and 42.1%, respectively). On average, stable substrates (i.e., woody debris and gravel) comprised only 19% of the available substrates in the reaches. The cross-sectional depth varied twice as much as the longitudinal thalweg depth (Table 1), reflecting the formation of point bars (on average, median bar width 2.2 m; bars cover 51.4% of reach). Channel units were mostly glides, rather than riffles or pools (on average, <8% of reach length contained riffles or pools). On average, the channels were relatively narrow (median bankfull width 12.3 m) and straight (CV of mid-channel bearing 24.3).

Deciduous vegetation dominated the 10 m wide riparian zones (74.9% cover), followed by mixed coniferous/deciduous vegetation (25.1% cover). On average, the size structure of the riparian canopy (Table 1) was composed of small trees <0.30 m diameter-at-breast height (dbh), and the understory and ground cover consisted mainly of woody shrubs and saplings (i.e., height between 0.50 and 5.0 m). Total human disturbance scores averaged only 0.18 (where possible scores were 0-6). Therefore, the 10 m wide riparian corridors were very minimally impacted by human activities. Woody debris and overhanging vegetation from riparian zones provided most of the in-stream fish cover, followed by live trees/rootwads and undercut banks.
Conifers comprised most of the forests in the upland watersheds (37.3% cover), followed by deciduous (22.8% cover) and mixed (13.8% cover) vegetation. On average, row-crop agriculture (15.6% cover) was the dominant human land use activity on the watersheds, followed by pastures/hay fields (4.5% cover) and urban areas (3.8% cover of roads, residences, commercial and industrial facilities, etc.). Percent cover of agriculture varied from 0 to 97%, while percent of pastures and urban areas varied from 1 to 18% of the watershed areas.

Dissolved oxygen levels were low (on average, 4.4 mg/L), but the oxygen measurements were taken during summer low flow conditions. Total alkalinity varied widely among reaches. The reaches in the southeastern coastal plain region averaged <20 mg/L $CaCO_3$, while northern reaches in the Blackland prairie region averaged up to 155 mg/L $CaCO_3$. On average, specific conductance, turbidity, ammonia-nitrogen, nitrate-nitrogen, phosphorus, dissolved carbon and total suspended solids were below the recommended minimum criteria for Mississippi streams (see USEPA 2000 and MDEQ 2003 for minimum criteria).

Description of benthic macroinvertebrate assemblage

On average, collectors (i.e., filterers and gatherers) comprised the dominant functional feeding group (51.2% relative abundance) followed by predators (19.2%), shredders (15.5%) and scrapers (9.5%) (Table 2). Clingers (28.3%), burrowers (22.8%), sprawlers (20.6%) and climbers contributed relatively even abundances to the composition of habit-type groups, followed by miners (3.8%) and swimmers (1.8%). Overall, the invertebrates were abundant (on average 5,802 individuals/m^2), but very small (on average TL<3.5 mm and only 2.9% of individuals in a sample were >15 mm TL).

Description of fisheries resources

Over the course of the study, 298 fish were caught in 216 hours of angling effort. The mean total catch rate was 1.4 fish/angler-hour (Table 3). Total bass catch rates (0.90 fish/angler-hour; all Micropterus spp. combined) were nearly twice as large as total sunfish catch rates (0.53 fish/angler-hour; all Lepomis spp. combined). Likewise, largemouth bass and spotted bass catch rates (0.31 and 0.38 fish/angler-hour, respectively) were larger, on average, than that for longear sunfish and bluegill sunfish (0.26 and 0.13 fish/angler-hour, respectively). Basses comprised 47% of the total catch, while sunfishes comprised 40% of the total catch. However, longear sunfish (22.85 of total catch) were proportionately more abundant than spotted bass (11.7% of total catch). On average, basses and sunfishes were relatively small (212.4 mm TL and 135.4 mm TL, respectively). Mean age-1 length of sunfishes (92.1 mm) was nearly the same as that for basses (113.0 mm).

Reduction of environmental and benthic macroinvertebrate matrices

We used PCA to reduce the dimensionality of the original environmental and benthic macroinvertebrate matrices. As a result, we obtained new independent variables for subsequent CCA with the fish catch matrix. The environmental matrix (67 variables) was reduced to six new principal components that explained 78.2% of the variation in the original environmental data (Table 4). These new environmental variables (i.e., the components) suggested that wadeable stream ecosystems in Mississippi were influenced by combinations of landscape and local-scale features. In addition, these new environmental variables suggested that anthropogenic activities and geographic/physiographic characteristics influenced the structure of wadeable stream ecosystems in Mississippi.

