Fish Assemblage Characteristics of Acid-Sensitive Streams in the Southern Appalachian Mountains

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Abstract: Relationships between fish abundance and diversity and stream pH and alkalinity were assessed to evaluate potential impacts of acidic precipitation on fish assemblages of southern Appalachian Mountain headwater streams. Data were obtained from first- and third-order reaches of 12 stream systems during spring and fall 1983 and spring 1984. Assemblages exhibited low diversity and typically had low biomass. All streams were slightly acidic (mean pH = 6.62; range 6.25–7.00) and very poorly buffered (mean total alkalinity = 58 μeq/liter; range 16–133), indicating extreme chemical sensitivity to acidification. However, statistically significant relationships between fish biomass or diversity and stream sensitivity were not consistently detected. The absence of such relationships suggests that acidification probably has not had a substantial impact on fish populations in headwater streams of the southern Appalachian Mountains.

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The climate, topography, and geology of the southern Appalachian Mountains interact to make streams in the region sensitive to acidic precipitation (Hendrey et al. 1980, Silsbee and Larson 1981). A recent survey of water chemistry indicated most headwater streams in the Southern Blue Ridge Province were slightly acidic and had extremely low buffering capacity (Winger et al. 1987). The potential for acidification impacts in these systems is further indicated by a decline in the pH of precipitation in the southeast since the 1950s (Likens 1976). Because of species-dependent sensitivity to acidification, fish assemblage characteristics can be useful

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indicators of past stream acidification and may provide information on the potential for future impacts (Haines 1981).

Detection of acidification impacts in the Southern Blue Ridge Province is impaired by the limited amount of historical data on water quality and fish assemblages of headwater streams. In other areas where acidification has occurred, fish assemblage abundance and diversity have been shown to be related to pH and alkalinity (Schofield 1976, Wright and Snekvik 1978, Pfeiffer and Festa 1980). Thus, detection of relationships between stream pH or alkalinity and fish assemblage characteristics in southern Appalachian streams could indicate that acidification has occurred as well as reflect the extent to which these streams might be affected by acidification in the future.

Our study was conducted to determine variability of fish assemblage characteristics in 12 undisturbed headwater stream systems and identify factors that correlate with this variability. Particular emphasis was placed on evaluating relationships between assemblages and chemical sensitivity of the streams to acidification. Consistency of these relationships was assessed by conducting separate evaluations at first- and third-order sample sites during 3 sampling seasons. Results of this study also provide baseline data suitable for monitoring future trends in stream fish assemblages.

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Methods

A sample of 12 streams representing major river drainages and typical headwater stream chemistry in the southern Appalachian Mountains (Fig. 1) was selected for study according to several criteria: (1) third-order sample sites occurred at elevations above 600 m (MSL); (2) no land disturbances existed in the watersheds; (3) no fish stocking had occurred in the 5 years prior to the study; and (4) sites were reasonably accessible to sampling. The streams were a subset of those evaluated in parallel studies of benthic macroinvertebrate communities (Lasier 1986) and water chemistry (Winger et al. 1987). Details of the locations and physical characteristics of the streams were reported by Fowler (1985).

Relationships between fish assemblages and stream sensitivity were evaluated by comparing fish abundance and diversity with stream pH and alkalinity. Effects of other chemical and physical stream characteristics on fish assemblages were also assessed to determine if influences of pH and alkalinity were masked by these factors. Alkalinity, pH, specific conductance, color, and dissolved concentrations of total aluminum, calcium, chloride, iron, magnesium, manganese, nitrate, potassium, sodium, and sulfate were determined (N = 2 replicates) during a 5-day in-

