Fish Species Diversity and Abundance in Relation to Stream Habitat Characteristics

Jeffrey W. Foltz, *Department of Aquaculture, Fisheries and Wildlife, Clemson University, Clemson, SC 29631*

Abstract: Fish species diversity and abundance were examined over a 3 year period at 6 study sites within a single watershed in the Piedmont of South Carolina. The fish community was dominated by 3 cyprinid species, but included 22 species. Average Shannon-Weaver fish species diversity estimates ranged from 0.15 to 1.87, and were related to substrate diversity. Fish species diversity increased downstream, and decreased in relation to silt in the substrate and frequency of drying. Fish abundance increased downstream and with depth, but was also influenced by substrate characteristics known to influence distribution of aquatic insects.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 36:305–311

Fish have received considerable attention in biomonitoring because of reasons discussed by Funk (1970), Hellawell (1977), Hocutt and Stauffer (1980) and Karr (1981). Fish are dependent upon both physical characteristics of their environment and other forms of aquatic life. Therefore, health of the fish community presumably reflects conditions of the entire aquatic community.

Much baseline information on species diversity and abundance is needed before these measurements can routinely be used to assess status of a fish community. Quantitative relationships between habitat characteristics and community metrics (e.g., diversity, abundance) need to be identified. An understanding of these relationships will assist management of soil and water resources, and aid development of future conceptual models.

Several studies reported longitudinal changes in fish species diversity (Kuehne 1982, Harrel et al. 1967, Sheldon 1968, Gorman and Karr 1978), and Gorman and Karr (1978) related fish species diversity to habitat complexity. However, no studies have simultaneously compared both species diversity and abundance to habitat characteristics. Objectives of this study were to examine and quantify the relationships between habitat parameters and fish species diversity and abundance in a small Piedmont watershed.

I wish to express my gratitude to Dylan Gibson, Teresa Wilson, Pat Walker and Ralph Holzenthal for assistance with the field collections. Special thanks are extended to Mr. John Crane for his help in all phases of this study. This research was supported in part by the U.S. Environmental Protection Agency, grant No. R806316010.

Methods

Six study sites were selected in the Broadway Creek system of the Savannah River drainage located at about 34° 35′ N lat., 82° 35′ W long. in the Piedmont of South Carolina. The watershed supported light agriculture (e.g., soybeans), but stream banks at all sites were forested. Stream order (Leopold et al. 1964) was ascertained from U.S. Geological Survey quadrangle maps and verified by longitudinal survey of the stream system. Pairs of first, second and third order sites were identified and a 90-m section at each site marked. Each site was sampled at 6-week intervals from 1979 through 1981.

Fish were captured with a back pack electroshocker operated at a voltage (e.g., 450 to 850) which produced 150 milliamps of current. A timer built into the electroshocker recorded the number of seconds (i.e., effort) the unit was operated. Specimens were preserved in 10% formalin, subsequently washed in water and transferred to 50% isopropyl alcohol. The following statistics were calculated for each sample:

1) species diversity (Shannon and Weaver 1949):

$$\bar{H} = \frac{C}{N}(N \log_{10} N - \Sigma n_i \log_{10} n_i)$$

where $C = 3.322$
N = total number of individuals
n_i = number of individuals in its species

2) catch per unit effort: the number of fish per 1000 seconds of effort.

Stream habitat was surveyed annually. At each site, 40 transects at 3-m intervals and perpendicular to stream flow were examined. Width of flowing water was measured to the nearest decimeter and depth recorded to the nearest cm at 3 locations along each transect. Substrate along each transect was visually examined and percent composition of clay, silt, sand, gravel, rubble and bedrock estimated to the nearest 10%. Frequency of drying was recorded because extended summer droughts during 1980 and 1981 resulted in occasional drying of first order sites. Annual substrate composition data for each site were rounded off to the nearest integer and substrate diversity computed according to the Shannon-Weaver (1949) formula.

