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Electrofishing Effort and Fish Species Richness and Relative Abundance in Ozark Highland Streams of Arkansas

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Abstract.—We sampled 15 stream sites in the Ozark Highlands ecoregion of Arkansas and examined the effect of increased backpack electrofishing effort on the richness and relative abundance estimates of fish species. Each site was 75 mean stream widths (MSWs) long and was divided into 15 consecutive segments that were each 5 MSWs long. For each site the percent of empirical and theoretical species richness and the percent of relative abundance similarity to the entire fish assemblage were calculated by adding consecutive segments using an approach that resulted in 15 accumulation curves per assemblage character for each stream site. On average, a distance of 53.8 MSWs (SD = 7.4) was needed to sample 95% of empirical species richness at a stream site, which was equal to an area of 2,722.0 m^2 (SD = 1,967.0). For sampling 95% of theoretical species richness, an average of 101.8 MSWs (SD = 34.5), or 5,055.7 m^2 (SD = 3,667.4), was needed. Obtaining 95% relative abundance similarity required an average sampling effort equivalent to 24.0 MSWs (SD = 8.9), or 1,269.7 m^2 (SD = 932.1). Mean stream width explained more variance in the reach lengths and areas needed for estimates of species richness and relative abundance than did riffle−pool sequence length or watershed size. Our results should offer insight into species richness and relative abundance accumulation rates when using a one-pass backpack electrofishing sample in Ozark Highland streams of Arkansas.

Obtaining an adequate sample of stream fish assemblages during stream surveys is important for the management and conservation of stream fishes. Some studies are designed to detect the presence or absences of a species (Bayley and Peterson 2001), and if that species is rare, the effort used to sample streams must sometimes be extensive (Angermeier et al. 2002). In addition, extensive sampling may be needed to adequately estimate fish assemblage attributes, such as species richness, in streams (Angermeier and Smogor 1995). When studying the structure of fish assemblages, one must also accurately estimate the relative abundance of fishes (Grossman et al. 1982; Yant et al. 1984). Because of the importance of obtaining accurate estimates of fish assemblage attributes, several studies have been conducted to determine the sampling effort needed to accurately estimate fish species richness and relative abundance in streams (Lyons 1992; Angermeier and Smogor 1995; Paller 1995; Peterson and Rabeni 1995; Patton et al. 2000; Cao et al. 2001).

Most natural resource agencies need to adequately sample at the least cost (Barbour et al. 1999). As a result, some have adopted fish sampling protocols that are a tradeoff between obtaining accurate and precise estimates of fish assemblage attributes and minimizing the cost and effort required. Meador et al. (1993), summarizing the work to date that contributed to standardizing sampling efforts for fish assemblages in wadeable streams, recommended sampling a minimum stream length of 150 m and a maximum length of 300–500 m when using two-pass electrofishing in wadeable streams for the National Water-Quality Assessment program. Their recommended sampling lengths, although based on literature reports, were somewhat arbitrary because no studies addressed a standard sampling effort across a broad spatial scale. For the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program, 40–48 channel widths (i.e., wetted width), or a minimum of 150 m is recommended for sampling in wadeable streams (McCormick and Hughes 2002).

Our goal was to provide information on the completeness of samples used for estimating richness and relative abundance of fish species when using a sampling technique (i.e., backpack electrofishing) typically used in wadeable Ozark Highland

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TABLE 1.—Mean stream width (MSW), mean riffle–pool length (R–P), watershed size, discharge, and observed (ESR) and theoretical (TSR) species richness estimates for 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000. The theoretical species richness at each site is a mean TSR estimate derived from a serial approach that generated 15 estimates per site (see Methods).

Site	MSW (m)	Mean R–P length (m)	Watershed size (km^2)	Discharge (m^3/s)	ESR	TSR
Big Creek	3.80	35.6	16.5	0.004	19	22
Brush Creek	8.68	77.3	57.5	0.169	24	29
Clear Creek	7.84	63.7	28.8	0.245	20	23
Diles Creek	9.08	64.5	25.0	0.140	21	29
Dry Creek	6.51	62.4	23.1	0.367	9	11
Greasy Creek	4.77	44.7	31.6	0.023	12	14
Hampton Creek	8.14	76.4	70.6	0.263	20	22
Harding Creek	4.99	35.4	11.8	0.070	24	27
Long Creek	10.53	97.8	73.6	0.296	26	31
Mill Creek	4.89	43.7	16.4	0.066	9	13
Mud Creek	9.98	107.9	28.3	0.387	19	26
North Big Creek	5.68	57.9	49.4	0.040	22	29
North Sylamore Creek	6.86	58.9	118.2	0.104	18	20
Tuttle Branch	5.21	61.1	13.6	0.011	13	15
Upshaw Creek	3.28	28.1	9.1	0.009	18	21

streams of Arkansas. Specifically, we (1) determined the average electrofishing effort (mean stream widths [MSWs] and area) needed to reach target percentages (i.e., 90%, 95%, 100%) of empirical and theoretical estimates of species richness and relative abundance similarity between subsamples and samples of fish assemblages, and (2) identified what sample-site variables were useful in predicting the average sampling effort needed.

Methods

Study Area

The Ozark Highlands ecoregion (Figure 1) is located in north-central and northwestern Arkansas, south-central Missouri, and northeast Oklahoma (Omernik 1987). Mountainous terrain, steep gradients, and fractured limestone geology characterize the region (Robison and Buchanan 1988) and support fast-flowing, spring-fed streams. Ozark Highland elevations in Arkansas range from approximately 60 to 680 m (Weih 2001). Land use is a major cause of regional water quality problems (Arkansas Department of Pollution Control and Ecology 1996). Many of these problems result from large amounts of animal production wastes (e.g., from poultry) that potentially can contaminate regional surface and ground waters because of local geology. The ichthyofauna in this ecoregion consists of at least 89 species, with cyprinids, percids, and centrarchids contributing the most to the relative abundance of fish assemblages (Giese et al. 1987).

We sampled 15 wadeable streams throughout the Ozark Highlands from 6 June to 1 August 2000 (Figure 1). We selected sample sites to include streams that differed in size and extent of anthropogenic disturbance and were distributed widely across the ecoregion, being located in all three ma-

TABLE 2.—Mean number of mean stream widths (MSWs), riffle–pool sequences, and mean areas (95% confidence intervals in parentheses) needed to obtain 90, 95, and 100% of empirical (ESR) and theoretical (TSR) species richness and relative abundance similarity (RAS). Data are from 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000.

