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Effects of Electrofishing Gear Type on Spatial and Temporal Variability in Fish Community Sampling

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Abstract.—Fish community data collected from 24 major river basins between 1993 and 1998 as part of the U.S. Geological Survey's National Water-Quality Assessment Program were analyzed to assess multiple-reach (three consecutive reaches) and multiple-year (three consecutive years) variability in samples collected at a site. Variability was assessed using the coefficient of variation (CV; SD/mean) of species richness, the Jaccard index (JI), and the percent similarity index (PSI). Data were categorized by three electrofishing sample collection methods: backpack, towed barge, and boat. Overall, multiple-reach CV values were significantly lower than those for multiple years, whereas multiple-reach JI and PSI values were significantly greater than those for multiple years. Multiple-reach and multiple-year CV values did not vary significantly among electrofishing methods, although JI and PSI values were significantly greatest for backpack electrofishing across multiple reaches and multiple years. The absolute difference between mean species richness for multiple-reach samples and mean species richness for multiple-year samples was 0.8 species (9.5% of total species richness) for backpack samples, 1.7 species (10.1%) for towed-barge samples, and 4.5 species (24.4%) for boat-collected samples. Review of boat-collected fish samples indicated that representatives of four taxonomic families—Catostomidae, Centrarchidae, Cyprinidae, and Ictaluridae—were collected at all sites. Of these, catostomids exhibited greater interannual variability than centrarchids, cyprinids, or ictalurids. Caution should be exercised when combining boat-collected fish community data from different years because of relatively high interannual variability, which is primarily due to certain relatively mobile species. Such variability may obscure longer-term trends.

Without baseline spatial and temporal data on the inherent variability in sampling of aquatic biological communities, detection of the effects of human-induced or natural perturbation is difficult (Meador and Matthews 1992). Resh and Rosenberg (1989) reviewed numerous studies of aquatic insects and concluded that most researchers combine sampling sites or sampling times for analyses, even though spatial and temporal variability may be significant. Assessing variability in samples of stream fishes is critical in developing cost-effective, optimal sampling designs for biological monitoring programs and to ensure accurate interpretations of environmental effects on aquatic biota (Peterson and Rabeni 1995).

Relatively few studies have quantified the spatial and temporal variability in stream fishes simultaneously. In these studies, the examination of relative spatial and temporal variability was based largely on the use of multiple longitudinal stream sites and monthly or periodic sampling (Gelwick 1990; Matthews 1990b; Meador and Matthews 1992; Taylor et al. 1996; Gido et al. 1997). The majority of stream fish community studies have been based on single samples collected at a given site and time. Moreover, the focus of most studies is on relatively small streams and wadeable sampling methods. Few studies have focused on the variability of fish community samples collected using boats.

Fish community structure (species richness and the abundance of individual species) is characterized as part of an integrated physical, chemical, and biological assessment of U.S. water quality under the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS). The design of the NAWQA Program incorporates sampling at multiple reaches and across multiple years. Multiple reaches provide the op-

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TABLE 1.—The 24 National Water-Quality Assessment Program river basins that were included in this study.

River basin	Number of sites	Mean number of fish species per site (5 samples per site)
Allegheny and Monongahela basins	1	11.2
Central Arizona basins	1	6.7
Central Columbia Plateau	2	5.8
Eastern Iowa basins	3	22.4
Hudson River basin	3	11.4
Kanawha–New River basin	1	20.3
Lake Erie–Lake Saint Clair drainage	3	23.5
Long Island–New Jersey Coastal drainages	1	20.2
Lower Illinois River basin	2	18.2
Nevada basin and range	1	3.7
Potomac River basin	2	15.0
Puget Sound basin	2	2.7
Red River of the North	4	12.3
Sacramento basin	2	5.9
San Joaquin–Tulare basins	3	12.1
South-central Texas	2	14.3
Southern Florida	1	21.4
South Platte River basin	3	7.0
Trinity River basin	1	15.2
Upper Colorado River basin	3	5.9
Upper Mississippi River basin	7	19.9
Upper Tennessee River basin	1	27.0
White River basin	3	24.0
Willamette basin	3	6.3
Total	55	14.1