Pearson's product moment correlation coefficients were calculated for fish species diversity and stream characteristics. Stepwise multiple regression was used to relate average annual species diversity and catch per unit effort to annual estimates of order, width, depth, substrate composition and substrate diversity. Curvilinearity was examined by including square and cubic functions of these variables in the stepwise routine. Only those variables which contributed significantly ($P \leq 0.05$) were included in the multiple regressions.

Results and Discussion

Twenty two species of fish were captured at the 6 study sites over a 3-year period. The ichthyofauna was dominated by 3 cyprinids; the yellowfin shiner (*Notropis lutipinnis*), bluehead chub (*Nocomis leptocephalus*), and creek chub (*Semotilus atromaculatus*) (Table 1). First order streams

Table 1. Percent Composition and Catch Per 1000 Seconds of Effort (CPUE) of 12,508 Fishes Sampled on 26 Occasions Over a 3-year Period (1979–1981)

		Stream Order					
		1		2		3	
Common Name	Scientific Name	%	CPUE	%	CPUE	%	CPUE
Creek chub	(*Semotilus atromaculatus*)	85	12.1	17	21.4	10	8.3
Bluehead chub	(*Nocomis leptocephalus*)	4	0.5	29	52.9	28	28.1
Yellowfin shiner	(*Notropis lutipinnis*)	2	0.1	52	99.8	52	60.6
Spottail shiner	(*Notropis hudsonius*)	0	0.0	0	0.0	<1	0.3
Rosyface chub	(*Hybopsis rubrifrons*)	0	0.0	<1	0.5	1	1.5
Golden shiner	(*Notemigonus crysoleucas*)	0	0.0	0	0.0	<1	<0.1
Northern hogsucker	(*Hypentelium nigricans*)	0	0.0	<1	0.6	2	1.1
Striped jumprock	(*Moxostoma rupiscartes*)	0	0.0	1	2.9	<1	0.5
Chain pickerel	(*Esox niger*)	0	0.0	0	0.0	<1	0.1
Flat bullhead	(*Ictalurus platycephalus*)	0	0.0	0	0.0	<1	<0.1
Snail bullhead	(*Ictalurus brunneus*)	0	0.0	0	0.0	<1	<0.1
Brown bullhead	(*Ictalurus nebulosus*)	0	0.0	<1	<0.1	<1	0.1
Yellow bullhead	(*Ictalurus natalis*)	0	0.0	<1	0.1	<1	0.1
Margined madtom	(*Noturus insignis*)	0	0.0	0	0.0	1	0.7
Pumpkinseed	(*Lepomis gibbosus*)	0	0.0	0	0.0	<1	<0.1
Warmouth	(*Lepomis gulosus*)	0	0.0	<1	<0.1	<1	<0.1
Redear sunfish	(*Lepomis microlophus*)	0	0.0	0	0.0	<1	<0.1
Bluegill	(*Lepomis macrochirus*)	8	0.7	<1	0.1	2	1.8
Redbreast sunfish	(*Lepomis auritus*)	<1	0.1	<1	<0.1	1	1.0
Green sunfish	(*Lepomis cyanellus*)	2	0.1	<1	<0.1	<1	0.1
Largemouth bass	(*Micropterus salmoides*)	0	0.0	<1	<0.1	1	0.7
Blackbanded darter	(*Percina nigrofasciata*)	0	0.0	<1	0.1	<1	0.4

were used principally by creek chubs, which comprised 85, 17, and 10% of the fish fauna in first, second, and third order streams respectively.

Investigations of longitudinal zonation in stream fish communities revealed that species diversity increased downstream (Sheldon 1968, Deacon and Bradley 1972, Whiteside and McNatt 1972). Increasing physical heterogeneity and mean depth were suggested sources of higher downstream diversities, presumably due to a greater variety of physical niches. Two previous studies quantified habitat diversity, and demonstrated that fish species diversity was related to habitat diversity (Tramer and Rogers 1973, Gorman and Karr 1978). In this study, fish species diversity was also correlated with substrate diversity (Table 2). However, substrate diversity when considered singularly, accounted for only 83% of the variation. Stronger relationships existed between fish species diversity and width and stream order (Table 2). Flowing width and stream order, which as expected demonstrated a strong correlation with one another, each accounted for about 92% of the variation when independently correlated with fish diversity.