Character	% of total	MSWs	Riffle–Pool	Area (m^2)
ESR	90	46.6 (4.7)	5.2 (0.6)	2,344.5 (939.8)
	95	53.8 (4.1)	6.0 (0.5)	2,722.0 (1,082.3)
	100	57.5 (3.7)	6.4 (0.6)	2,951.7 (1,164.8)
TSR	90	86.1 (16.9)	9.6 (2.0)	4,313.8 (1,773.3)
	95	101.8 (19.0)	11.3 (2.2)	5,055.7 (2,017.9)
	100	119.5 (21.3)	13.2 (2.5)	5,881.5 (2,282.8)
RAS	90	15.9 (3.4)	1.8 (0.4)	827.1 (338.7)
	95	24.0 (4.9)	2.7 (0.6)	1,269.7 (512.9)
	100	70.1 (2.3)	7.8 (0.7)	3,519.4 (1,256.5)

TABLE 3.—Mean percent (95% confidence intervals) of maximum empirical species richness (ESR), theoretical species richness (TSR), and relative abundance similarity (RAS) when the stated number of mean stream widths (MSWs) were electrofished at 15 Ozark Highland stream sites from 6 June to 1 August 2000.

Character	MSWs	Mean
ESR	25	76.1 (3.4)
	50	91.9 (1.9)
	75	100.0 (0.0)
	100	NA
TSR	25	61.4 (5.1)
	50	76.5 (5.0)
	75	86.9 (4.8)
	100	95.2 (4.6)
RAS	25	94.7 (1.6)
	50	98.8 (0.4)
	75	100.0 (0.0)
	100	NA

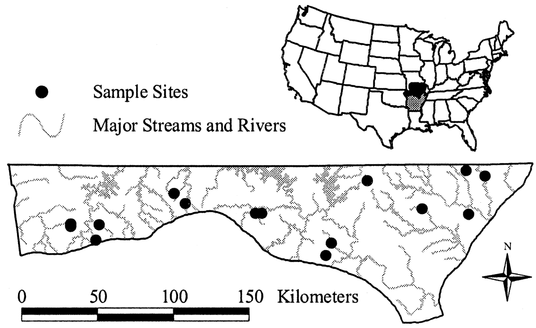

FIGURE 1.—The location of 15 Ozark Highland ecoregion stream sites in Arkansas sampled from 6 June to 1 August 2000.

jor Ozark Highland river drainages (Illinois, White, and Black River drainages). We confirmed that human activity levels varied among watersheds by quantifying land use upstream of each site, using the Arkansas Gap data layer (Smith et al. 1998) and a geographic information system (ESRI 1996).

Data Collection

We measured select physical features of each sample site in a stream reach 75 MSWs long; using MSW scaled the sample-site length to the stream size. On the basis of literature reports (Lyons 1992; Angermeier and Smogor 1995) and the sampling protocol of the Arkansas Department of Environmental Quality (ADEQ), which attempts to sample all observable habitat and collect most species (W. Keith, ADEQ, personal communication), we thought 75 MSWs would be sufficient to estimate the richness and relative abundance of fish species when sampling fish assemblages by backpack electrofishing. We visually classified habitat units in each reach as riffles or pools, depending on adjacent habitat units, relative water depths and velocities, and surface turbulence of all habitat units in a given stream (Arend 1999). We also measured the total length of each habitat unit. At transects in each habitat unit, we measured stream width (wetted width) according to a stratified transect design (Platts et al. 1983). The number of transects per habitat unit ranged from one to eight, depending on habitat unit length and heterogeneity of channel width and depth (Platts et al. 1983). We attempted to keep distances between transects evenly distributed to accurately represent the mean wetted width. We also measured discharge at one transect per site (Gallagher and Stevenson 1999). After measuring habitat features, we calculated the arithmetic mean of all wetted-width measurements for use as a field estimate of MSW. We divided stream reaches of 75 MSWs into 15 segments that were each 5 MSWs long.

A four-person crew, operating a pulsed DC, Smith-Root backpack electrofisher outfitted with two anodes and one cathode, collected fish in each segment by wading upstream. Two crew members dipnetted fish. Riffles were fished by placing two dip nets side by side while anodes were waved in an upstream to downstream direction toward the dip nets. Using this technique, the crew proceeded slowly through each riffle. Pools were fished from side to side in an upstream direction (Barbour et al. 1999), while ensuring that all habitats were sampled (e.g., undercut banks, rootwads, boulders, etc.). We did not use block nets to enclose each stream segment because placing block nets in the sample reach could potentially increase fish capture probabilities when compared with a single-pass electrofishing sample. This also reflects how stream fishes were sampled historically in much of Arkansas. In addition, other studies found that block nets do not increase catch rates (Paller 1995) or affect estimates of species richness or assemblage structure (Simonson and Lyons 1995).

Fish collected from each stream segment were kept separate, preserved in 10% formalin, and identified to species in the laboratory. We removed age-0 fishes (except lamprey ammocoetes; Family Petromyzontidae) from all segment samples because they could not be identified accurately. We did not omit lamprey ammocoetes, which we considered as one species because of identification difficulties, from our samples because lamprey adults in Arkansas migrate to streams in late winter