portunity to assess variability at the sampling-unit level for collecting fish community data. Assessing sampling variability at the reach scale is important because, for example, it forms the basis for defining the precision of measures developed in establishing biocriteria (Karr and Chu 1997). Multiple-year sampling provides an opportunity to assess short-term interannual variability in estimates of fish community structure. An understanding of how interannual temporal variability compares with spatial or multiple-reach sampling variability is critical to addressing important environmental assessment issues (e.g., can data collected in different years be combined without adding large amounts of variability to an analysis, or does interannual variability potentially obscure any longer-term trends?).

Our goal, as part of the NAWQA Program, was to assess the variability among fish community samples collected across multiple sampling reaches at a site and at a single sampling reach over multiple years. Specific objectives were to (1) assess and compare three properties of fish communities—the coefficient of variation (SD/mean) of species richness, the Jaccard index, and the percent similarity index—among samples from multiple reaches at a site for a given year and among multiple years at a site for a given reach and (2) examine the relations among these properties, electrofishing sampling gear types, and stream habitat.

Methods

The NAWQA program focuses on major river basins across the United States (Gilliom et al. 1995). Review of data collected during 1993–1998 indicated that studies conducted in 24 river basins included a combined total of 55 sites at which three consecutive stream reaches were sampled within a given year and where one of these stream reaches also was sampled during three consecutive years (Table 1).

Sampling.—At each site, sampling reach lengths were based on the number and diversity of stream habitat types (pools, riffles, and runs), meander wavelengths, and minimum–maximum sampling distances (Meador et al. 1993b; Fitzpatrick et al. 1998). The sampling reach included, where possible, at least two different stream habitat types. Where this was not possible (e.g., a stream that is a continuous run), the length of the sampling reach included one meander wavelength, based on 20 times the distance of the channel width (Leopold et al. 1964). Established before sampling, the minimum and maximum reach lengths were 150 and

300 m at wadeable sites and 300 and 1,000 m at nonwadeable sites.

For this study, 275 total reaches (55 sites × 5 reaches/site) were established where fish community data were collected at three reaches within a single year (N = 165 multiple-reach samples) and at a single reach during three consecutive years (N = 165 multiple-year samples). Where possible, distances between stream reaches were equal to the average reach length for each site. Wetted channel width (m) and stream depth (m) were measured along transects (Fitzpatrick et al. 1998), and mean channel width and mean stream depth were determined. Channel width and stream depth were recorded for only one reach at a site.

Fish were sampled during summer low-flow periods from 1993 to 1998. Electrofishing gear consisted of three types: backpack, towed-barge, and boat-mounted units. All electrofishing methods were conducted using a pulsed-DC waveform. Recommended pulse frequencies ranged from 30 to 60 pulses/s (Meador et al. 1993a). Operators of electrofishing gear received training in the sampling protocol (Meador et al. 1993a) and in electrofishing principles (e.g., power transfer theory) to help standardize electrofishing effort and increase the efficiency of electrofishing operations (Reynolds 1996).

In wadeable streams, backpack and towed-barge electrofishing began at the downstream boundary of the sampling reach and two passes were conducted in an upstream direction. Boat electrofishing began at the upstream boundary of the sampling reach and proceeded in a downstream direction, one pass along each shoreline. Of the 275 total reaches, 100 reaches (20 sites) were sampled by backpack electrofishing, 120 reaches (24 sites) were sampled using a towed barge, and 55 reaches (11 sites) were sampled by boat electrofishing. Regardless of the gear chosen for use at a site, that gear was used consistently for all three reaches and years at that site. Fish were identified to species and counted. Fish that could not be identified in the field were retained for identification in the laboratory (Walsh and Meador 1998).