We interpreted the new environmental variables as 1) human land use; 2) stream size and nutrient runoff (i.e., ammonia, nitrates, dissolved organic carbon, phosphorus); 3) canopy cover and habitat quality (i.e., amount of stream shade and habitat assessment scores); 4) alkalinity and small riparian trees; 5) sedimentation and straightened channels; 6) channel incision and sand substrate. The benthic macroinvertebrate matrix (13 metrics) was reduced to six components that explained 94.3% of the variation in the original data (Table 4). We interpreted the new benthic macroinvertebrate variables as 1) burrowers; 2) collectors and scrapers; 3) large individuals and predators; 4) small individuals, climbers and shredders; 5) miners and sprawlers and 6) swimmers. Because PCA is an orthogonal analysis, the new independent variables (i.e., components) were not linearly related. Therefore, multicollinearity between these new variables was minimized in subsequent CCA.

Environmental influences on fisheries resources in wadeable streams

Centrarchid fisheries resources in wadeable streams from Mississippi were associated with the following environmental gradients: 1) land use, 2) stream size and nutrient runoff, 3) canopy cover and habitat quality, and 4) channel incision and sand substrate (Figure 2). The CCA results suggested that largemouth bass abundance was correlated with minimally incised channels and proportionately less sand substrate in favor of other substrates. Additionally, largemouth bass, spotted bass, total bass and total sunfish abundances were correlated with increasing amounts of canopy cover (i.e., shaded channels with forested riparian zones) and relatively low habitat assessment scores (i.e., some sedimentation, few pools, relatively straight channels). Spotted bass were also correlated with wider streams, larger drainage areas and discharges, as well

Table 3. A summary of centrarchid catch characteristics from reaches within 12 wadeable streams from Mississippi. Centrarchids were sampled with ultra-light fishing gear on three occasions during summers 2004 and 2005.[1]

Catch characteristics	Mean	Std. error
Catch rate (CPUE: fish/angler-hour)		
Total	1.4	0.27
Total bass	0.90	0.17
Total sunfish	0.53	0.16
Largemouth bass *Micropterus salmoides*	0.31	0.06
Spotted bass *M. punctulatus*	0.38	0.15
Longear sunfish *Lepomis megalotis*	0.26	0.06
Bluegill sunfish *L. macrochirus*	0.13	0.04
Catch composition		
% Total bass	47.0	7.10
% Total sunfish	40.3	6.60
% Largemouth bass	35.0	6.60
% Spotted bass	11.7	5.61
% Longear sunfish	22.8	5.77
% Bluegill sunfish	9.7	3.19
Size structure (mm)		
Mean total length basses (spotted bass + largemouth bass)	212.4	10.85
Mean total length sunfishes (all *Lepomis* spp. combined)	135.4	6.32
Mean length age-1 basses	113.0	6.52
Mean length age-1 sunfishes	92.1	5.85

[1]Total=all fish species combined
Total bass=spotted bass and largemouth bass combined
Total sunfish=longear, bluegill, green, and redear sunfishes combined.

Table 4. PCA ordination results of an environmental matrix and a benthic macroinvertebrate matrix. Components with broken-stick eigenvalues ≥ 1.0 were retained as new independent variables in a subsequent CCA with a fish matrix. The purpose of these PCA ordinations was to reduce the number of environmental and benthic macroinvertebrate variables to a manageable set for further CCA.

New variable name	Proportion of variance explained in original data	Broken-stick eigenvalue
New environmental variables	78.2% (cumulative)	
Land use	24.8%	4.79
Stream size/nutrient runoff	18.1%	3.79
Canopy cover/ habitat quality	11.3%	3.29
Alkalinity/small riparian trees	9.2%	2.96
Sediment/ straightened channels	8.6%	2.71
Channel incision/ sand substrate	6.2%	2.51
New invertebrate metrics	94.3% (cumulative)	
Burrowers	29.0%	3.18
Collectors/scrapers	19.9%	2.18
Large/predators	16.8%	1.68
Small/climbers/ shredders	13.7%	1.35
Miners/sprawlers	9.6%	1.10
Swimmers	5.3%	0.90

as increasing nutrient levels. In contrast to spotted bass, longear sunfish were correlated with narrower streams, smaller drainages and discharges, as well as decreasing nutrient levels. Longear sunfish were similar to largemouth bass in that they were correlated with increased canopy cover and relatively low habitat assessment scores. Bluegill sunfish were correlated with more heavily impacted conditions than other fishes, especially increased land use and channel incision as well as proportionately more sand substrate instead of wood and gravel. Juvenile growth (i.e., from agew-0 to age-1) and adult size of basses and sunfishes were correlated with open canopies and large habitat assessment scores (i.e., stable substrate, pools, sinuous channels).