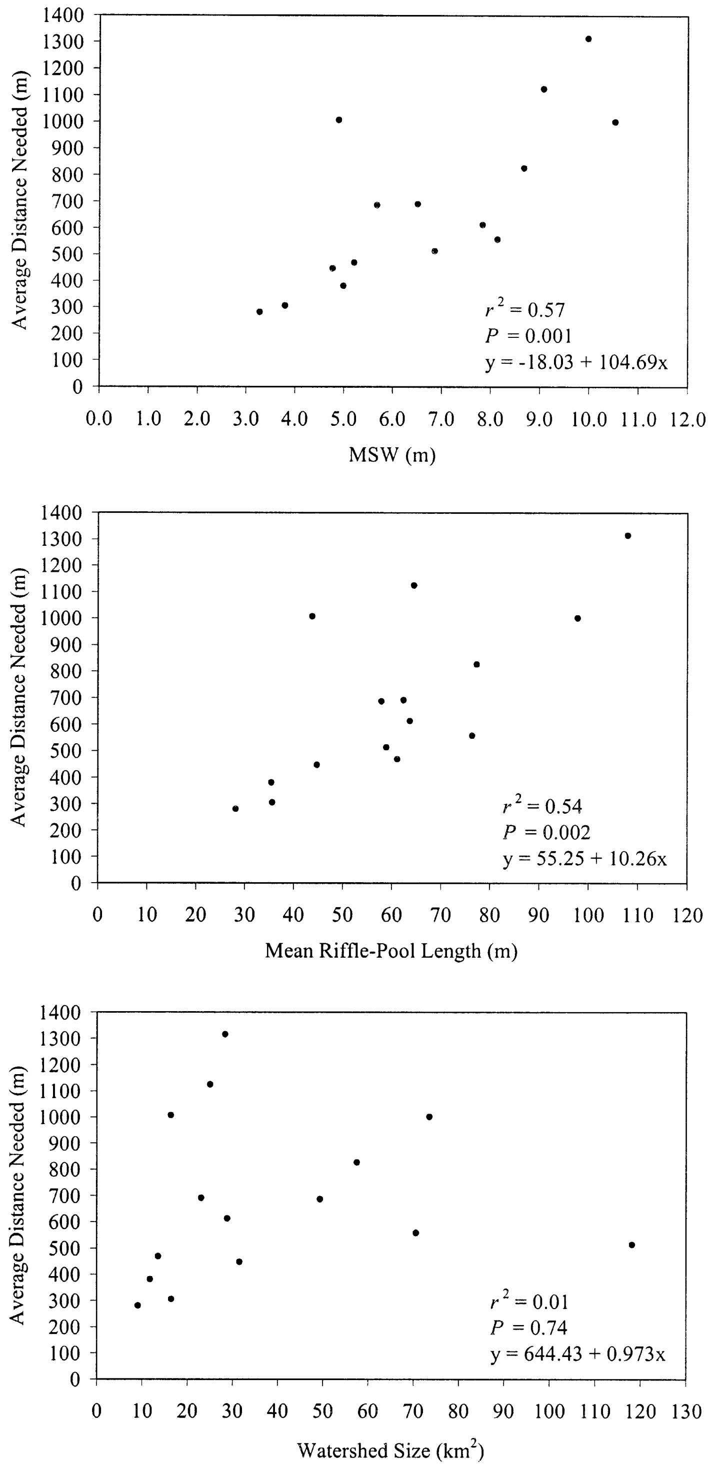

FIGURE 2.—Relations between mean stream width (MSW; m), mean riffle–pool length (m), and watershed size (km^2) and the mean reach lengths needed (m) to obtain 95% theoretical species richness at 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000. Relations were assessed by simple linear regression at α = 0.05.

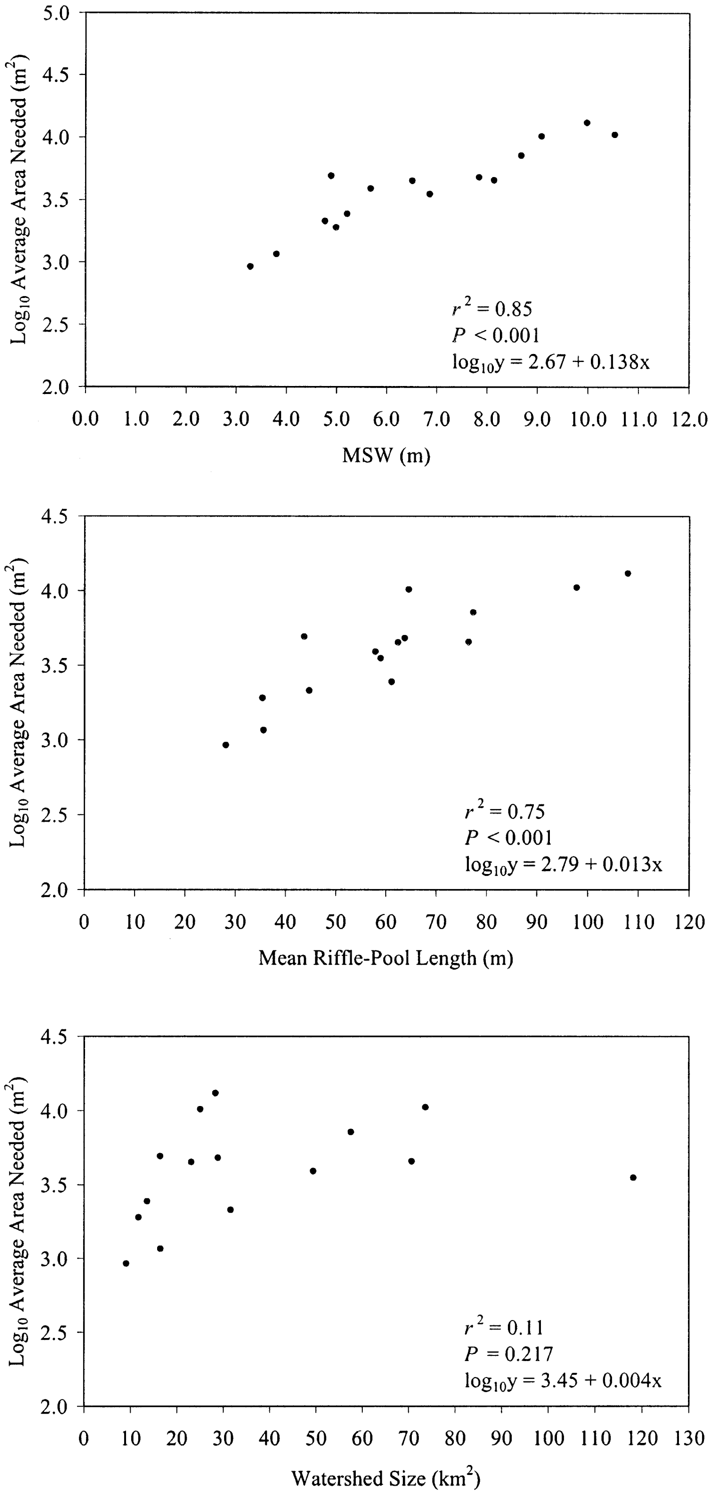

FIGURE 3.—Relations between mean stream width (MSW; m), mean riffle–pool length (m), and watershed size (km^2) and the mean $\log_{10}$ areas needed (m^2) to obtain 95% theoretical species richness at 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000. Relations were assessed by simple linear regression at $\alpha = 0.05$.