Statistical analyses.—Coefficients of variation (CV) were calculated to assess variability in fish species richness at a site. For multiple reaches, species richness was determined for each of the three reaches at a site for a given year, and the CV of species richness was determined for each site. Similarly for multiple years, species richness was determined for each of the 3 years of sampling at a site and the CV of species richness was determined.

Fish communities at pairs of sampling reaches were compared using the Jaccard index (JI; Ludwig and Reynolds 1988) and the percent similarity index (PSI; Wolda 1981). For each site, three values were determined for each index for multiple-reach comparisons and three for multiple-year comparisons. The JI represents the proportion of species in common between two samples and, thus, reflects similarities in species composition. The index is unbiased, even for small sample sizes (Ludwig and Reynolds 1988). Values for the JI range from 0 (no species in common) to 1.0 (identical species composition). The PSI incorporates information regarding similarities in two samples, based on both species richness and relative abundance. The PSI commonly has been used in fish ecology studies (Matthews et al. 1988; Cashner et al. 1994) and also is unbiased (Linton et al. 1981). Values for the PSI range from 0 (no species in common) to 100 (all species in common and of identical abundance). Use of the CV, JI, and PSI provided an opportunity to assess variability of fish community structure using different properties of fish communities: total species richness, species composition, and relative abundance.

All data were tested for normality using the Kolmogorov–Smirnov test. When nonnormality was indicated, data were transformed to improve normality by using $\log_{10}(x + 1)$ or the arcsine square root, and the transformed data were retested. Tests indicated that transformations improved normality. Multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) were conducted to compare CV, JI, and PSI values between multiple reaches and multiple years and to compare among electrofishing gear types within multiple-reach and multiple-year samples. Pearson's product-moment correlation analysis was used to assess relations among channel width, stream depth, and measures of fish community (CV, JI, and PSI).

For MANOVA, statistical differences were determined based on Wilk's lambda (λ). For ANOVA, Tukey's Studentized range test was used to compare mean values. All differences were declared to be statistically significant at $\alpha = 0.05$.

Results

Variation in the CV, JI, and PSI between multiple-reach and multiple-year samples can be visualized as the deviation from a 1:1 relationship between values for multiple-reach samples and

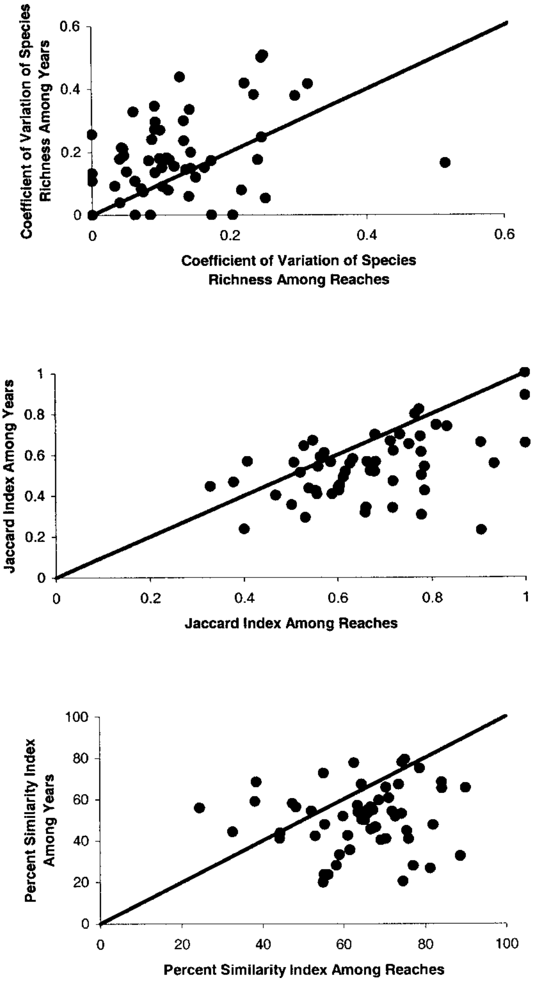

FIGURE 1.—Relationships between coefficient of variation of fish species richness, Jaccard index, and percent similarity index values determined from multiple-reach and multiple-year samples. Lines represent 1:1 relationships between the values for multiple-reach samples and those for multiple-year samples.