Interpretation of relationships between fish species diversity and habitat factors is difficult because environmental variables in streams are typically correlated and confounded with one another (Reid 1961). For example, in this study, substrate diversity was significantly correlated with width, depth and stream order; all 3 relationships suggesting a downstream increase in habitat complexity (Table 2). Factors such as stream order, width, and depth encompass other relationships. In this study, all 3 factors were significantly correlated with percent sand and gravel in bottom substrate (Table 2).

Average flowing widths of the 6 sites ranged from 0.6 to 3.3 m, and average depth ranged from 2 to 11 cm (Table 3). Mean substrate diversity ranged from 1.00 for a first order stream to 1.93 for a third order stream. Drying was confined to the pair of first order streams, which during the 3-year study period, were dry 18 and 8% of the time. Average fish species diversity

Table 2. Correlation Coefficients Between Stream Order, Width, and Depth, and Fish Species Diversity, Substrate Diversity and Substrate Composition. All Correlation Coefficients are Significant ($P \leq 0.05$)

Longitudinal Parameter	Fish Species Diversity[a]	Substrate Diversity	% Substrate Composition	
			Sand	Gravel
Order	0.973	0.961	−0.691	0.920
Width (dm)[b]	0.969	0.909	−0.554	0.910
Depth (cm)[c]	0.927	0.939	−0.611	0.924

[a] Correlation between fish species diversity and substrate diversity = 0.910, $P = 0.009$.
[b] Correlation between flowing width and stream order = 0.974, $P = 0.001$.
[c] Correlation between depth and stream order = 0.947, $P = 0.002$.

ranged from 0.15 for the first order site which dried most frequently, to 1.87 for the widest third order stream.

Stepwise multiple regression was utilized in order to select those stream characteristics which were useful for predicting fish species diversity and abundance. Stream order, percent silt in bottom substrate and frequency of drying were selected for predicting fish species diversity (Table 3). Whereas stream order contributed positively to fish diversity, effects of increasing silt and drying were negative; the model explained 98% of the variation.

Catch per unit effort or abundance increased in relation to stream order and the cube of depth (Table 3). Carrying capacity of a small stream environment is undoubtedly related to the presence of wide and deep pools, which provide cover not available in the fast current of shallow riffles. Abundance of fishes was also related to habitat factors known to influence abundance of aquatic insects, the principal food base for small stream fish communities. In general, the insect fauna of clean stony riffles is richer than that of silty reaches, both in numbers and total biomass (Hynes 1970). Abundance of detritivorous insects such as Plecoptera, Trichoptera, and Ephemetoptera has been correlated with the presence of rubble and gravel sub-

Table 3. Average Fish Species Diversity and Catch Per Unit Effort (CPUE) in Relation to Average Habitat Parameters. Partial Coefficients of Determination (r^2) Are Given Only for those Independent Variables which Contributed Significantly to Prediction of Diversity or CPUE

	Partial r^2		Site					
Variable	Diversity	CPUE	I–A	I–B	II–A	II–B	III–A	III–B
Order	0.95		1	1	2	2	3	3
Flowing width (dm)		0.22	6	7	19	13	33	24
Depth (cm)		0.06[a]	6	2	10	7	11	9
Substrate								
Silt (%)	0.01		13	1	1	4	6	10
Sand (%)		0.09	60	72	40	46	47	41
Gravel (%)			20	24	38	38	40	35
Rubble (%)		0.32	4	1	13	8	4	10
Bedrock (%)		0.26	0	<1	0	1	5	4
Substrate diversity			1.48	1.00	1.73	1.52	1.74	1.93
Frequency of drying (%)	0.02		18	8	0	0	0	0
Fish species diversity[b]			0.15	0.39	1.36	1.45	1.87	1.54
Catch per unit effort (CPUE)[c]			18	8	266	97	105	115

[a] Depth^3

[b] Fish species diversity = 0.661 order − 0.016 frequency dry − 0.023 % silt; $R^2 = 0.98$, $F_{regression} = 274.25$, $P \leq 0.0001$.