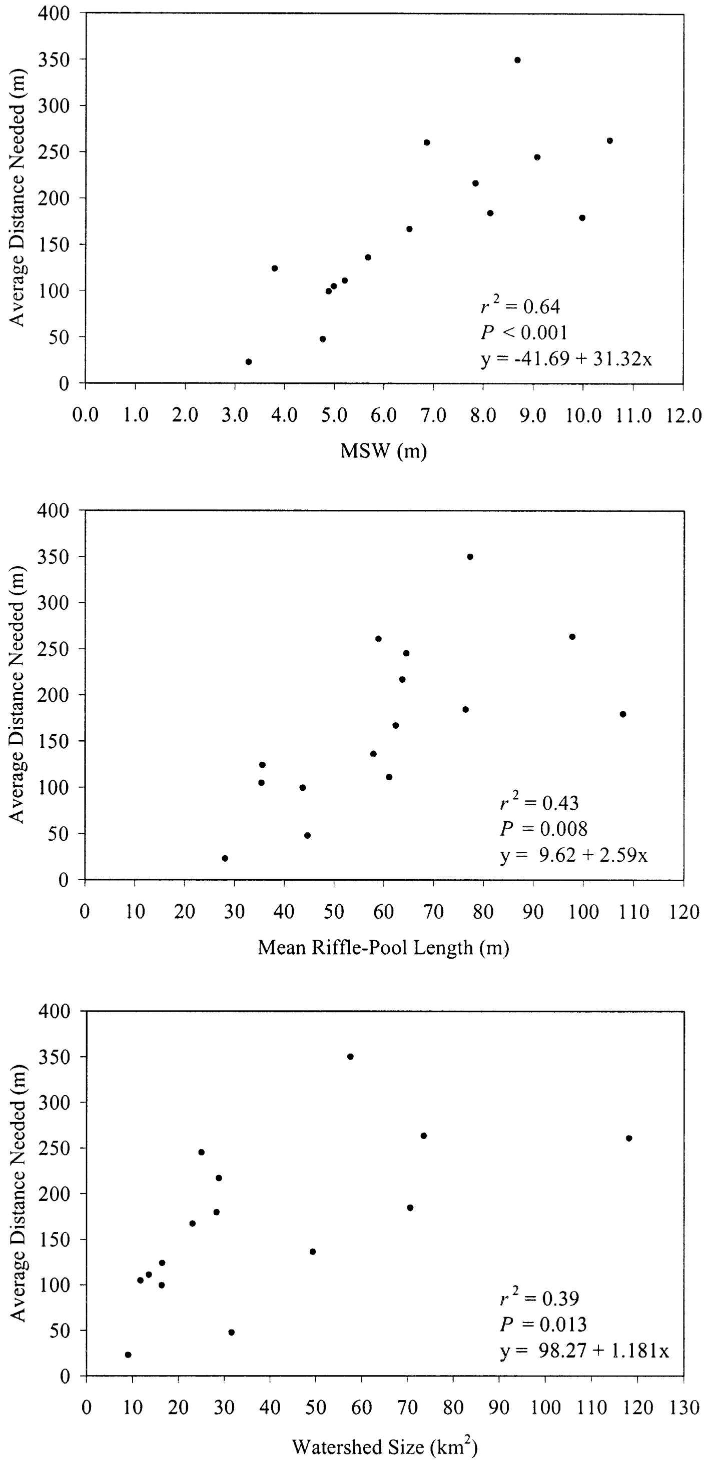

FIGURE 4.—Relations between mean stream width (MSW; m), mean riffle–pool length (m), and watershed size (km^2) and the mean reach lengths needed (m) to obtain 95% relative abundance similarity at 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000. Relations were assessed by simple linear regression at α = 0.05.

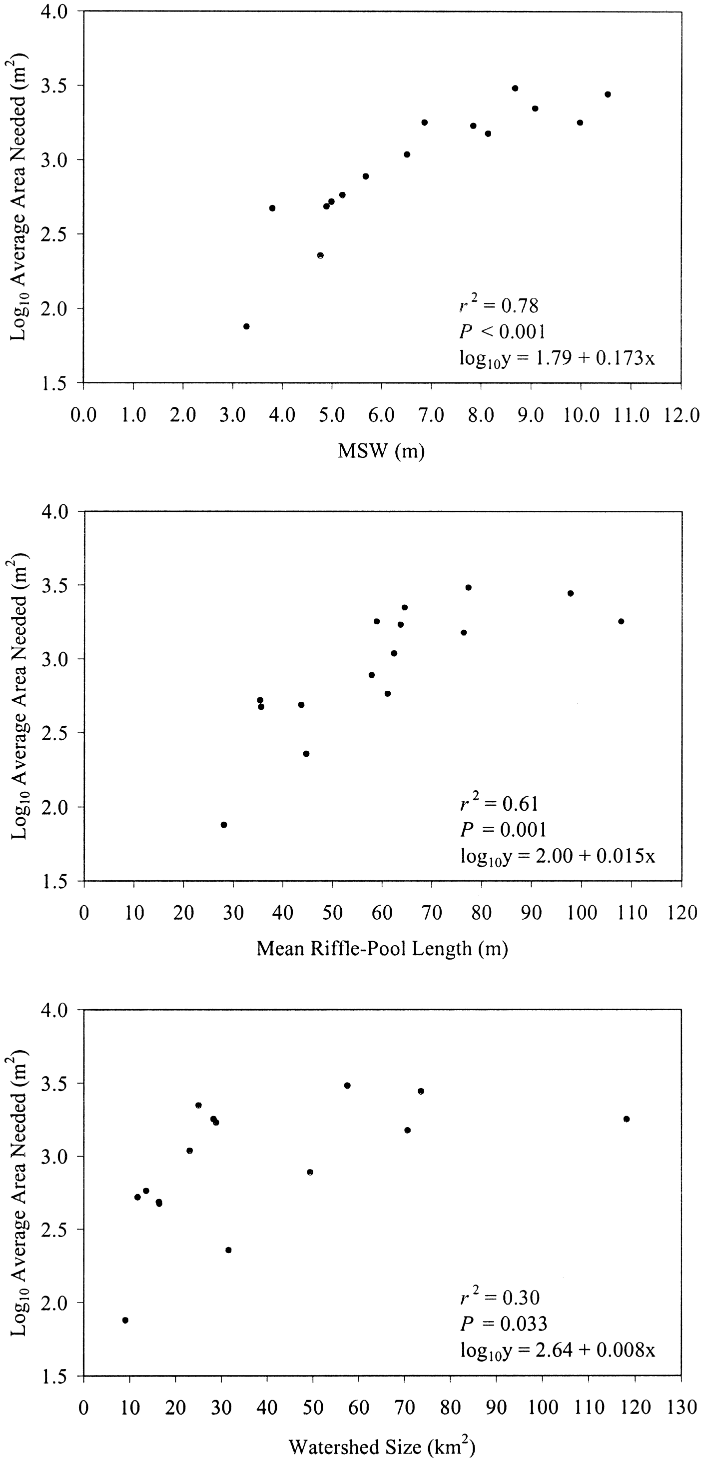

FIGURE 5.—Relations between mean stream width (MSW; m), mean riffle–pool length (m), and watershed size (km^2) and the mean areas needed (m^2) to obtain 95% relative abundance similarity at 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000. Relations were assessed by simple linear regression at $\alpha = 0.05$.