Centrarchid fisheries resources also were correlated with benthic macroinvertebrate groups that reflected environmental gradients of wadeable stream ecosystems in Mississippi (Figure 3). The CCA results suggested that spotted bass, total bass, total sunfish and total (i.e., all fishes combined) CPUE were correlated with increasing proportions of scrapers and decreasing proportions of collectors. In contrast, longear sunfish and growth of age-0 sunfish were correlated with proportionately more collectors and proportionately less scrapers. Benthic macroinvertebrate assemblages with abundant scrapers and fewer collectors reflect stream environments with stable substrates such as wood and gravel, allowing periphyton to attach and grow. Periphyton is the main food source for scraping invertebrates. In addition, periphyton and scrapers tend to be found in larger (e.g., 4-6th order), open canopy streams with abundant sunlight and nutrients. Conversely, benthic macroinvertebrate assemblages with abundant collectors and fewer scrapers reflect environments with less primary productivity in favor of detrital energy pathways.

Largemouth bass abundance was correlated with swimmers, while bluegill sunfish and percent total sunfish were correlated with proportionately fewer swimmers. These results suggested that largemouth bass were associated with lentic habitats (i.e., pools and backwater) provided by beaver dam pools, meandering channels with scour holes and/or pools formed by woody debris jams. In contrast, bluegill sunfish were associated with relatively straight channels, less stable substrate and fewer pools. These conditions are advantageous for bluegill sunfish because they can escape predation by pool-dwelling largemouth bass and spotted bass.

Longear sunfish were correlated with proportionately few burrowing invertebrates, while percent total bass were correlated with proportionately more burrowers. In addition, longear sunfish were correlated with large and predatory benthic macroinvertebrates (i.e., higher trophic levels), while total catch rates and largemouth bass catch rates were correlated with small, non-predatory invertebrates (i.e., lower trophic levels).

