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[Article]

Associations between Watershed Characteristics and Angling Success for Sport Fishes in Mississippi Wadeable Streams

J. Brian Alford*[1] and Donald C. Jackson

Mississippi State University, College of Forest Resources, Department of Wildlife and Fisheries, Box 9690, Mississippi State, Mississippi 39762, USA

Abstract.—We developed and evaluated multiple linear regression models to describe the associations between watershed land use and geomorphology and angling success (catch per unit effort [CPUE; fish/h]) for sport fishes in wadeable streams in Mississippi. The mean angler CPUE for all species combined, sunfishes *Lepomis* spp., and black bass *Micropterus* spp. was strongly and positively associated with the percentage of forest cover, stream density, total road density, and primary highway density. The mean angler CPUE of largemouth bass *M. salmoides* and longear sunfish *L. megalotis* was negatively associated with the percentage of agricultural land but positively associated with rural road density. The mean CPUE of spotted bass *M. punctulatus* was negatively associated with elevation and the number of road crossings in the watershed but positively associated with rural road density. Model validation procedures revealed that the prediction errors were relatively large, so that the ability to predict mean angler CPUE from individual streams was low for all models. However, the species group models were precise, explaining 83, 71, and 80%, respectively, of the variation in the mean CPUE for all species, sunfishes, and black bass from an independent data set. In contrast, the species-specific models were relatively imprecise, explaining less than 33% of the variation in the mean CPUE in the independent data. We advocate a landscape-level management perspective—in concert with more traditional assessments of water quality and biological integrity—to address the connection between sport fishing and conservation in wadeable streams in Mississippi.

In the southeastern United States, warmwater coastal plain streams that are characterized as wadeable (Strahler stream orders 1–5; average depth <1 m) typically support sport fisheries for black bass (primarily largemouth bass *Micropterus salmoides* and spotted bass *M. punctulatus*), sunfishes *Lepomis* spp., and channel catfish *Ictalurus punctatus* (Jackson 2004; Shewmake and Jackson 2004; Alford and Jackson 2006). In contrast, smallmouth bass *M. dolomieu* tend to dominate the sport fisheries in more highland warmwater streams (Reed and Rabeni 1989; White 1996; Fisher and Burroughs 2003). By comparison with the sport fisheries in highland streams, those in coastal plain streams receive very limited, if any, management attention (Schramm et al. 1996; Fisher et al. 1998).

Traditionally, the management of wadeable-stream sport fisheries (e.g., those for smallmouth bass and salmonids) has relied on assessments of the instream habitat conditions (water quality, flow regime, and substrate composition) necessary for fish survival and production (Raleigh et al. 1986; Rankin 1986; Lyons 1991; Clarkson and Wilson 1995; Sowa and Rabeni 1995). However, stream fishes and the habitats that support them are influenced by hierarchical constraints occurring in the surrounding terrestrial landscapes (Frisell et al. 1986; Imhof et al. 1996; Strayer et al. 2003). These constraints include human land use in watersheds as well as regional geology and climate (Roth et al. 1996; Allan 2004; Creque et al. 2005). Research directed at the landscape-scale influences on wadeable stream fisheries tends to focus on recreationally and commercially important salmonid fisheries (Bowlby and Roff 1986; Kocovsky and Carline 2006), fish assemblages (Rashleigh et al. 2005), biological integrity (Roth et al. 1996), or water quality (Johnson and Gage 1997). In contrast, our understanding of the landscape influences on sport fisheries in warmwater, coastal plain streams is negligible.

Mississippi contains approximately 121,670 km of fishable streams (MDEQ 2003), and these systems provide ample opportunities for anglers to catch a wide variety of fish as well as large numbers of them. However, statewide stock assessments of the sport fisheries in wadeable streams have not been conducted since the 1980s (Robinson and Rich 1980, 1981, 1984), and instream habitat associations with sport fisheries have not been addressed until recently (Shewmake and Jackson 2004; Alford and Jackson 2006). Currently, Mississippi's wadeable-stream sport fisheries are not being actively managed (e.g., via

* Corresponding author: balford@wlf.louisiana.gov

[1] Present address: Louisiana Department of Wildlife and Fisheries, Research and Assessment Division, 2000 Quail Drive, Baton Rouge, Louisiana 70808, USA.