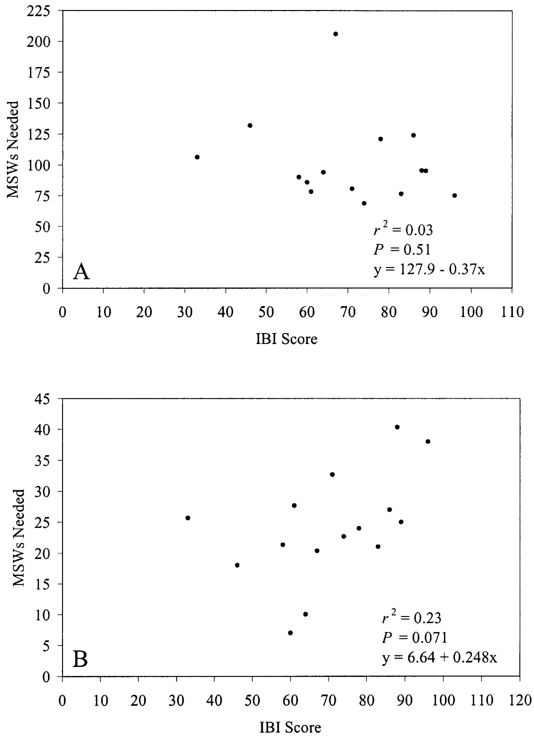

FIGURE 6.—Relations between index of biotic integrity (IBI) scores and the number of mean stream widths (MSWs) needed to reach (**A**) 95% theoretical species richness and (**B**) 95% relative abundance similarity at 15 Ozark Highland stream sites sampled from 6 June to 1 August 2000. Relations were assessed by simple linear regression at $\alpha = 0.05$.

and early spring to spawn (Robison and Buchanan 1988), times of the year when Arkansas streams are not typically sampled. Including ammocoetes in our samples indicated past adult lamprey use of a stream site.

Sampling Effort Needed

We evaluated the effect of electrofishing effort on estimates of fish species richness and relative abundance. We analyzed species richness by using our empirical data (empirical species richness; ESR) and a predictive model (theoretical species richness; TSR), whereas relative abundance was analyzed using empirical data only.

Empirical species richness.—We analyzed ESR relations with sampling effort by using a serial analysis technique that analyzed all possible serial combinations of sample segments when segments 1 and 15 were looped together (L. Reynolds, Oregon State University, personal communication); hereafter, this is referred to as ‘‘serial technique.’’ This approach assessed accumulation rates starting at each sample segment for each site, while preserving the directional sequence of sampled stream segments. Therefore, we constructed 15 accumulation curves (i.e., sampling effort versus species richness) per site. For example, one accumulation curve started at segment 1, and ended at segment 15 (i.e., 1, 2, 3, . . . , 14, 15). Another curve started at segment 2, and ended at segment 1 (i.e., 2, 3, 4, . . . , 15, 1). This technique minimized the influence of the actual starting point, and described the variability in accumulation rate at each sample site.

For all 15 accumulation curves constructed for each site, we determined the number of MSWs at which 90, 95, and 100% of the maximum ESR was achieved. We computed the mean number of MSWs needed to obtain each percentage of ESR from all 15 site accumulation curves. We determined the mean area needed at each site by multiplying the number of MSWs needed by MSW to obtain the reach length needed and then multiplied this reach length by MSW again to determine the average area needed per site. Next, we calculated a mean of the mean sampling efforts needed (i.e., distance and area) at each site to reach 90%, 95%, and 100% ESR.

Theoretical species richness.—We used the approach of Cao et al. (2001) for our theoretical estimate of species richness. We estimated TSR by determining the mean species richness between two replicate sampling units, as well as the similarity between those two sampling units, by using the Jaccard coefficient. Cao et al. derived the relationship as

$$\mathrm{TSR} = \frac{\overline{\mathrm{SR}}}{\mathrm{JC}}$$

where TSR was the theoretical species richness, $\overline{\mathrm{SR}}$ was the mean species richness of both replicate sampling units, and JC was the Jaccard coefficient (Krebs 1999).

When estimating TSR for Ozark Highland stream sites, we used two groups of seven sample segments, each equivalent to 35 MSWs, for our two replicate sampling units. We used the serial technique to obtain 15 TSR estimates for each sample site. We obtained 15 estimates by comparing two groups of seven adjacent sample segments to each other, always omitting one sample segment. For example, we obtained one estimate by comparing sample segments 1 through 7 combined to sample segments 8 through 14 combined, omitting segment 15. We obtained a second estimate by comparing sample segments 2 through 8 combined to sample segments 9 through 15 combined, omitting segment 1. We used the average TSR estimates for each site for further analyses.

To determine the sampling distances needed to collect 90, 95, and 100% TSR, we applied linear regression to our empirical MSWs sampled versus mean species richness data. Mean species richness, recalculated every five MSWs, was the mean species richness determined by the serial technique. Because the empirical relationship was nonlinear, we log-transformed both the MSWs sampled and the mean species richness data. The relationship was $\log_{10}$(mean species richness) = $\log_{10}a$ + $b \cdot \log_{10}$(MSWs sampled). We used this relationship to predict, sometimes by extrapolation, the number of MSWs and areas needed to reach 90, 95, and 100% of TSR estimates at each sample site. We then converted species richness into a percentage of the predicted mean TSR.

Relative abundance.—We assessed the effect of sampling effort on relative abundance by determining the similarity of fish assemblages between those in accumulated segments and those in all 15 segments combined. We calculated relative abundance similarity (RAS) by using the Simplified Morisita's index (Horn 1966; Krebs 1999), which ranges from 0 (no similarity) to 1 (complete similarity), and expressed the RAS result as a percentage.

We used the serial approach to generate 15 relative abundance accumulation curves for each sample site. From those data, we determined the mean number of MSWs at which 90, 95, and 100% RAS was permanently achieved, for all 15 iterations, for all 15 stream sites. We used the distances at which a percent similarity was permanently achieved because similarity sometimes fluctuated around the target percentage as sampling effort increased. We computed the mean of the mean number of MSWs, as well as areas, needed to reach 90, 95, and 100% RAS at each site.

In addition to determining the number of MSWs needed, we also calculated the number of riffle–pool sequences needed to reach 90, 95, and 100% ESR, TSR, and RAS. To do this, we calculated the number of riffle–pool sequences that equaled the reach lengths needed. We also estimated what percent ESR, TSR, and RAS would have been obtained with sampling efforts of 25, 50, 75, and 100 MSWs.

Sampling Effort Predictors

Having determined relations between the number of MSWs sampled and the species richness and relative abundance, we assessed relations between the reach length needed to achieve 95% TSR and RAS at each site and MSW, mean riffle–pool sequence length, and watershed size, to determine whether these variables could be used to predict the average reach length (m) that must be sampled to obtain 95% TSR and RAS. For these analyses, we multiplied the mean number of MSWs needed at all 15 stream sites by the MSW of each site. This yielded an average reach length needed for each site. Next, we used simple linear regression ($N = 15$; $\alpha = 0.05$) to assess relations between MSW, mean riffle–pool sequence length, and watershed size and the average reach length needed to sample 95% TSR and RAS at each sample site. The variable that significantly explained the most variation in the effort needed was considered the best predictor. We did not assess relations between the predictor variables and ESR because observation of species accumulation curves indicated that at most sites no asymptote was reached by 75 MSWs. Therefore, given that species richness was probably underestimated at those sites, making predictions on inaccurate estimates would not be useful.