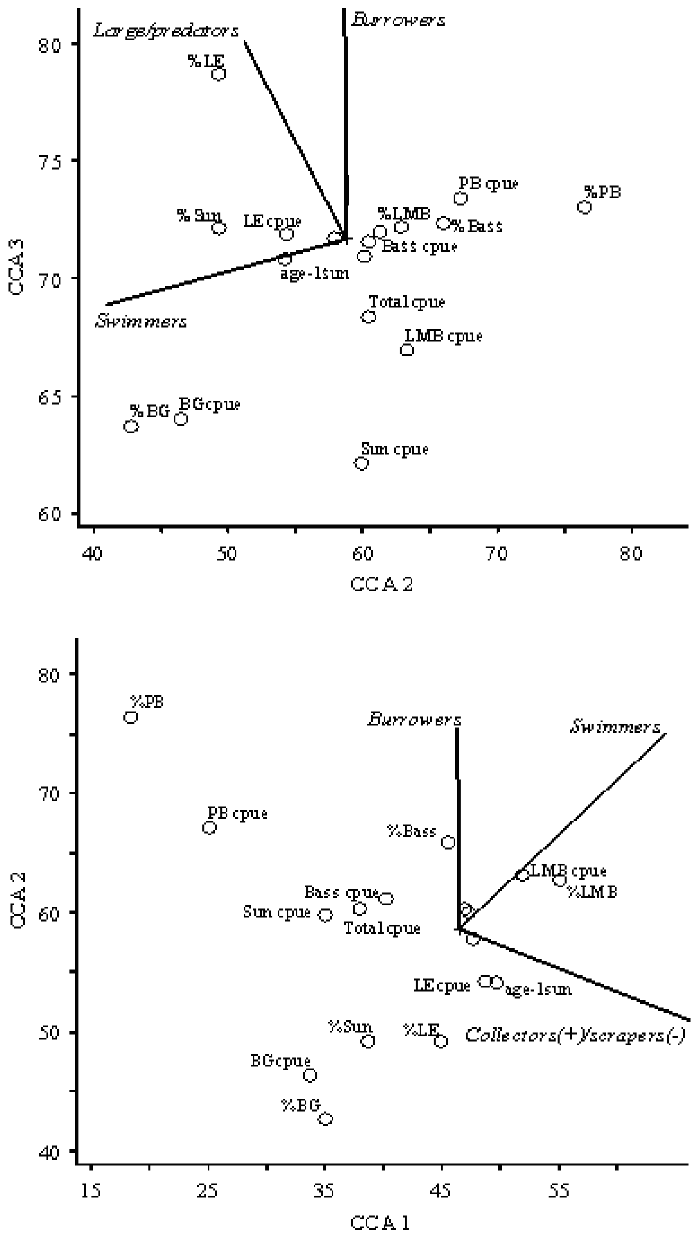

Figure 3.— Joint-plots describing a canonical correspondence analysis (CCA) ordination of centrarchid catch characteristics (circles). Benthic macroinvertebrate metrics associated with catch characteristics are in italics. LMB=largemouth bass; PB=spotted bass; LE=longear sunfish; BG=bluegill sunfish; Total cpue=all fishes combined; Total bass=largemouth and spotted bass combined; Sun=all Lepomis spp. combined; TL=mean total length; age-1=mean length at age 1.

A testable model for centrarchid fisheries in wadeable streams from Mississippi

To reduce the dimensionality of the original fish matrix, we used PCA to define gradients in centrarchid catch characteristics. The first three principal components explained 76.6% of the variation in the original fish matrix (Table 5). The first principal component (i.e., axis) represented a catch diversity and size gradient. The variables total catch rate, total sunfish catch rate, percent total basses, and mean total length of basses and sunfishes were negatively correlated with the first principal component (eigenvectors≥-0.32). The second principal component represented a spotted bass/longear sunfish gradient. Spotted bass were negatively correlated with principal component two (eigenvectors≥-0.34), while longear sunfish were positively related to the component (eigenvectors≥0.35). The third principal component represented a gradient in largemouth bass/bluegill sunfish abundance and growth of bass and sunfish. Largemouth bass were negatively correlated with the third component (eigenvectors≥-0.40), while bluegill sunfish and growth were positively correlated with the component (eigenvectors≥0.30). To develop a testable model for centrarchid catches in Mississippi wadeable streams, the site scores (i.e., locations of the reaches in species space) were used as new dependent variables in subsequent MLR analyses.

We developed a testable model that can potentially predict centrarchid catch characteristics in Mississippi's wadeable streams. The model describes the relationship between centrarchid abundance and size (i.e., site scores from principal component one) and environmental characteristics of Mississippi wadeable streams. We used the information from the CCA results to select independent variables reflecting landscape and local-scale processes as well as anthropogenic activities and natural geographic/physiographic characteristics. Using best subsets regression and backward elimination, we found a comprehensive and parsimonious MLR model ($N=12$; $F=10.87$; $P=0.0007$; $R^2=0.76$) for centrarchid fisheries resources in Mississippi's wadeable streams:

$$Y_{ij} = -37.562 + 1.298 * \text{latitude} - 0.072 * \text{rfor30};$$

where the dependent variable (Y_{ij}) is a gradient of large to small abundances and sizes of bass and sunfish. The independent variable "latitude" is the y-coordinate of the reach mid-point in decimal degrees, and "rfor30" is the percent of the 30 m wide riparian corridor that is forested. To address assumptions of linear regression analysis, inspections of the model's studentized residuals suggested the errors have constant variance, and they are independent and normally distributed.

Conceptually, the model says that as one proceeds towards the northern region of the state and riparian corridors (30 m wide) have proportionately less forest cover, wadeable stream reaches in Mississippi tend to support, on average, smaller total catch rates and sunfish catch rates, proportionately fewer basses, and smaller sizes of basses and sunfishes (Figure 4). Likewise, as one proceeds

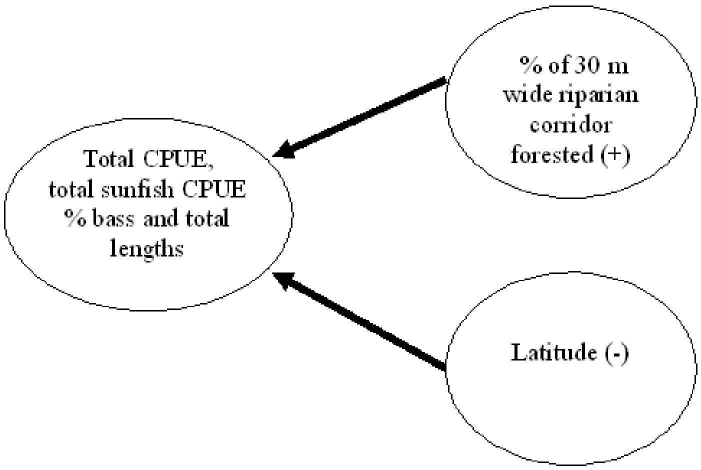

Figure 4. A conceptual illustration of a testable MLR model developed for centrarchid fisheries resources in Mississippi's wadeable streams.