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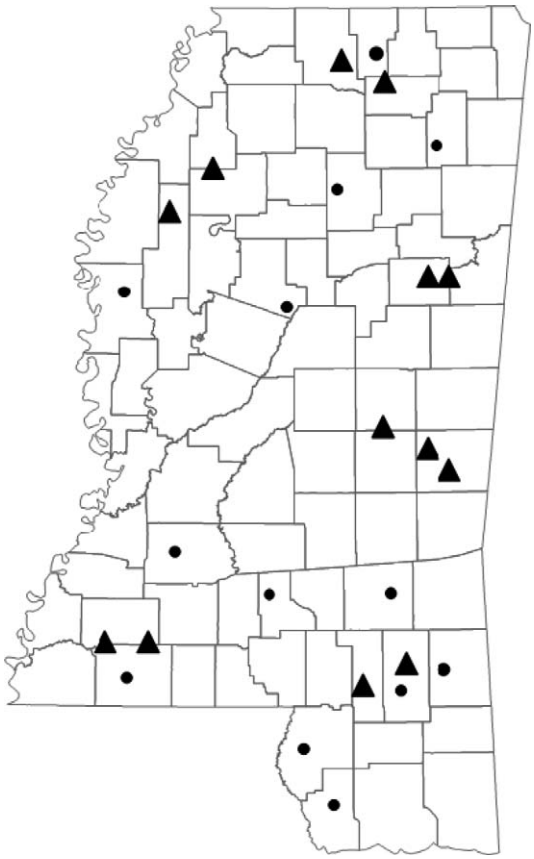

FIGURE 1.—Locations of the 26 wadeable stream reaches sampled by angling during July–October 2003–2005. The circles denote the X-sites (midpoints) of 13 reaches sampled 3–4 times during 2004 and 2005, the data from which were used to develop watershed-scale regression models of black bass and sunfish angling success. The triangles denote independent reaches sampled 2–4 times during the summers of 2003 and 2004; the data from these reaches were used to evaluate the accuracy and precision of the candidate models.

length limits and habitat restoration), even though they are exploited to some unknown extent.

Because stream fishes and their habitats are directly impacted by watershed characteristics, our goal was to evaluate the association between angling success for black bass and sunfishes in wadeable streams and watershed land use and geomorphology. In addition, we developed models that can be used as decision support tools for assessing the fisheries potential of individual wadeable streams in Mississippi. This watershed-scale perspective will enable fisheries managers to identify a large number of suitable stream sites at a broad scale using remote-sensing technology, thus reducing the labor costs of physically sampling habitat and fishes at an exhaustive number of potential sites.

Study site

In 2004 the U.S. Environmental Protection Agency (EPA) conducted a nationwide wadeable streams assessment (WSA) to characterize the relative health of small streams (EPA 2006). For the WSA and our study, wadeable streams were defined as being, on average, less than 1 m deep and being classified as stream order 1–5. In Mississippi, 13 sample reaches were randomly chosen by EPA personnel using a generalized random tessellation stratified (GRTS) design (Stevens and Olsen 2004). This study addressed the condition of wadeable streams at broad regional scales, including the southeastern U.S. coastal plain region. For it, we used the reaches from Mississippi that were included in the WSA (Figure 1). Subsequently, the population of interest in our study was all perennial, wadeable stream reaches in Mississippi that were mapped at the 1:100,000 scale and included in the U.S. Geological Survey's (USGS) national hydrography data set (NHD; www.nhd.usgs.gov). The reaches in the NHD were identified by their geographic coordinates (latitude and longitude) and randomly selected a priori using the GRTS sampling design. For the WSA the GRTS design ensured that, although smaller reaches (e.g., first- and second-order ones) were more numerous than larger reaches (e.g., third- to fifth-order ones), the larger reaches would not be excluded from the study just because there were fewer of them in the NHD.

The X-site geographic coordinates for a reach, which represented the reach's mid-point, were located in the field using a handheld Global Positioning System device or topographic map. The reach length was then calculated as 40 times the mean wetted width of the stream at the X-site. Research as part of the EPA's Environmental Monitoring and Assessment Program indicates that this reach length typically encompasses at least two meanders in wadeable streams, and it is generally the most appropriate length for characterizing the physical habitat and biota in these systems (Kaufman et al. 1999).