We also assessed relations between the MSW, mean riffle–pool length, and watershed size, and the average $\log_{10}$ areas (m^2) needed (i.e., MSW multiplied by the average reach length needed) to achieve 95% TSR and RAS. We assessed sample site-$\log_{10}$ area relations by using simple linear regression at $\alpha = 0.05$.

We determined whether a significant relationship existed between the quality of a stream site and the average MSWs needed for 95% TSR and RAS. We assessed stream site quality by using an index of biotic integrity (IBI; Karr 1981) developed for the ecoregion (Dauwalter 2002). The 10 IBI metrics were significantly correlated with various physical, chemical, and land-use variables. We used simple linear regression ($N = 15$; $\alpha = 0.05$) to test for a significant relationship between IBI scores, potentially ranging from 0 to 100, and the average MSWs needed to obtain 95% TSR and RAS. We used raw IBI scores because arcsine transformation did not improve data normality.

Habitat Variability

To determine which stream habitat characteristic varied least, a useful measure for predictive purposes, we tested for significant differences between stream width and riffle–pool sequence length variability by using the coefficients of variation (CV, defined as 100 × SD/mean) for both variables measured at each site. We tested for differences among the CVs by using a paired *t*-test ($N = 15$; $\alpha = 0.05$).

Results

Sample Sites

A variety of stream sizes and conditions were represented when we chose our 15 sample sites. Watershed land use for our stream sites averaged 53.49% (range = 0.0–99.2%) forested, 1.19% (range = 0.0–13.6%) urban, and 45.25% (range = 0.8–93.6%) agriculture; pastureland was the only agricultural land use identified. Mean stream width for our stream sites ranged from 3.3 to 10.5 m, mean riffle–pool length ranged from 28.1 to 107.9 m, and reach length ranged from 246 to 790 m (Table 1). Discharges averaged 0.1464 cubic m^3/s (SD = 0.1338), and ranged from 0.009 to 0.387 m^3/s. We collected 50 species among all stream sites; richness ranged from 9 to 26 species (Table 1; Appendix A).

Sampling Effort Needed

Estimating species richness required more sampling effort than estimating relative abundances (Table 2). Eleven of 15 species accumulation curves did not reach an asymptote by 75 MSWs. Only 1 of 15 curves clearly reached an asymptote, whereas 3 others appeared to approach an asymptote. Therefore, ESR did not appear to reflect the true species richness at most stream sites and we did not include it in the analyses of sampling effort predictors. All but two regressions of $\log_{10}$(MSWs sampled) versus $\log_{10}$(mean species richness) used for estimating TSR resulted in an $r^2 > 0.95$ (mean = 0.964; SD = 0.039); all were highly significant ($P < 0.001$). Accuracy and precision of species richness and relative abundances increased as sampling effort increased (Table 3).

Sampling Effort Predictors

Mean stream width was the best predictor of the sampling efforts needed for TSR and RAS estimates. Mean stream width was the best predictor of the reach lengths (Figure 2) and areas (Figure 3) needed for 95% TSR at each site. Mean stream width was also the best predictor of the reach lengths (Figure 4) and areas needed (Figure 5) for 95% RAS estimates at each site. Quality of the stream site did not appear to cause the sampling effort needed for estimates of species richness and relative abundance to deviate from that expected (Figure 6).

Habitat Variability

Stream width was less variable than riffle–pool sequence length. Among sample streams, CVs (mean ± SD) for stream width (43.2 ± 12.1%) and riffle–pool sequence length (64.3 ± 19.6%) differed significantly ($P < 0.001$).

Discussion

Species richness and relative abundance are each important attributes when using biological indicators to study fish assemblages and determine stream health (Karr et al. 1986). Our data indicated that differences in sampling effort can affect estimates of fish species richness and relative abundance in Ozark Highland streams. When determining the effort needed when sampling Ozark Highland stream fishes, we recommend scaling sampling distances, or areas, by MSW (at base flow); not only did this factor explain the most variability in the sampling efforts needed but also it was less variable than riffle–pool sequence length, even though each variable is a significant predictor of needed efforts.

The sampling effort needed to accurately estimate fish species richness and relative abundance in wadeable Ozark Highland streams exceeded those suggested for most U.S. regions. An electrofishing sample equal to 35 MSW was suggested for estimating species richness in midwestern U.S. streams (Lyons 1992). In three Virginia streams, sampling 22–67 MSWs with an electric seine collected 90% of species, and 15–20 MSWs estimated relative abundances (Angermeier and Smogor 1995). A 35–158 MSW single-pass electrofishing sample was needed to collect all species in 10 South Carolina Coastal Plain streams (Paller 1995). In Great Plains streams in Wyoming, 14–50 MSWs sampled by electrofishing, or 21–74 MSWs sampled by seining, were required to collect 100% of species (Patton et al. 2000).

Although the efforts needed in Ozark Highland streams appear to exceed those for streams in other U.S. regions, most of the other studies used different analytical techniques. Cao et al. (2001) used their predictive model to make regional comparisons by using data from Oregon, Virginia (Angermeier and Smogor 1995), and Wyoming (Patton et al. 2000). When they applied their predictive model to Oregon streams, an average of 198 MSWs (SD = 138) needed sampling to collect all species when electrofishing. Applying the model to three Virginia streams, they found that comparable results require sampling an average 103 MSWs (SD = 28). For Great Plains streams in Wyoming, their model found that an average of 41 (SD = 33) MSWs needed sampling to collect all species. The sampling effort of 120 MSWs needed to reach 100% TSR in Ozark Highland streams was within the range of these other regions. Conversely, the average sampling effort needed to obtain 90% and 95% TSR in Ozark Highland streams made up a greater percentage of the effort needed for 100% TSR (72.1% and 84.5%, respectively) than what was determined for Oregon (41.4% and 69.7%), Virginia (38.8% and 61.1%), and Wyoming streams (36.6% and 61.0%) when using the predictive model (Cao et al. 2001). Relative abundance similarity in the Arkansas Ozark Highlands accumulated more slowly, on average (needing 24.0 MSWs), than the 15–20 MSWs reported for three Virginia streams (Angermeier and Smogor 1995). Although we used a different similarity index, our results should be generally comparable; indeed, both studies indicate that good estimates of species relative abundance can be achieved with relatively less sampling effort than estimates of species richness require.