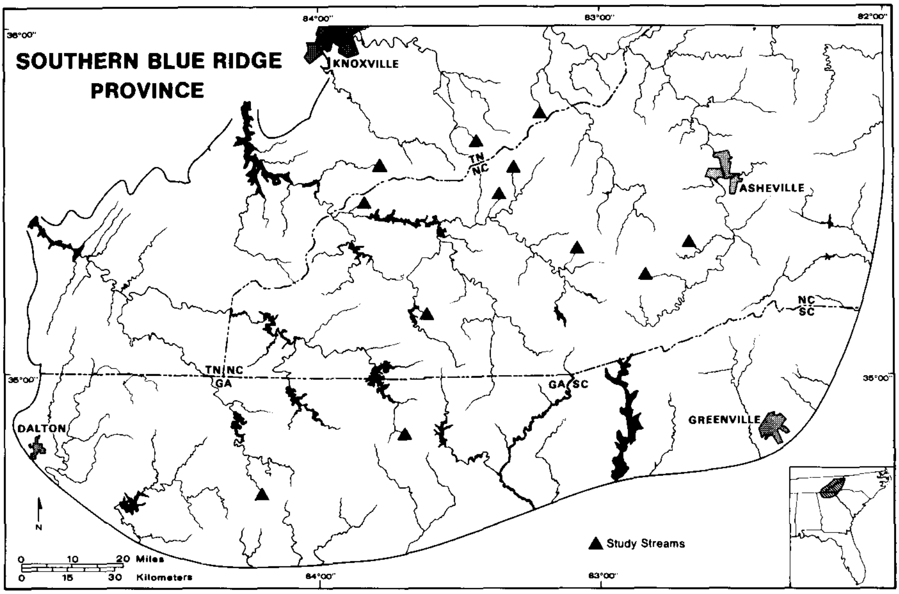

Figure 1. Southern Blue Ridge Province and locations of 12 streams evaluated for acidification impacts on fish.

terval at the end of 3 fish sampling periods (April–June [spring] 1983, August–September [summer] 1983, and April–June [spring] 1984). Water samples were collected during low-flow conditions; standard analytical methods were used as described by Winger et al. (1987). We also measured watershed area, elevation, gradient, discharge, mean width and depth, run/riffle/pool ratio, and substrate composition at each sample site. Data on detrital standing crop and maximum summer temperature were obtained from Lasier (1986).

Fish abundance was estimated by electrofishing 2 100-m zones within each first- and third-order stream and using removal/depletion methods (Zippin 1958) and a maximum likelihood estimator (Carle and Strub 1978). Details of the sampling method and its precision were described by Fowler (1985). Population estimates, mean weights of species collected, and stream measurements were used to calculate fish biomass (kg/ha) and density (number/ha) in each sampling zone.

Several univariate and multivariate techniques were used to describe variability of fish assemblage characteristics among streams and to evaluate relationships with environmental variables. Multivariate techniques are useful for detecting species- or assemblage-level relationships with environmental variables (Felley and Hill 1983, Tonn and Magnuson 1983). Analysis of variance and Duncan's Multiple Range Tests were used to test for differences of fish assemblages, water quality, and physical characteristics among stream systems. Pearson correlation coefficients and stepwise regressions were used to evaluate species associations and define relationships between fish biomass and environmental variables. Cluster analysis (centroid method) was used to determine groups of streams that had similar fish assemblages (SAS Inst. Inc. 1982), and then multivariate analysis of variance was used to determine if environmental variables differed among the groups of streams. Except where otherwise noted, all tests of statistical significance were made at $P = 0.05$. Results of statistical tests were similar whether data were $\log_{10}$-transformed or not; hence, results shown are for untransformed data.

Results

Fish diversity was low at all sites. Four clusters of first-order streams were identified from the species occurrence data: 5 streams that contained only brook trout (*Salvelinus fontinalis*), 4 streams that contained only rainbow trout (*Salmo gairdneri*), 2 streams that contained brook trout and rainbow trout, and 1 stream that contained no fish (Table 1). Species composition was more variable among third-order streams; 10 different species combinations were observed in the 12 streams. Cluster analysis identified 4 sets of third-order streams: 4 streams had relatively diverse assemblages with mottled sculpin (*Cottus bairdi*) present; 4 streams contained rainbow trout and longnose dace (*Rhinichthys cataractae*) (mottled sculpin absent); 3 streams contained rainbow trout (longnose dace and mottled sculpin absent); and 1 stream contained only brook trout.

Estimates of density (number/ha) and biomass (kg/ha) provided equivalent information on variability of fish abundance among streams; hence, only the results for biomass evaluations are reported. Brook trout biomass varied significantly

Table 1. Clusters of streams and species occurrence for first- and third-order sites at 12 streams in the Southern Appalachian Mountains. Abbreviations are BT (brook trout), RBT (rainbow trout), SCU (mottled sculpin), LND (longnose dace), BRT (brown trout), BND (blacknose dace), and CC (creek chub).