towards the coastal region of the state and riparian zones are covered by proportionately more forest, wadeable stream reaches in Mississippi, on average, have larger total catch rates and sunfish catch rates, increased proportions of basses, and larger sizes of basses and sunfishes. The predictive ability of the model can be tested by incorporating a new, independent dataset from different wadeable stream reaches in Mississippi. The differences between observed and predicted values can then be evaluated. This validation procedure is required to evaluate the effectiveness of this model to predict the abundance and size of centrarchid fisheries resources in Mississippi's wadeable streams.

DISCUSSION

We found that centrarchid fisheries resources in Mississippi wadeable streams were correlated with a combination of local and landscape-scale human impacts to streams. Channel incision, substrate size, nutrient runoff, canopy cover and habitat quality were local-scale environmental characteristics associated with wadeable stream fisheries resources. These local attributes were probably influenced by landscape-scale characteristics, especially land use activities and stream size. Our results suggest that wadeable streams in Mississippi can support a centrarchid fishery in landscapes with small to moderate levels of land use (e.g., 1-18% of watershed area) in conjunction with forested riparian buffers.

Shields et al. (1998) studied the effects of channel rehabilitation on channel incision and sedimentation in reaches that drain large agricultural landscapes in Northern Mississippi. They found that fish abundance and fish size (especially largemouth bass and other fisheries resources) were greater in reaches where the banks were rehabilitated with stone spurs and willow posts. The bank modifications increased channel sinuosity and bank stability, providing sport fishes with larger residual pool area and slower mean current velocities. We found that increased channel incision and proportionately more sand substrate were negatively correlated with total catch rate, largemouth bass, total bass and sunfish abundances. Our results suggest that forested riparian zones minimize channel incision and excessive sedimentation, maintain sinuous channels that facilitate pool formation and provide backwater areas for centrarchid fisheries resources. In addition, these pools and backwater areas benefit anglers by providing access to catchable fish.

Landscapes covered by small to moderate amounts of agriculture, yet buffered by forested riparian corridors apparently increase primary and secondary productivity in wadeable streams, which can increase fish production (Nislow and Lowe 2006). For example, Krueger and Waters (1983) showed that fish stock biomass (all species combined) and invertebrate biomass differed significantly among three headwater trout streams in Minnesota with respect to human impacts to their watersheds. In their study, a stream within an agricultural landscape had large mean annual alkalinity concentrations of (245 mg/L), nitrates (5.0 mg/L), and proportionately more sand substrate compared to two streams in forested landscapes. Annual herbivore-detritivore biomass was larger in the agricultural stream (119.6 g/m2) compared to the forested streams (27.0 g/m2 and 36.9 g/m2, respectively). Similarly, the annual fish stock biomass was substantially larger in the agricultural stream (466.4 kg/ha) than the forested streams (46.6 kg/ha and 134.9 kg/ha, respectively).

We hypothesize that small to moderate levels of landscape development in combination with locally forested riparian zones increase nutrients inputs (Herlihy et al. 1998), such that fungal and bacterial productivity increases (Wainright et al. 1992; Koetsier et al. 1997; Benstead et al. 2004). This increase in primary productivity leads to an increase in secondary invertebrate production (Sponseller and Benfield 2001; Shieh et al. 2002), followed by increases in growth and abundance of basses and sunfishes. Microbial production increases dramatically when organic inputs from forested riparian zones (especially leaf litter) are available (Peckarsky 1980; Pomeroy and Wiebe 1988; Peterson et al. 2001). In Oregon, diatom production and diversity (Naymik et al. 2005) streams were maximized at moderate levels (~ 30% of watershed area) of watershed timber harvest compared to watersheds with no timber harvest. Kiffney et al. (2003) showed that periphyton and aquatic insect biomass were greatest when riparian buffer strips were 10-30 m wide (i.e., moderate timber harvest) compared to no riparian buffer (i.e., heavy timber harvest).