To validate the models developed from the WSA data set, we collected data from 13 reaches not included in the WSA (Figure 1). Data from 11 of these reaches came from a study by Shewmake and Jackson (2004). For their study, they randomly selected eight reaches located in U.S. Forest Service lands throughout the state and three reaches located on a timber company's property in eastern Mississippi. Two additional independent reaches were originally selected for the WSA but were dropped from this data set. One of these was a human-constructed canal that was not considered a representative site for the WSA study

(EPA 2006), and the other was considered unsafe at the time of initial site verification owing to a recent precipitation event. However, for our study, we sampled these two reaches on later dates during summer 2004 under safer, low-flow conditions and included them in the independent data set.

Methods

Assessment of watershed characteristics.—The watershed boundary for a reach was defined as the upland geographic area that drained to the downstream end of the reach. Total watershed area (km^2) was delineated by digitizing a polygon along the boundary of a watershed onto a map layer in ArcMap (Environmental Systems Research Institute, 2005). The watershed area was then calculated as the area of the polygon and used to calculate the densities of particular watershed attributes (e.g., stream and road densities).

We used remotely sensed watershed land use–land cover (LULC) data and human population data that were collected by the USGS in 2001 and stored in their Seamless Data Distribution System data set (www.seamless.usgs.gov). The LULC elements characterized by the USGS data set include the percentage of the watershed covered by natural vegetation, unnatural vegetation, forest, wetlands, total agriculture (i.e., row crops, pasture or hay, and silviculture) and urban or recreational areas. Road densities were calculated as the length of road (km) per watershed area (km^2). Roads were classified as class 1 (interstate and state highways), class 2 (secondary highways and county roads), and class 3 (rural roads, off-road trails, neighborhood roads, and logging trails). To assess the extent of human development in the watersheds, we computed population density change as the percentage difference in human population density from the 1990 census to the 2000 census.

Sampling protocol for sport fishes.—During the summers of 2003–2005 (July–October), fish were sampled by angling with ultralight fishing gear consisting of a spinning reel with 1.8-kg-test line and a rod 1.7 m long. "Beetle-spin" lures were used to fish all of the reaches on all occasions. These lures consisted of chartreuse grub bodies (5.1 cm long), 3.5-g chartreuse jig heads, and #0 nickel spinner blades. We chose this lure type because it effectively captures the target species, which consisted of black bass *Micropterus* spp. and sunfishes *Lepomis* spp.

Individual reaches were fished on at least three occasions during a particular summer at approximately 1-month intervals. Throughout the study, four anglers judged to have similar skills were used to sample sport fishes from the 26 reaches. At approximately 0900 hours on each sample date, two anglers entered the reach at its downstream end. They waded continuously and fished in an upstream direction until the entire reach was sampled; in general, the reaches were fished for 2–3 h. Each of the two anglers waded along each of the two banks and fished simultaneously from the bank to the middle of the reach, such that all areas of the reach were sampled systematically by the two anglers. To minimize angler bias, the anglers did not vary their level of fishing effort based on any preconceived notion that black bass or sunfishes were more or less abundant in particular habitats (e.g., pools versus shallow runs). Thus, all habitats were fished with approximately the same level of intensity. All captured fish were processed in the stream and released. We recorded the number of fish caught for each species and the total effort (hours for each angler).

Catch per unit of effort (CPUE [fish/angler-hour]) was used as an index of relative abundance and angling success because angler CPUE tends to be strongly correlated with other indices of abundance (Isaak et al. 1992; Arterburn and Berry 2002; Hetrick and Bromaghin 2006) as well as the actual abundances of fish populations (Tsuboi and Endou 2008; Martin and Fisher 2009). Fishing intensity (e.g., casting frequency, reeling speed, and wading speed) was similar among anglers, sites, and sample dates, and no fish were removed from the streams. Thus, we considered our angling success–relative abundance estimates to be minimally biased because catchability was assumed to be homogeneous among anglers.

To validate the performance (accuracy and precision) of the models generated from the WSA data set, we used watershed, fish catch, and angler effort data from the 13 additional stream reaches as the independent data set (see Figure 1). Fish catch and effort data for these streams were collected during summer 2003–2004 by Shewmake and Jackson (2004), and we used the same fish sampling gear and methods that were used in their study. Also, three of the four anglers that participated in their study participated in our study. Therefore, we considered the sampling effort and catchability to be similar between data sets.