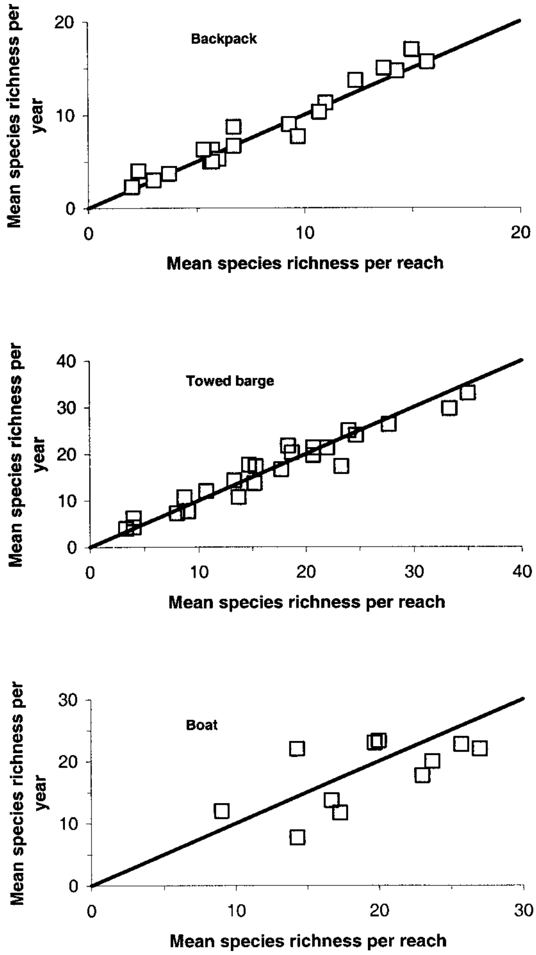

FIGURE 2.—Relationships between mean fish species richness determined from multiple-year samples and mean fish species richness determined from multiple-reach samples by backpack, towed-barge, and boat electrofishing. Lines represent 1:1 relationships between the values for multiple-reach samples and those for multiple-year samples.

values for multiple-year samples (Figure 1). The mean CV for species richness among reaches at a site, 0.13, was significantly less than the mean CV for species richness among years (0.19) at a site for a given reach (ANOVA: $P = 0.004$). The mean JI value for multiple reaches, 0.67, was significantly greater than the mean JI value of 0.54 for multiple years (ANOVA: $P = 0.0001$). The mean PSI value for reaches, 64.3, was also significantly greater than the mean of 50.6 for multiple years (ANOVA: $P = 0.0001$).

Variation in species richness determinations between multiple-reach and multiple-year samples can be visualized as the deviation from a 1:1 relationship between mean values for multiple-reach samples and mean values for multiple-year samples (Figure 2). The absolute difference between mean species richness for multiple-reach samples and mean species richness for multiple-year samples was determined. The mean difference for backpack electrofishing was 0.8 species or 9.5% of the mean species richness per site (multiple-year and multiple reach samples combined) of 8.4 species. The mean species richness per site sampled by towed-barge electrofishing was 16.8 species, and the mean absolute difference between

TABLE 2.—Mean values and analysis-of-variance comparison between multiple-reach and multiple-year samples obtained by different electrofishing gear types. Shown are the coefficient of variation (CV; SD/mean) of fish species richness, the Jaccard index (JI), and the percent similarity index (PSI). *P*-values are provided for comparisons between multiple-reach and multiple-year samples for each electrofishing gear type. Letters indicate comparisons among electrofishing gear types for each measure; means with the same letters are not significantly different.