Landscape-scale impacts to streams must be mediated through forested riparian buffers. In the western United States, local impacts to wadeable stream riparian zones have reduced survival and recruitment of salmonids. Riparian zone deforestation has lead to siltation of spawning sites, declines in food resources by reducing coarse substrate availability for invertebrates, and sedimenta-

Table 5. PCA ordination results of a centrarchid catch matrix describing abundances and size structure of centrarchids caught by angling in reaches within 12 wadeable streams in Mississippi. Site scores represent graphical locations of the sample reaches along a particular axis. Percentages are the percent of the total variation in the original data explained by a particular axis. Eigenvectors (i.e., loadings) are analogous to correlations of centrarchid catch variables to a particular axis (i.e., component). [1]

	Site scores				Eigenvectors		
Reach name	Axis 1 37.4%	Axis 2 22.1%	Axis 3 17.1%	Catch characteristic	Axis 1	Axis 2	Axis 3
Coles Creek	-1.40	1.31	-0.99	Total cpue	-0.34	-0.19	-0.03
Green Creek	0.17	0.35	0.71	Total bass cpue	-0.23	-0.04	0.39
Jourdan River	-2.86	-2.89	3.23	Total sunfish cpue	-0.35	-0.15	-0.04
Bogue Phalia	7.01	-2.51	0.94	Largemouth bass cpue	-0.18	-0.13	-0.40
Brushy Creek	-0.25	-0.95	-0.79	Spotted bass cpue	-0.25	-0.35	0.08
Horse Creek	0.39	1.88	-1.62	Longear sunfish cpue	-0.17	0.31	0.07
Unknown Trib.	2.07	-2.13	-0.47	Bluegill sunfish cpue	-0.24	-0.19	0.40
Cypress Creek	0.46	0.05	-2.12	% Total basses	-0.32	-0.06	-0.24
L. Bogue Homo	-0.42	-0.03	-0.43	% Total sunfishes	-0.18	0.35	0.15
W. Hobolochitto Cr.	-2.17	0.95	0.64	% Largemout bass	-0.17	0.19	-0.45
Catalpa Creek	-2.70	-3.20	-2.10	% Spotted bass	-0.20	-0.34	0.12
Trim Cane Creek	-0.31	2.92	3.00	% Longear sunfish	-0.05	0.45	0.08
				% Bluegill sunfish	-0.22	0.05	0.37
				Mean length total bass	-0.34	0.17	-0.13
				Mean length total sunfish	-0.34	0.17	-0.10
				Mean length age-1 bass	-0.20	-0.05	0.32
				Mean length age-1 sunfish	-0.10	0.35	0.30

[1] Total bass=largemouth bass and spotted bass combined
Total sunfish=longear, bluegill, green, and redear sunfish combined

tion of holding areas such as pools and eddies (Chiasson 1996; Jones et al. 1999; Zimmerman et al. 2003). In contrast, riparian zone recovery, or return time, has improved habitat availability for catchable salmonids in California wadeable streams. For example, Opperman and Merenlender (2004) compared salmonid habitat parameters between clear-cut reaches (control) and reaches that were naturally reforested from clear-cutting. The reforested sites were historically clear-cut for timber harvest, but in 1982 and 1991 they were bought by private landowners. The landowners then built large fences around these stream reaches for hunting. These experimental exclosures made the channels narrower and deeper, lowered maximum water temperature by 1°C on average, and provided large woody debris that helped to create pools.

Geographic location and riparian land cover influence centrarchid fisheries resources in wadeable streams from Mississippi. We found that a gradient representing centrarchid abundance and size increased in response to decreases in latitude and increases in percent cover of forest in 30 m wide riparian corridors. Our model should be tested with independent data before it can be used to predict abundances and sizes of centrarchids from wadeable streams in Mississippi. However, the model provides guidance towards the future management of a wadeable stream fishery in Mississippi. If the model is validated, it can be used to locate candidate streams in Mississippi that potentially support centrarchid fisheries resources.

We focused primarily on density-independent factors that influence sport fishes in Mississippi wadeable streams. We assumed density-dependent factors (predation, competition, angler harvest, etc.) did not influence our catch characteristics. Additionally, we assumed that temporal variation in angling did not affect our results. Only two of the reaches in our study were fished by anglers other than our research team (Brushy Creek and L. Bogue Homo Creek), but these anglers fished only the area immediately around access points. During each successive fish sample throughout our study, fish were always caught in the same portion of a reach. Therefore, temporal variation in angling was negligible.

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