Statistical analyses.—We used multiple linear regression analysis to develop candidate models and identify important watershed characteristics associated with angling success for each species and species group (all species, black bass, and sunfishes) (Draper and Smith 1998). We used "best-subsets" regression at (= 0.05 to create a set of candidate models containing 1–4 descriptor variables. Up to 10 models were evaluated for each of the species and species groups. For each of these models we calculated Mallow's C_p statistics, adjusted R^2 values, and Akaike's information criterion values to determine the best candidate model for each

TABLE 1.—Remotely sensed watershed data collected by the USGS in 2001 for 13 Mississippi wadeable streams and used to develop regression models of angling success for black bass and sunfishes.

Watershed characteristic	Average (range)
Latitude at X-site (°N)	32.3 (32.0–34.8)
Longitude at X-site (°W)	89.5 (88.4–90.8)
Area (km^2)	194.8 (0.5–1,482.6)
Elevation at X-site (m)	69.8 (3–137)
Percent natural vegetation	73.7 (11.6–100)
Percent forest	68.8 (1.3–100)
Percent wetland	4.9 (0–17.7)
Percent urban	1.3 (0–11.8)
Percent total agriculture	22.4 (0–87.6)
Percent pasture	12.0 (0–27.2)
Percent row crops	10.4 (0–81.9)
Percent total agriculture on slopes >3%	10.5 (0–27.1)
Percent pasture on slopes >3%	7.7 (0–22.5)
Percent row crops on slopes >3%	2.7 (0–10.8)
Percent total agriculture on slopes >9%	1.3 (0–3.2)
Percent pasture on slopes >9%	0.9 (0–3.2)
Percent row crops on slopes >9%	0.3 (0–1.2)
Stream density (km/km^2 of watershed)	1.1 (0.7–2.0)
Total road density (km/km^2)	1.1 (0–3.4)
Class 1 road density (km/km^2)	0.05 (0–0.6)
Class 2 road density (km/km^2)	0.09 (0–0.4)
Class 3 road density (km/km^2)	0.95 (0–2.5)
Total number of road crossings/stream km	0.3 (0–1.3)
Number of class 1 road crossings/stream km	0.03 (0–0.4)
Number of class 2 road crossings/stream km	0.04 (0–0.2)
Number of class 3 road crossings/stream km	0.23 (0–0.76)
Number of people/km^2, 1990	18.5 (2.4–87.2)
Number of people/km^2, 2000	19.1 (2.6–85.6)

species and species group. To determine the most important descriptor variables in each of the best candidate models selected from the initial group of 10, we calculated partial correlation coefficients (PCCs) for each variable in the final models. This parameter assesses the relative strength of a particular descriptor variable on the response variable given the presence of other descriptor variables in the model. Finally, variance inflation factors (VIFs) were calculated for each descriptor variable in the candidate models. If a descriptor variable had a VIF less than 4.0, we concluded that it did not have a collinear relationship with the other descriptor variables, that is, that it would not artificially increase the parameter estimates and standard errors of the other variables (Draper and Smith 1998). Therefore, the final candidate models were retained only if they had descriptor variables with VIFs less than 4.0.

The assumptions for regression analysis were addressed by obtaining Studentized residual plots to check for homogeneous variances and mean errors of zero. Normality plots of the residuals were used to check that the errors were normally distributed, and the Durbin-Watson test was used to check that they were uncorrelated (Draper and Smith 1998). All regressions were performed with SAS version 9.1 (SAS Institute, Cary, North Carolina) and SPSS version 9.0.

We used *t*-tests with $\alpha = 0.05$ to determine whether the mean angler CPUE differed between the sites used for model development (i.e., the WSA sites) and the independent sites from Shewmake and Jackson 2004. To validate model accuracy, we calculated the root mean square error of validation ($RMSE_v$) for each model (Snee 1977) and subtracted the estimated standard error (s_e) of the mean difference between the observed and predicted values. The $RMSE_v$ is a measure of the average size of the prediction error for the validation data (i.e., the magnitude of the difference between the observed and predicted values). It is computed by means of following formula:

$$RMSE_v = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(y_j - \hat{y}_j)^2},$$

where n is the sample size of the validation data set, y_j is the observed value for observation j, and $\hat{y}_j$ is the predicted value for observation j. The values of $RMSE_v$ are directly proportional to the s_e of the mean difference between the observed and predicted values (Snee 1977), such that model accuracy increases as the difference between $RMSE_v$ and s_e approaches zero. Conversely, as the difference between $RMSE_v$ and s_e becomes greater than zero, the model has less ability to predict the response values using independent data.