Estimates of species richness and relative abundance are often used in indices designed to assess and monitor stream health (Karr 1981); therefore, obtaining precise estimates is important. Given the costs associated with sampling, managers are unlikely to adopt a sampling protocol and associated effort that will yield accurate estimates of species richness (100+ MSWs); however, they are likely to adopt a protocol that calls for a relatively low effort to accurately and precisely estimate relative abundances. Our results indicate that little precision would be lost by generating species richness estimates at lower efforts. For example, if a standard sampling effort of 25 MSWs, as opposed to 100 MSWs, was adopted for Ozark Highland streams, one would obtain accurate estimates of relative abundance and lose only 1% in the 95% confidence interval surrounding the percentage of species collected (Table 3). One percent represents 0.31 species at Long Creek, where species richness was predicted to be highest (31 species). Thus, adopting a lesser sampling effort would not result in a meaningful loss in precision for estimates of relative abundance or species richness.

Although we think our estimated sampling efforts were accurate, if they are inaccurate, the results they provide should represent conservative estimates. Cao et al. (2001) detected only negative bias when applying their model, indicating that any inaccuracies in TSR estimates were overestimates. Our one site that clearly reached an asymptote, Big Creek, showed a bias of three fewer species than what the model predicted (TSR). Hence, the estimated distances needed to sample a given percentage of TSR would have been greater than those actually needed if the model contained inaccuracies. In any case, most of our ESR estimates appeared to underestimate the true (i.e., unknown) species richness because most of our empirical species accumulation curves failed to reach an asymptote by 75 MSWs. Therefore, we recommend using our TSR results when determining the backpack electrofishing effort needed to sample a target percentage of the fish species present in Ozark Highland streams.

Both MSW and mean riffle–pool sequence length potentially can be used to predict the electrofishing effort needed in Ozark Highland streams. The areas that need sampling can be better predicted than the reach lengths needed confirming our preconceived belief that MSW would be useful for scaling sampling effort (i.e., distance or area) to stream size. Conversely, although the average effort needed was significantly related to mean riffle–pool sequence length, the riffle–pool sequence length was significantly more variable than stream width at a sample site. Increased variability in riffle–pool sequence lengths may limit the usefulness of mean riffle–pool sequence length as a consistent predictor of the average effort needed when applied to streams beyond those included in our study. Watershed size proved not to be a useful predictor of the effort needed; it did not significantly predict the effort needed for estimates of species richness and significantly explained only a relatively small amount of the variation in the efforts needed to estimate relative abundance. Also, no significant relation was detected between the average MSWs needed and the stream conditions (i.e., IBI scores); therefore, stream condition need not be accounted for when determining the needed sampling efforts.

Most species were collected in a few sample segments in particular streams and therefore may not be collected when electrofishing in Ozark Highland streams, even when extensive effort is exerted. Angermeier and Smogor (1995) suggested that discontinuous spatial distributions of species affect species accumulation rates, especially when many species are collected in a small proportion of units sampled. Angermeier and Schlosser (1989) suggested that geographic differences in species area curves may be explained by population and community dynamics in regions that experience greater seasonal and annual environmental variation, but they deemed habitat complexity more important in environmentally stable regions. We observed that at some sites 95% ESR was surpassed at the same sample segment for most of the 15 accumulation curves. This indicated that one or two species (e.g., yellow bullhead *Ameiurus natalis,* Long Creek; see Appendix A) collected per site were very important in achieving 95% of ESR. Further research is needed to determine the factors affecting the distribution and abundance of Ozark Highland fishes (Matthews 1982), how distribution and abundance affect accumulation curves, and how those attributes can be used to predict which species will not be collected during electrofishing surveys (e.g., Bayley and Peterson 2001).

In summary, we have provided insight towards the accuracy and precision of estimates of fish species richness and relative abundance based on electrofishing in wadeable Ozark Highland streams in Arkansas. Although some variability will exist in estimates when exerting any amount of sampling effort, using a consistent effort will improve the chances to characterize fish assemblages precisely when comparing ecoregion streams. In addition, our results should provide regional professionals with valuable information when setting their study objectives and forming their sampling protocols relative to available resources. Though individual study or management objectives may not require accurate assessments of species richness, knowledge of what information a given sampling episode may potentially yield is important and should be recognized. Further, our results ultimately should contribute to the body of literature dealing with the geographically broader question about how much sampling is enough to characterize assemblages of stream fishes.

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Appendix: Species Abundances

TABLE A.1.—Species abundance from Big Creek (1), Brush Creek (2), Clear Creek (3), Diles Creek (4), Dry Creek (5), Greasy Creek (6), Hampton Creek (7), Harding Creek (8), Long Creek (9), Mill Creek (10), Mud Creek (11), North Big Creek (12), North Sylamore Creek (13), Tuttle Branch (14), and Upshaw Creek (15) in Arkansas' Ozark Highlands; streams were sampled from 6 June to 1 August 2000.