Fish community measure	Electrofishing gear type	Multiple reach	Multiple year	*P*-value
CV	Backpack	0.11 z	0.18 z	0.053
	Towed barge	0.14 z	0.18 z	0.214
	Boat	0.13 z	0.23 z	0.072
JI	Backpack	0.75 z	0.62 z	0.012
	Towed barge	0.62 y	0.53 zy	0.016
	Boat	0.59 y	0.43 y	0.001
PSI	Backpack	69.5 z	54.8 z	0.003
	Towed barge	59.2 y	50.3 zy	0.023
	Boat	65.8 zy	43.7 y	0.001

species richness for multiple-reach samples and species richness for multiple-year samples was 1.7 species (10.1%). The mean species richness per site sampled by boat electrofishing was 18.5 species, and the mean absolute difference between species richness for multiple-reach samples and species richness for multiple-year samples was 4.5 species (24.4%).

For backpack electrofishing, measures of fish community structure varied significantly between multiple-reach and multiple-year samples (MANOVA: $F = 3.20$, $P = 0.035$). Values for the CV of fish species richness did not vary significantly between multiple-reach and multiple-year samples, whereas mean backpack-collected values for JI and PSI were significantly greater for multiple-reach than for multiple-year samples (Table 2). For towed-barge electrofishing, measures of fish community structure varied significantly between multiple-reach and multiple-year samples (MANOVA: $F = 2.66$, $P = 0.039$). Values for the CV of fish species richness did not vary significantly between multiple-reach and multiple-year samples, whereas mean towed-barge values for JI and PSI were significantly greater for multiple-reach than for multiple-year samples (Table 2). For boat electrofishing, measures of fish community structure varied significantly between multiple-reach and multiple-year samples (MANOVA: $F = 7.27$, $P = 0.002$). Values for the CV of fish species richness did not vary significantly between multiple-reach and multiple-year samples, whereas mean boat-collected values for JI and PSI were significantly greater for multiple-reach than for multiple-year samples (Table 2).

For multiple-reach samples, measures of fish community structure varied significantly among electrofishing gear types (MANOVA: $F = 2.91$, $P = 0.012$). The ANOVA indicated that the CV for species richness did not vary significantly among electrofishing methods ($P = 0.508$); however, mean JI ($P = 0.039$) and PSI ($P = 0.044$) values were significantly greatest in samples collected by backpack electrofishing across multiple reaches (Table 2).

For multiple-year samples, measures of fish community structure also varied significantly among electrofishing gear types (MANOVA: $F = 2.21$, $P = 0.048$). The CV for species richness did not vary significantly among electrofishing methods ($P = 0.401$). Mean JI ($P = 0.002$) and PSI ($P = 0.047$) values, however, were significantly greater for samples collected by backpack electrofishing than for samples collected by boat electrofishing across multiple years.

The comparatively high variability in fish community samples collected by boat electrofishing across multiple years prompted additional analyses of these data. The boat-collected fish samples included representatives of four taxonomic families at all sites: Catostomidae, Centrarchidae, Cyprinidae, and Ictaluridae. For multiple-year samples collected by boat electrofishing, measures of fish community structure varied significantly among taxonomic families (MANOVA: $F = 2.24$, $P = 0.04$). The mean CV for catostomid species richness, 0.92, was significantly greater ($P = 0.025$) than the CV values for centrarchids, cyprinids, and ictalurids (Table 3). Similarly, the mean JI value for catostomid species richness, 0.29, was significantly lower ($P = 0.024$) than JI values for centrarchids, cyprinids, and ictalurids. Also, the mean PSI value for catostomid species richness, 28.5, was significantly lower ($P = 0.018$) than the PSI values for centrarchids, cyprinids, and ictalurids (44.4). No significant differences were detected in fish community measures among centrarchids, cyprinids, and ictalurids collected by boat sampling across multiple years ($P > 0.05$).