To evaluate model precision, we regressed the mean CPUE values from the independent data on the watershed-scale variables from the candidate models ($\alpha = 0.05$). The candidate models were considered precise if the coefficients of determination (R^2 values) for the independent regression models were 0.60 or more.

Results

The reaches in our study drained watersheds covered primarily by forests and agriculture (Table 1). Percent urban land use, road density, and the number of road crossings per kilometer of stream were generally small. On hill slopes of 3% or more, land use was also relatively small, and on hill slopes exceeding 9% land use was negligible (Table 1). The reaches drained relatively flat landscapes (elevation at the X-sites, 3–137 m above sea level) but had a broad range of drainage size (watershed area, 1–1,483 km^2).

A total of 598 fish were caught in 78 fishing trips during the summers of 2003–2005. Overall, centrarchids made up 95% of the total angling catch, which included largemouth bass, spotted bass, longear sunfish *Lepomis megalotis*, bluegill *Lepomis macrochirus*,

TABLE 2.—Mean CPUE (fish/angler-hour) of sport fish from 26 Mississippi wadeable streams. The reaches were fished 2–5 times during the summers of 2003–2005. For all species and species groups, mean CPUE was not significantly different between the test and validation sites ($t < 2.0$; $P > 0.05$).

	Test sites			Validation sites		
Taxon	Mean	SD	Range	Mean	SD	Range
All fish	0.86	0.81	0–2.50	0.95	0.84	0–2.50
Black bass	0.56	0.52	0–1.75	0.56	0.52	0–1.58
Sunfishes	0.32	0.40	0–1.16	0.28	0.39	0–1.30
Largemouth bass	0.22	0.24	0–0.72	0.33	0.53	0–1.58
Spotted bass	0.19	0.43	0–0.62	0.24	0.24	0–0.67
Longear sunfish	0.19	0.19	0–0.33	0.20	0.32	0–1.08
Bluegill	0.10	0.16	0–0.29	0.08	0.14	0–0.42

white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, shadow bass *Ambloplites ariommus*, and redear sunfish *Lepomis microlophus*. The noncentrarchid fishes that were caught included channel catfish, shortnose gar *Lepisosteus platostomus*, spotted gar *Lepisosteus oculatus*, freshwater drum *Aplodinotus grunniens*, pickerel *Esox* spp., and creek chub *Semotilus atromaculatus*. The mean CPUE for the principal species and species groups varied from 0.08 to 0.95 fish/angler-hour and was similar between test and validation sites ($t < 2.0$; $P > 0.05$; Table 2). In general, angling success for the principal species was greatest for largemouth bass, followed by spotted bass and longear sunfish, then bluegills.

Our best candidate models indicated that, on average, angling success for sport fishes in Mississippi wadeable streams was associated with a combination of human land use and geomorphic characteristics (Table 3). The mean CPUEs for all species, black bass, and sunfishes were positively associated with percent forest cover, stream density, total road density, and primary highway density. Partial correlation coefficients revealed that, after accounting for the variation in the other variables in the models, stream density (PCC $>$ 0.50) and total road density (PCC $>$ 0.60) were stronger descriptors of total species, black bass, and sunfish CPUE than percent forest (PCC $>$ 0.47) or rural road density (PCC $>$ 0.24).

Mean largemouth bass CPUE was negatively associated with percent total agriculture but positively associated with rural road density. Percent total agriculture (PCC $= -0.67$) had a slightly stronger influence on mean largemouth bass CPUE than did rural road density (PCC $= 0.64$). Mean spotted bass CPUE was negatively associated with elevation and the number of rural road crossings per kilometer of stream but positively associated with rural road density. Elevation (PCC $= -0.75$) had a stronger influence on mean spotted bass CPUE than rural road crossings (PCC $= -0.27$) and rural road density (PCC $= 0.29$). Percent total agriculture (PCC $= -0.42$) was negatively associated with mean longear sunfish CPUE, whereas rural road density (PCC $= 0.51$) was positively associated with it. Mean bluegill CPUE was not significantly associated with any particular watershed-scale variables.

Model validation analyses revealed that the candidate models were relatively inaccurate because the prediction errors (i.e., the differences between $RMSE_v$ and s_e) were large for these models. For the total species, black bass, and sunfish models, the prediction errors were 12.7, 13.2, and 11.9, respectively. The prediction errors for the largemouth bass, spotted bass, and longear sunfish models were 22.7, 7.6, and 17.8, respectively.