	Stream site						
Species	1	2	3	4	5	6	7
Larval lamprey *Ammocoetes* sp.	0	0	0	0	0	0	3
Shadow bass *Ambloplites ariommus*	0	0	0	3	0	0	0
Ozark bass *Ambloplites constellatus*	0	25	0	0	0	0	1
Yellow bullhead *Ameiurus natalis*	1	14	7	6	5	0	10
Black bullhead *Ameiurus melas*	0	1	2	1	0	0	0
Pirate perch *Aphredoderus sayanus*	0	0	0	0	0	0	0
Central stoneroller *Campostoma anomalum*	721	237	383	154	119	257	343
White sucker *Catostomus commersoni*	0	0	0	0	0	0	0
Banded sculpin *Cottus carolinae*	3	138	0	0	0	16	33
Ozark sculpin *Cottus hypselurus*	0	0	0	0	0	0	2
Common carp *Cyprinus carpio*	0	0	1	0	0	0	0
Creek chubsucker *Erimyzon oblongus*	30	0	0	1	0	0	0
Greenside darter *Etheostoma blennioides*	0	8	0	0	0	5	0
Rainbow darter *Etheostoma caeruleum*	43	136	3	70	0	35	98
Fantail darter *Etheostoma flabellare*	0	0	49	40	0	0	0
Stippled darter *Etheostoma punctulatum*	21	3	0	0	0	0	0
Orangethroat darter *Etheostoma spectabile*	226	1	257	7	57	242	71
Banded darter *Etheostoma zonale*	0	0	4	0	0	0	0
Northern studfish *Fundulus catenatus*	2	0	0	4	0	3	63
Blackspotted topminnow *Fundulus olivaceus*	19	3	4	14	12	3	7
Western mosquitofish *Gambusia affinis*	6	0	6	0	0	0	0
Northern hog sucker *Hypentelium nigricans*	3	3	0	1	0	1	7
Brook silverside *Labidesthes sicculus*	0	0	0	0	0	0	0
Green sunfish *Lepomis cyanellus*	6	31	25	4	84	0	19
Warmouth *Lepomis gulosus*	0	2	0	0	0	0	0
Bluegill *Lepomis macrochirus*	0	14	73	0	1	0	0
Longear sunfish *Lepomis megalotis*	207	60	50	69	0	0	9
Redear sunfish *Lepomis microlophus*	0	0	0	0	0	0	0
Spotted sunfish *Lepomis punctatus*	0	0	0	0	0	0	0
Cardinal shiner *Luxilus cardinalis*	0	0	4	0	0	0	0
Striped shiner *Luxilus chrysocephalus*	0	3	0	0	0	0	0
Duskystripe shiner *Luxilus pilsbryi*	0	79	0	0	0	6	77
Bleeding shiner *Luxilus zonatus*	0	0	0	5	0	0	0
Smallmouth bass *Micropterus dolomieu*	0	0	0	1	0	0	2
Spotted bass *Micropterus punctulatus*	2	1	2	0	0	0	0
Largemouth bass *Micropterus salmoides*	0	1	4	0	1	0	0
Red riverhorse *Moxostoma carinatum*	0	0	0	0	0	0	0
Black redhorse *Moxostoma duquesnei*	0	0	0	0	0	0	0
Golden redhorse *Moxostoma erythrurum*	0	0	0	0	0	0	0
Hornyhead chub *Nocomis biguttatus*	0	23	0	8	0	1	26
Bigeye shiner *Notropis boops*	1	0	2	1	4	0	0
Ozark minnow *Notropis nubilus*	15	22	0	3	0	0	47
Telescope shiner *Notropis telescopus*	0	0	0	0	0	0	0
Ozark madtom *Noturus albater*	0	0	0	0	0	0	0
Slender madtom *Noturus exilis*	19	32	17	8	0	8	10
Logperch *Percina caprodes*	0	1	0	0	0	0	0
Southern redbelly dace *Phoxinus erythrogaster*	0	0	0	1	0	27	13
Bluntnose minnow *Pimephales notatus*	24	0	17	0	0	0	15
Fathead minnow *Pimephales promelas*	0	0	0	0	0	0	0
Creek chub *Semotilus atromaculatus*	96	7	5	5	5	0	0

Appendix: Continued

TABLE A.1.—Extended.

Species	Stream site 8	9	10	11	12	13	14	15
Larval lamprey *Ammocoetes* sp.	0	0	0	0	0	8	0	0
Shadow bass *Ambloplites ariommus*	0	0	0	0	11	0	0	1
Ozark bass *Ambloplites constellatus*	0	31	0	0	0	29	0	0
Yellow bullhead *Ameiurus natalis*	4	0	0	1	4	1	0	2
Black bullhead *Ameiurus melas*	1	0	0	0	0	0	0	0
Pirate perch *Aphredoderus sayanus*	10	0	0	0	0	0	0	4
Central stoneroller *Campostoma anomalum*	423	423	417	390	1,082	53	598	864
White sucker *Catostomus commersoni*	0	37	0	0	0	0	0	0
Banded sculpin *Cottus carolinae*	0	37	23	0	2	26	184	0
Ozark sculpin *Cottus hypselurus*	0	0	606	0	0	0	0	0
Common carp *Cyprinus carpio*	0	4	0	0	0	0	0	0
Creek chubsucker *Erimyzon oblongus*	9	0	0	0	5	0	0	34
Greenside darter *Etheostoma blennioides*	10	13	0	0	21	2	0	0
Rainbow darter *Etheostoma caeruleum*	152	273	1	0	260	109	5	60
Fantail darter *Etheostoma flabellare*	135	0	0	0	1	51	0	26
Stippled darter *Etheostoma punctulatum*	0	3	0	0	0	0	41	0
Orangethroat darter *Etheostoma spectabile*	12	74	1	155	20	3	20	45
Banded darter *Etheostoma zonale*	0	0	0	0	0	0	0	0
Northern studfish *Fundulus catenatus*	0	7	0	0	0	4	0	0
Blackspotted topminnow *Fundulus olivaceus*	29	6	0	12	3	34	0	4
Western mosquitofish *Gambusia affinis*	0	0	0	11	7	0	0	28
Northern hog sucker *Hypentelium nigricans*	3	26	0	0	3	0	0	0
Brook silverside *Labidesthes sicculus*	0	0	0	1	0	0	0	0
Green sunfish *Lepomis cyanellus*	21	36	12	26	33	0	80	18
Warmouth *Lepomis gulosus*	0	0	0	4	0	0	0	0
Bluegill *Lepomis macrochirus*	7	0	0	63	0	0	19	0
Longear sunfish *Lepomis megalotis*	125	113	0	38	195	132	0	27
Redear sunfish *Lepomis microlophus*	0	0	0	1	0	0	0	0
Spotted sunfish *Lepomis punctatus*	5	0	0	0	0	0	0	0
Cardinal shiner *Luxilus cardinalis*	0	0	0	0	0	0	0	0
Striped shiner *Luxilus chrysocephalus*	6	2	0	0	0	0	0	0
Duskystripe shiner *Luxilus pilsbryi*	0	33	8	0	0	57	3	0
Bleeding shiner *Luxilus zonatus*	57	0	0	0	40	0	0	11
Smallmouth bass *Micropterus dolomieu*	4	7	0	0	7	23	0	0
Spotted bass *Micropterus punctulatus*	0	0	0	1	3	0	0	0
Largemouth bass *Micropterus salmoides*	2	0	0	4	3	0	0	2
Red riverhorse *Moxostoma carinatum*	0	1	0	0	0	0	0	0
Black redhorse *Moxostoma duquesnei*	0	0	0	1	0	0	0	0
Golden redhorse *Moxostoma erythrurum*	0	2	0	0	0	0	0	0
Hornyhead chub *Nocomis biguttatus*	0	1	0	0	0	13	1	14
Bigeye shiner *Notropis boops*	8	28	0	71	10	0	0	0
Ozark minnow *Notropis nubilus*	0	35	0	0	20	0	211	0
Telescope shiner *Notropis telescopus*	2	0	0	0	0	18	0	0
Ozark madtom *Noturus albater*	0	0	0	0	0	3	0	0
Slender madtom *Noturus exilis*	53	3	0	2	4	29	0	0
Logperch *Percina caprodes*	0	6	0	0	0	0	1	0
Southern redbelly dace *Phoxinus erythrogaster*	0	0	205	0	0	0	0	4
Bluntnose minnow *Pimephales notatus*	61	40	0	21	3	0	7	2
Fathead minnow *Pimephales promelas*	0	0	0	1	0	0	0	0
Creek chub *Semotilus atromaculatus*	47	11	1	1	0	0	6	58