First-order		*Third-order*	
Cluster 1		Cluster 1	
Bradley Fork	BT	Moses Creek	BT
Cosby Creek	BT	Cluster 2	
Moses Creek	BT	Anthony Creek	RBT
Roaring Fork	BT	Corbin Creek	BT, RBT, CC
Slate Rock Creek	BT	Jarrett Creek	RBT, BRT
Cluster 2		Cluster 3	
Anthony Creek	RBT	Cooper Creek	RBT, LND
Cooper Creek	RBT	Cosby Creek	BT, RBT, LND
Davidson River	RBT	Roaring Fork	RBT, LND, BND
Jarrett Creek	RBT	Twentymile Creek	RBT, LND
Cluster 3		Cluster 4	
Chester Creek	BT, RBT, SCU	Bradley Fork	BT, RBT, SCU, LND, BRT
Corbin Creek	BT, RBT	Chester Creek	RBT, SCU, LND, BRT
Cluster 4		Davidson River	RBT, SCU, LND, BND
Twentymile Creek	no fish	Slate Rock Creek	BT, RBT, SCU

Table 2. Mean biomass (kg/ha) of fish in first-order streams. In periods when biomass differed significantly among streams (ANOVA, $P < 0.05$), means in a column followed by the same letter were not significantly different.

	Brook trout			Rainbow trout		
Stream	Spring 1983	Summer 1983	Spring 1984	Spring 1983	Summer 1983	Spring 1984
Anthony Creek	—	—	—	16.6 A	23.7	10.3
Bradley Fork	24.6 A	37.9 A	22.3 A	—	—	—
Chester Creek[a]	2.0 CD	2.3 B	1.8 B	5.8 ABC	6.9	3.6
Cooper Creek	—	—	—	4.3 BC	10.1	7.2
Corbin Creek	0.6 D	1.6 B	—	13.1 AB	16.2	6.7
Cosby Creek	11.9 BC	28.3 A	14.7 A	—	—	—
Davidson River	—	—	—	7.2 ABC	23.1	10.8
Jarrett Creek	—	—	—	0.7 C	2.3	—
Moses Creek	9.2 BCD	14.0 AB	20.6 A	—	—	—
Roaring Fork	5.3 BCD	17.3 AB	—	—	—	—
Slate Rock Creek	15.4 AB	36.1 A	23.8 A	—	—	—
Twentymile Creek	—	—	—	—	—	—
Average	5.7	11.4	6.9	4.0	6.8	3.2
Std. Dev.	4.6	10.1	4.8	4.9	10.8	5.6
Prob. >F	<0.01	<0.01	<0.01	<0.05	0.26	0.38
R^2	0.85	0.80	0.89	0.72	0.57	0.52

[a] Also contained mottled sculpin.

among first-order streams during all sampling periods, whereas rainbow trout and total biomass varied significantly during spring 1983 (Table 2). Detection of statistically significant differences in rainbow trout abundance was hampered by its occurrence in only the lower sampling zone of 4 streams, producing high within-stream variability of rainbow trout and total biomass estimates. Total fish abundance tended to be greater in the 5 streams containing only brook trout (average among periods = 19 kg/ha) than in the 6 streams containing rainbow trout (average = 10 kg/ha).

In third-order streams, rainbow trout, brook trout, longnose dace, and mottled sculpin biomass varied significantly during all periods (Table 3). Total biomass also differed significantly among streams, but the variation did not appear to be strongly related to species occurrence. The three clusters of streams that included rainbow trout plus 1 to 4 additional species (third-order clusters 2, 3, and 4 in Table 1) had average total biomass of 27 to 31 kg/ha. The single stream in Cluster 1 contained only brook trout and averaged 14 kg/ha.

Alkalinity measurements (Tables 4, 5) indicated all 12 streams would be highly sensitive to acid deposition using criteria of Hendrey et al. (1980). Alkalinity ranged from 28 to 103 μeq/liter (mean 59) at first-order and 34 to 108 μeq/liter (mean 59) at third-order sites. In first-order streams, pH ranged from 6.45 to 6.95 (mean 6.62), and in third-order streams it ranged from 6.36 to 7.00 (mean 6.66). Alkalinity and pH values were representative of the ranges reported by Winger et

Table 3. Mean biomass (kg/ha) of fish in third-order streams. Means in a column followed by the same letter were not significantly different.