Correlation analysis of multiple-reach backpack samples revealed that PSI values decreased significantly with increasing channel width ($P = 0.008$, $r = -0.66$). No other variables were significant for backpack, towed-barge, or boat electrofishing samples among multiple reaches. Correlation analysis of multiple-year towed-barge samples indicated that JI values decreased signif-

TABLE 3.—Mean values and analysis-of-variance comparison among four selected taxonomic families of fish collected by boat electrofishing gear. Shown are the coefficient of variation (CV = SD/mean) of fish species richness, the Jaccard index (JI), and the percent similarity index (PSI) calculated from multiple-year samples. Letters indicate comparisons among taxonomic families; means with the same letters are not significantly different from each other.

Fish community measure	Catostomidae	Centrarchidae	Cyprinidae	Ictaluridae	*P*-value
CV	0.92 z	0.46 y	0.52 y	0.43 y	0.025
JI	0.29 z	0.55 y	0.51 y	0.50 y	0.024
PSI	28.5 z	50.5 y	43.9 y	44.4 y	0.018

icantly with increasing stream depth ($P = 0.043$, $r = -0.43$). No other variables were significantly related to electrofishing methods among multiple years.

Discussion

Analyses of measures of species richness, species composition, and relative abundance among multiple-reach samples suggested relatively low variability in these metrics among reaches within a site for streams across the United States, regardless of sampling methods. The mean CV value for species richness among reaches within a site was 0.13, whereas mean JI and PSI values were 0.67 and 64.3, respectively. Paller (1995) used the coefficient of variation of species richness to examine interreplicate variation in catch per unit effort based on collections using backpack, towed-barge, and boat-mounted electrofishing gear. Paller (1995) chose a CV of 0.20 as a maximum desirable level of variability in catch per unit effort. Matthews et al. (1988) considered PSI values greater than 60 as indicative of similarity in communities. Matthews (1990a) compared fish communities collected by seining in adjacent 100-m reaches at five sites on Brier Creek, Oklahoma, and reported 60–70% similarity in species composition for between-reach comparisons, which is similar to the results of this study. High variability in fish community measures across reaches within a site may indicate that samples are too variable to reliably represent a sample of the fish community at a site, thus making detection of the effects of human-induced perturbation difficult. The results of the present study suggest that, overall, the relatively low variability in fish community measures across reaches at a site should have limited influence on site-to-site comparisons and the ability to detect effects of environmental impacts.

Whereas relatively low variability was observed in fish community measures among reaches, greater variability was observed in fish community samples among years. Compared with values for fish community samples among reaches, mean JI and PSI values of 0.54 and 50.6, respectively, and a mean CV of 0.19 suggest that variability among years was relatively high for all three properties of fish communities (i.e., species richness, species composition, and relative abundance).

Variability in fish community samples tended to increase with variability in channel width and stream depth for backpack and towed-barge electrofishing gear. Many factors are involved in the selection of a sampling gear type at a site. Stream depth determines whether wadeable or nonwadeable gear will be used. However, variation in stream width and depth at sites sampled by wadeable electrofishing gear affected variability in fish community samples. Variability in species composition and their relative abundances (PSI values) among reaches within a site were related to increasing channel width, whereas variability in species composition (JI values) among years at a site was related to increasing stream depth.

Variability in multiple-reach and multiple-year fish community samples may be related to a combination of sampling gear efficiency, environmental conditions, and fish mobility. Though measures of species composition and relative abundance varied among electrofishing gear types for multiple-reach samples, JI values were 0.59 or greater, whereas PSI values were 59.2 or greater. In contrast, relatively high interannual variability was observed, particularly for species composition and relative abundance across electrofishing gear types, JI values being as low as 0.43 and PSI values as low as 43.7. Matthews et al. (1988) seined Piney Creek, Brier Creek, and the Kiamichi River in Oklahoma across multiple years and found that PSI values at a site ranged from 6 to 87 (the mean PSI for all interannual comparisons was 59.5). They suggested that a lack of similarity at some sites over time might be related to differences in environmental conditions among years and the greater mobility of fishes at downstream sites.