[c] CPUE = 6.624 width (dm) + 8.708 % rubble + 0.038 depth^3 (cm) − 0.736 % sand − 32.985 % bedrock; $F_{regression} = 60.64$, $P \leq 0.0001$.

stratum (Sprules 1947). In this study, percent rubble in bottom substrate accounted for 32% of the variation (Table 3). The presence of bedrock and sand had significant negative influences upon fish abundance, explaining 26 and 9% of the variation respectively. These data demonstrate that presence of substratum, which are colonizable by insects and relatively stable, significantly influences the abundance of fishes. In addition to influencing a fish community's food base, larger substratum such as rubble would provide more cover for smaller species and immature forms of fishes.

Fish species diversity in small, relatively undisturbed streams can be predicted accurately with knowledge of only several habitat characteristics: stream order, percentage silt in bottom substrate and frequency of drying. Prediction of fish abundance, on the other hand, requires information on a greater variety of habitat parameters; parameters which are associated with food and cover for fishes.

Models developed and discussed in this paper were not intended for broadscale application, but to serve as conceptual framework for future studies. Studies of this nature offer the potential for identification of critical habitat parameters. Their usefulness could include predicting losses of fish species diversity or changes in abundance resulting from habitat changes.

Literature Cited

Deacon, J. E., and W. G. Bradley. 1972. Ecological distribution of fishes of the Moapa River in Clark Co., Nevada. Trans. Am. Fish. Soc. 101:408–419.

Funk, J. L. 1970. Warm water streams. Pages 141–152 *in* N. G. Benson, ed. A century of fisheries in North America. Spec. Publ. No. 7. Am. Fish. Soc., Wash., D.C.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507–515.

Harrel, R. C., B. J. Davis, and T. C. Dorris. 1967. Stream order and species diversity of fishes in an intermittent Oklahoma stream. Amer. Midland Nat. 78:428–436.

Hellawell, J. 1977. Biological surveillance and water quality monitoring. Pages 69–88 *in* J. S. Alabaster, ed. Biological monitoring of inland fisheries. Proceedings of a symposium of the European Inland Fisheries Advisory Commission—F.A.O., Helsinki, Finland. Applied Sci. Publ. Ltd., London.

Hocutt, C. H., and J. R. Stauffer, Jr. 1980. Biological monitoring of fish. D. C. Heath Co., Lexington, Mass. 416pp.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press. 555pp.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21–27.

Kuehne, R. A. 1962. A classification of streams, illustrated by fish distribution in an eastern Kentucky Creek. Ecology 43:608–614.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman and Co., San Francisco. 522pp.

Reid, G. K. 1961. The ecology of inland waters and estuaries. Reinhold, New York. 375pp.

Shannon, C. E., and W. Weaver. 1949. The mathematical theory of communication. Univ. Ill. Press, Urbana. 117pp.

Sheldon, A. L. 1968. Species diversity and longitudinal succession in stream fishes. Ecology 49:193–198:

Sprules, W. M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. Univ. Toronto Stud. Biol. Ser. 56:1–81.

Tramer, E. J., and P. M. Rogers. 1973. Diversity and longitudinal zonation in fish populations of two streams entering a metropolitan area. Amer. Mid. Nat. 90: 366–374.

Whiteside, B. G., and R. M. McNatt. 1972. Fish species diversity in relation to stream order and physiochemical conditions in the Plum Creek drainage basin. Amer. Mid. Nat. 88:90–101.