Stream	Brook trout			Rainbow trout			Longnose dace			Mottled sculpin		
	Spring 1983	Summer 1984	Spring 1984	Spring 1983	Summer 1983	Spring 1984	Spring 1983	Summer 1983	Spring 1984	Spring 1983	Summer 1983	Spring 1984
Anthony Creek	—	—	—	38.4 A	35.9 A	56.9 A	—	—	—	—	—	—
Bradley Fork[a]	0.7 C	1.5 B	NS[b]	32.4 AB	33.0 AB	NS	3.1 ABC	4.0 B	NS	3.9 B	7.4 AB	NS
Chester Creek[a]	—	0.2 B	—	6.9 DE	19.8 BCDE	10.2 EF	0.7 BC	—	0.9 BC	1.1 B	6.0 B	2.2 B
Cooper Creek	—	—	—	18.4 CD	26.9 ABC	33.0 BC	5.1 A	3.8 B	8.2 A	—	—	—
Corbin Creek[c]	0.2 C	—	—	17.0 CD	13.4 DE	17.8 DE	—	—	—	—	—	—
Cosby Creek	14.7 A	21.1 A	21.6 A	2.8 E	7.4 E	6.8 FG	3.0 ABC	1.1 B	0.2 C	—	—	—
Davidson River[a, d]	—	—	—	11.7 CDE	20.0 BCDE	11.6 EF	2.1 ABC	8.6 A	2.6 BC	12.1 A	8.8 AB	8.1 A
Jarrett Creek[a]	—	—	—	8.1 DE	13.4 DE	11.6 EF	—	—	—	—	—	—
Moses Creek	6.8 B	8.8 A	24.8 A	—	—	—	—	—	—	—	—	—
Roaring Fork[d]	—	—	—	35.2 AB	26.6 ABCD	39.8 B	4.7 A	3.1 B	1.0 BC	—	—	—
Slate Rock Creek	1.1 C	2.1 B	0.4 B	6.0 DE	19.0 CDE	13.9 EF	—	—	—	10.3 A	10.7 A	8.8 A
Twentymile Creek	—	—	—	23.8 BD	21.2 BCD	26.2 CD	3.8 AB	3.1 B	3.4 B	—	—	—
Average	1.9	2.8	4.2	16.7	19.7	20.7	1.9	2.0	1.5	2.3	2.7	1.7
Std. Dev.	1.1	5.4	2.3	5.7	5.5	4.4	1.3	1.8	1.1	2.8	1.6	1.0
Prob. >F	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
R^2	0.97	0.71	0.97	0.91	0.87	0.96	0.81	0.80	0.90	0.81	0.93	0.95

[a] Also contained brown trout.
[b] NS indicates that no sample was taken.
[c] Also contained creek chub.
[d] Also contained blacknose dace.

Table 4. Mean pH and alkalinity in first-order streams. Means in a column followed by the same letter were not significantly different.

Stream	pH			Alkalinity (μeq/liter)		
	Spring 1983	Summer 1983	Spring 1984	Spring 1983	Summer 1983	Spring 1984
Anthony Creek	6.33 G	6.43 G	6.65 D	16 I	37 G	40 F
Bradley Fork	6.58 CD	6.53 F	6.53 FG	40 D	66 E	73 C
Chester Creek	6.25 H	6.65 D	6.55 F	26 G	72 E	53 E
Cooper Creek	6.65 B	6.55 F	6.75 B	82 A	70 E	58 DE
Corbin Creek	6.45 F	6.95 B	6.50 G	39 DE	80 D	48 EF
Cosby Creek	6.50 EF	6.65 D	6.53 FG	21 H	34 G	28 G
Davidson River	6.53 DE	6.60 E	6.73 BC	30 F	50 F	39 FG
Jarrett Creek	6.60 BC	6.90 C	6.95 A	49 C	108 B	89 B
Moses Creek	6.90 A	7.00 A	6.95 A	64 B	133 A	112 A
Roaring Fork	6.48 EF	6.65 D	6.70 C	35 E	82 D	68 CD
Slate Rock Creek	6.53 DE	6.23 H	6.60 E	35 E	53 F	56 E
Twentymile Creek	6.58 CD	6.63 DE	6.75 B	36 E	93 C	70 C
Average	6.53	6.65	6.68	39	73	61
Std. Dev.	0.03	0.02	0.02	2	3	5
Prob. >F	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
R^2	0.99	0.99	0.99	0.99	0.99	0.98

Table 5. Mean pH and alkalinity in third-order streams. Means in a column followed by the same letter were not significantly different.