We observed relatively high variability in species richness in samples collected by boat electrofishing among years. If the mean fish species richness among reaches is used as a benchmark instantaneous estimate of fish species richness at a site, then the mean estimate of fish species richness among years can give an indication of interannual variability in fish species richness estimates. Our findings suggest that interannual estimates of variability in fish species richness for wadeable sampling gear were relatively similar. For backpack electrofishing, the results suggested that interannual sampling could result in ± 1 species (or about 10%) compared with the mean reach estimate. Similarly, for towed-barge sampling, interannual sampling could result in ± 1 to ± 2 species (or about 10%) relative to the mean reach estimate. However, for boat electrofishing, interannual sampling may produce estimates of fish species richness that are ± 4 to ± 5 species compared with a mean reach estimate (about 25%).

Relatively high variability in species composition and relative abundance was also observed in samples collected by boat electrofishing among years. Cashner et al. (1994) compared fish community samples collected by boat electrofishing during 2 years at six sites on two streams in coastal Louisiana and noted substantial variability in samples between years. They reported that the mean JI value for between-year comparisons of the six sites sampled by boat electrofishing was 0.44, whereas the mean PSI value was 56.0. They concluded that the interannual variability in fish community samples was related to the dynamic nature of environmental conditions combined with the mobility of fish in nonwadeable systems. In our study, a lack of relations between environmental conditions and variability in fish community measures determined from samples collected by boat electrofishing may suggest that interannual variability may be attributed more to the sampling efficiency of boat electrofishing than to changing environmental conditions.

Relatively high interannual variability in fish community samples collected by boat electrofishing may be attributed to the presence of certain mobile species. Simon and Sanders (1999) noted that schools of the pelagic gizzard shad *Dorosoma cepedianum* often are collected sporadically in rivers in large numbers and that variations in the presence and abundance of this species could bias intersite comparisons in fish community structure. Of the four taxonomic families examined in our study, catostomids exhibited greater interannual variability than centrarchids, cyprinids, or ictalurids. Thus, relatively high interannual variability in fish community samples collected by boat electrofishing may be significantly influenced by the presence of catostomids that may be relatively more mobile across years compared with centrarchids, cyprinids, or ictalurids.

Crew experience also may be an important factor related to fish community variability, especially interannual variability in boat-collected samples. Our study was not designed to assess relations between variability in fish community measures and electrofishing crew composition. However, Hardin and Connor (1992), in a study of boat electrofishing crew efficiency conducted on Florida lakes, noted that less experienced crews collected samples to estimate catch per unit effort of largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* with significantly greater variability than more experienced crews. Crew composition may remain relatively more stable across sites at a given time compared with crew composition stability over time. Hardin and Connor (1992) recommended that samples should be taken by the same crew, whenever possible.

In conclusion, the results of this study suggest that monitoring studies should be designed and data analyzed with an awareness of reach-scale spatial variability associated with interannual variability, particularly in boat-collected samples of fish community structure. In this study, we asked (1) can data collected in different years be combined without adding large amounts of variability to an analysis? and (2) does interannual variability potentially obscure any longer-term trends? The results suggest that when using backpack or towed-barge electrofishing, combining data collected in different years may add relatively little variability to analyses. However, when using boat electrofishing, combining data collected in different years may add significant variability to analyses of species richness, species composition, and relative abundance. Therefore, caution should be exercised when combining boat-collected fish community data from different years because of relatively high interannual variability, primarily attributable to certain relatively mobile species. Such variability may obscure detection of any longer-term trends when analyzing boat-collected fish community data from large rivers.

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References

Cashner, R. C., F. P. Gelwick, and W. J. Matthews. 1994. Spatial and temporal variation in the distribution of fishes of the Labranche wetlands area of the Lake Pontchartrain estuary, Louisiana. Northeast Gulf Science 13:107–120.

Fitzpatrick, F. A., I. R. Waite, P. D'Arconte, M. R. Meador, M. A. Maupin, and M. E. Gurtz. 1998. Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program. U.S. Geological Survey, Water-Resource Investigations Report 98-4052, Raleigh, North Carolina.