The watershed variables from the total, black bass, and sunfish mean CPUE models exhibited relatively good precision when regressed with the independent data. These descriptor variables explained 83, 71, and 80% of the variation in mean total, black bass, and sunfish CPUE, respectively, in the independent data set (Table 4). At the species level the watershed variables were relatively imprecise ($P > 0.15$ for all models), explaining only 19, 32, and 33% of the variation in mean largemouth bass, longear sunfish, and spotted bass CPUE, respectively.

Discussion

Wadeable streams in the southeastern U.S. coastal plain region can be managed at the watershed scale, not only for water quality or biological integrity but also to support sustainable sport fisheries. We found that angling success for black bass and sunfishes in Mississippi wadeable streams increased with greater forest cover in the watersheds as well as small increases in stream and road density. At smaller spatial scales, studies have shown that angling success in southeastern U.S. coastal plain streams tends to be

TABLE 3.—Linear regression models of the associations between sport fish CPUE (fish/angler-hour) and watershed characteristics from 13 wadeable streams in Mississippi. No statistically significant model could be developed for mean bluegill CPUE.

Estimated model[a]	R^2	F	df	P
Mean total CPUE = −3.63 + 1.30(PFOR) + 18.14(STRMDENS) + 2.59(RDDENS) + 0.52(RDDENSC1)	0.90	18.27	4, 12	0.0004
Mean black bass CPUE = −8.03 + 2.25(PFOR) + 17.95(STRMDENS) + 2.69(RDDENS) + 0.53(RDDENSC1)	0.87	13.25	4, 12	0.001
Mean sunfish CPUE = −7.46 + 2.07(PFOR) + 16.19(STRMDENS) + 2.36(RDDENS) + 0.62(RDDENSC1)	0.80	7.80	4, 12	0.01
Mean largemouth bass CPUE = 3.17 – 2.20(PAGT) + 3.72(RDDENSC3)	0.73	13.54	2, 12	0.001
Mean spotted bass CPUE = −4.13 – 1.42(Elevation) + 3.02(RDDENSC3) – 3.44(STRXDC3)	0.62	4.84	3, 12	0.03
Mean longear sunfish CPUE = 1.58 – 1.54(PAGT) + 2.85(RDDENSC3)	0.56	6.43	2, 12	0.02

[a] Variables are as follows: PFOR = percent of watershed that is forested; STRMDENS = stream density (km/km^2); RDDENS = total road density (km/km^2); RDDENSC1 = primary highway density (km/km^2); PAGT = percent of watershed with agriculture; RDDENSC3 = rural road density (km/km^2); Elevation = elevation above sea level (m); and STRXDC3 = number of rural road crossings/stream km.

greater in systems containing clear water, a mix of sand, gravel, and clay substrates, heavily forested riparian canopies, woody debris cover, and glide–pool habitats (Shewmake and Jackson 2004; Alford and Jackson 2006). These instream and riparian attributes are directly influenced by human land use practices in the surrounding watersheds. In Mississippi, conversion of forested watersheds to predominately agricultural landscapes leads to eroded stream banks, reduced riparian buffers, loss of woody debris cover, fewer and shallower pool habitats, greater turbidity, and excessive fine sediments in stream channels (Shields et al. 2000, 2003). Subsequently, the recreational fisheries in these systems shift from being composed of primarily black bass and sunfishes to catfish and suckers (Catostomidae; Jackson 2000; Jackson and Ye 2000; Shephard and Jackson 2006). We found that an increase in agricultural land use in watersheds was negatively associated with angling success for largemouth bass and longear sunfish in Mississippi wadeable streams. In addition, the number of stream crossings in a watershed was negatively associated with angling success for spotted bass. Thus, the management of black bass and sunfish sport fisheries in warmwater, coastal plain, wadeable streams should be oriented toward the conservation of forested watersheds with low road densities (up to 3.4 km/km^2), especially within riparian buffer zones (e.g., 30 m from the stream bank (Alford and Jackson 2006).

Our watershed models showed that total road density was associated more strongly and positively with total species, black bass, and sunfish mean CPUE than was percent forest cover. Some caution is advised, however, with regard to the application of our models. They are explicitly spatial and correlative in nature. They do not suggest that building more roads in a forested watershed will lead to greater angling success for black bass and sunfishes. Relative to the road densities in other studies, those in our data set were low, varying from 0 to 3.4 km/km^2. Western U.S. reaches selected as "least-disturbed" reference sites for an aquatic vertebrate index of biotic integrity had average road densities between 4.9 and 8.7 km/km^2 (Pont et al. 2009). In addition, Mississippi has a relatively flat landscape and watersheds with low basin relief. In such terrain, roads located outside of the typical riparian buffer zones (30–100 m) may have less influence on sediment loading compared with roads in more highland regions.