Stream	pH			Alkalinity (μeq/liter)		
	Spring 1983	Summer 1983	Spring 1984	Spring 1983	Summer 1983	Spring 1984
Anthony Creek	6.55 CDE	6.73 D	6.75 DE	41 D	78 CDE	52 EF
Bradley Fork	6.30 G	6.30 G	6.75 DE	32 E	48 FG	48 FG
Chester Creek	6.40 FG	6.65 E	6.60 F	22 G	61 EF	43 FG
Cooper Creek	6.63 C	6.60 E	6.75 DE	77 A	73 CDE	55 EF
Corbin Creek	6.50 CDEF	6.95 B	6.60 F	34 E	92 BC	51 EFG
Cosby Creek	6.60 CD	6.40 F	6.60 F	27 FG	37 G	39 G
Davidson River	6.75 B	6.75 D	6.88 B	39 D	69 DEF	60 DE
Jarrett Creek	6.50 CDEF	6.88 C	6.85 BC	48 C	104 B	86 B
Moses Creek	6.90 A	7.15 A	6.95 A	72 B	139 A	112 A
Roaring Fork	6.43 EF	6.75 D	6.85 BC	34 E	89 BCD	74 FG
Slate Rock Creek	6.55 CDE	6.63 E	6.68 E	31 EF	61 EF	45 FG
Twentymile Creek	6.48 DEF	6.83 C	6.78 CD	34 E	79 CDE	68 CD
Average	6.55	6.72	6.75	41	77	61
Std. Dev.	0.05	0.03	0.03	2	9	5
Prob. >F	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
R^2	0.94	0.99	0.96	0.99	0.94	0.97

al. (1987) for 28 Southern Blue Ridge Province headwater streams. Alkalinity and pH varied significantly among streams during each sampling period (Tables 4, 5).

Fish species occurrence appeared to be unaffected by stream pH, alkalinity, and other measured variables. For example, average pH and alkalinity for the group of first-order streams that contained only brook trout (Cluster 1, Table 1) were similar to the averages for streams that contained only rainbow trout (Cluster 2), brook trout and rainbow trout (Cluster 3), and no fish (Cluster 4). All environmental variables were also similar among the 4 clusters of third-order streams.

Neither pH nor alkalinity proved to be statistically significant predictors of fish biomass or density. Correlation coefficients between species abundance and alkalinity or pH were not significant, and alkalinity and pH were not consistently important components of stepwise regression models relating fish abundance to environmental variables. Results were nonsignificant whether all streams or only those where each species occurred were included in the analyses. Some significant relationships were detected between fish abundance and other physical and chemical stream variables, but the relationships usually varied among sample periods and stream orders, providing no consistent basis for understanding factors that regulated biomass.

Discussion

Regardless of whether first- or third-order streams were studied, whether analyses included individual species or all species, or whether single- or multivariable models were utilized in data analysis, no consistent, statistically significant relationships were found among fish assemblage characteristics and pH or alkalinity. The absence of such relationships could be interpreted in several ways, but we believe that the results show that acidification has not significantly impacted fish assemblages in streams of the Southern Blue Ridge Province. In other systems where acidification has been documented or suspected, pH and fish abundance or diversity have typically been positively correlated (Schofield 1976, Wright and Snekvik 1978).

A comparison of results obtained in this study with historical data yields information about trends in fish assemblages of this region. Surveys as far back as 1937 showed brook trout, rainbow trout, brown trout (*Salmo trutta*), longnose dace, blacknose dace (*Rhinichthys atratulus*), and mottled sculpin were the most common species in relatively undisturbed headwater streams at elevations above 600 m (Messer and Ratledge 1962; Richardson et al. 1963; Messer 1965; Lennon and Parker 1960; C. Hubbs unpubl. checklist of fishes, 1937 from Uplands Res. Ctr., Great Smoky Mtn. Natl. Park, Gatlinburg, Tenn.). Hence, the species of fish commonly found in high elevation headwater streams in the southern Appalachian Mountains appear to have remained the same during the past 50 years.

Present baseflow water chemical characteristics are not indicative of acidified conditions previously found to be harmful to fish. Brook trout, rainbow trout, and brown trout appear to tolerate pH levels as low as 5.5 under natural conditions (Schofield 1976, Grande et al. 1978, Wright and Snekvik 1978) and few North American freshwater fishes respond to chronically low pH until values decline below 6.0 (Haines 1981). Total dissolved aluminum concentrations of the study streams (Winger et al. 1987) were typically well below levels reportedly toxic to fish when pH is above 6.0 (Haines 1981).

Although baseflow pH and alkalinity did not appear to influence fish assemblage characteristics in headwater streams of this region, it is possible that acute pH depressions following storm events may be important now or could become important if acidification continues. Data describing storm-flow chemistry in 5 of the streams we studied showed pH depressions of 0.11 to 0.59 units within 24 hours (P. Frey, unpubl. data, U.S. Environ. Protection Agency, Athens, Ga.; H. Olem, unpubl. data, Water Resour. Div., Tenn. Valley Authority, Chattanooga). Too few data on storm chemistry were available to assess relationships with fish assemblages, but repeated pH depressions during periods of frequent rain, as typically occurs in winter and early spring, could be harmful to sensitive early life stages of fish.

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