Gelwick, F. P. 1990. Longitudinal and temporal comparisons of riffle and pool fish assemblages in a northeastern Oklahoma Ozark stream. Copeia 1990: 1072–1082.

Gido, K. B., D. L. Propst, and M. C. Molles, Jr. 1997. Spatial and temporal variation of fish communities in secondary channels of the San Juan River, New Mexico and Utah. Environmental Biology of Fishes 49:417–434.

Gilliom, R. J., W. M. Alley, and M. E. Gurtz. 1995. Design of the National Water-Quality Assessment Program: occurrence and distribution of water-quality conditions. U.S. Geological Survey, Circular 1112.

Hardin, S., and L. L. Connor. 1992. Variability of electrofishing crew efficiency, and sampling requirements for estimating reliable catch rates. North American Journal of Fisheries Management 12: 612–617.

Karr, J. R., and E. W. Chu. 1997. Biological monitoring: essential foundation for ecological risk assessment. Human and Ecological Risk Assessment 3:993–1004.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. Freeman, San Francisco.

Linton, L. R., R. W. Davies, and F. J. Wrona. 1981. Resource utilization indices: an assessment. Journal of Animal Ecology 50:283–292.

Ludwig, L. A., and J. F. Reynolds. 1988. Statistical ecology: a primer on methods and computing. Wiley, New York.

Matthews, W. J. 1990a. Fish community structure and stability in warmwater Midwestern streams. U.S. Fish and Wildlife Service Biological Report 90:16–17.

Matthews, W. J. 1990b. Spatial and temporal variation in fishes of riffle habitats: a comparison of analytical approaches for the Roanoke River. American Midland Naturalist 124:31–45.

Matthews, W. J., R. C. Cashner, and F. P. Gelwick. 1988. Stability and persistence of fish faunas and assemblages in three midwestern streams. Copeia 1988: 945–955.

Meador, M. R., T. F. Cuffney, and M. E. Gurtz. 1993a. Methods for sampling fish communities as part of the National Water-Quality Assessment Program. U.S. Geological Survey, Open-file Report 93-104, Raleigh, North Carolina.

Meador, M. R., C. R. Hupp, T. F. Cuffney, and M. E. Gurtz. 1993b. Methods for characterizing stream habitat as part of the National Water-Quality Assessment Program. U.S. Geological Survey, Open-File Report 93-408, Raleigh, North Carolina.

Meador, M. R., and W. J. Matthews. 1992. Spatial and temporal patterns in fish assemblage structure of an intermittent Texas stream. American Midland Naturalist 127:106–114.

Paller, M. H. 1995. Interreplicate variance and statistical power of electrofishing data from low-gradient streams in the southeastern United States. North American Journal of Fisheries Management 15: 542–550.

Peterson, J. T., and C. F. Rabeni. 1995. Optimizing sampling effort for sampling warmwater stream fish communities. North American Journal of Fisheries Management 15:528–541.

Resh, V. H., and D. M. Rosenberg. 1989. Spatial-temporal variability and the study of aquatic insects. Canadian Entomologist 121:941–963.

Reynolds, J. B. 1996. Electrofishing. Pages 221–254 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Simon, T. P., and R. E. Sanders. 1999. Applying an IBI based on great-river fish communities. Pages 475–505 *in* T. P. Simon, editor. Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, Florida.

Taylor, C. M., M. R. Winston, and W. J. Matthews. 1996. Temporal variation in tributary and mainstem fish assemblages in a Great Plains stream system. Copeia 1996:280–289.

Walsh, S. J., and M. R. Meador. 1998. Guidelines for quality assurance and quality control of fish taxonomic data collected as part of the National Water-Quality Assessment Program. U.S. Geological Survey, Water-Resources Investigations Report 98-4239, Raleigh, North Carolina.

Wolda, H. 1981. Similarity indices, sample size, and diversity. Oecologia 50:296–302.