We used watershed characteristics to model angling success for sport fishes in Mississippi wadeable stream reaches because fish habitat, along with survival and

TABLE 4.—Results of regressions run with independent data to validate the use of selected watershed variables to predict the mean CPUE (fish/angler-hour) of sport fish from 13 wadeable streams in Mississippi. The descriptor variables were chosen from the best candidate regression models developed from 13 other streams.

Taxon	Descriptor variables[a]	R^2	F	P
All fish species	PFOR RDDENS STRMDENS RDDENSC1	0.83	9.88	0.003
Black bass	PFOR RDDENS STRMDENS RDDENSC1	0.71	4.93	0.03
Sunfishes	PFOR RDDENS STRMDENS RDDENSC1	0.80	7.97	0.01
Largemouth bass	PAGT RDDENSC3	0.19	1.15	0.36
Spotted bass	Elevation RDDENSC3 STRXDC3	0.33	1.44	0.39
Longear sunfish	PAGT RDDENSC3	0.32	2.30	0.15

[a] See Table 3.

production, are influenced hierarchically by larger-scale landscape features (Frisell et al. 1986; Imhof et al. 1996; Strayer et al. 2003). However, when we tested our species models with independent watershed and angling data, they had relatively poor accuracy. Biotic interactions such as competition or encounters with predators (Schlosser 1982; Scott and Angermeier 1998; Sammons and Bettoli 1999), instream physicochemical conditions unaccounted for by the watershed-scale models, and random variation in angler catch rates could help explain the inaccuracy.

Nonetheless, the descriptor variables from the models explained a large amount of the variation in mean total species ($R^2 = 0.83$), black bass ($R^2 = 0.71$), and sunfish CPUE ($R^2 = 0.80$) from the independent data set. Thus, there is a strong association between the geomorphic and land use characteristics in the species group models and angling success for sport fish in Mississippi wadeable streams.

Other studies support the use of watershed characteristics as descriptor variables for fish stock characteristics. In more highland salmonid and smallmouth bass streams, watershed-based models have been developed using geologic, hydrologic, and LULC data to describe landscape-level associations with fish abundance or biomass (Lanka et al. 1987; Creque et al. 2005; Rashleigh et al. 2005; Kocovsky and Carline 2006), and in some cases these models have performed as well as or better than models using instream habitat as descriptors of fish abundance. For example, Lanka et al. (1987) compared regression models of trout biomass in Wyoming streams using geomorphic watershed characteristics (e.g., basin relief, stream density, and channel slope) and instream habitat (e.g., channel width, substrate size distribution, and current velocity). They found that watershed variables explained as much or more of the variation in trout biomass as the instream habitat variables. Also, Creque et al. (2005) found that watershed-scale models derived from remotely sensed geographic data explained more of the variation in salmonid densities in Michigan streams than models developed with instream habitat data.

Another advantage of using watershed characteristics to model fish abundance is that watershed data can be collected at much lower cost (i.e., from geographical information systems or topographic maps) than instream habitat data, thus reducing labor costs and the time spent in the field. Once suitable stream reaches have been identified from the watershed models, the template will be set for more traditional management activities at the reach scale (Roni et al. 2002), including stock assessments and instream habitat management or restoration.

In concert with more traditional water quality and biotic integrity assessments, our results provide an alternative management perspective oriented toward sport fisheries that can be used to address conservation in wadeable streams in Mississippi. Ultimately, the management of warmwater sport fisheries in coastal plain wadeable streams should take a landscape-scale approach and promote the conservation of forested watersheds. Our study is unique in that it employs an angling perspective to address watershed influences on sport fishery resources. However, the active management of terrestrial landscapes to enhance stream resources or angling opportunities can be challenging. Watersheds typically occupy property controlled by several landowners with diverse value systems, and they encompass land areas so large that active management of entire watersheds may be impractical. Therefore, public outreach programs should be used to educate landowners on the value of conserving forested watersheds, especially regarding their capacity to support sustainable sport fisheries for black bass and sunfishes in southeastern U.S. wadeable streams.

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