SNP:FISH
Shenandoah National Park: Fish In Sensitive Habitats
Project Final Report, Volume I

A.J. Bulger B.J. Cosby C.A. Dolloff
K.N. Eshleman J.R. Webb J.N. Galloway

Abstract

Surface waters in the Southern Appalachian mountains support a high diversity of fish species. Yet the Southern Appalachian Assessment concluded that 70% of sampled locations show moderate to severe fish community and/or habitat degradation, one cause of which is acidic deposition. The mid-Atlantic Highlands has one of the highest rates of acidic deposition in the US, and our research in forested headwater catchments in western Virginia has demonstrated that both chronic and episodic acidification occur in streams in the region. Our studies have also shown that changes in water quality accompanying acidification are related to observable biogeochemical characteristics of the landscape. The susceptibility of streams to acidification is largely geologically determined and empirical relationships can be used to classify sensitive landscape types. Rates of acidification are moderated by forest and soil biogeochemical processes and can be projected using the process-based MAGIC model. The effects of stream acidification on fish are documented in this report for the first time for streams in the Shenandoah National Park (SNP), VA. These effects can be observed at different ecosystem levels and can be quantified using regression models:

1) community-level effects (reduced species richness in streams);
2) population-level effects (increased mortality of brook trout, *Salvelinus fontinalis*); and
3) effects on single organisms (reduced condition factor of individuals).

Based on these results, we can now link water-quality changes to adverse effects (both lethal and sub-lethal) on fish in SNP streams. These linkages provide a unique resource with which we can construct conceptual and mathematical models that have both scientific and management utility; models that can aid our understanding of the complex interactions in the stream ecosystems and can quantify expected responses. The results of this study (and the computer model linking the chain of effects) provide the capability for park managers to incorporate acidification effects on fish as one component in any integrated analyses of the past, current, and future responses to acidic deposition of aquatic resources in the park.

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Dept. of Environmental Sciences
Clark Hall, University of Virginia
Charlottesville, VA 22903

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Prepared by Keith N. Eshleman
University of Maryland, Center for Environmental Sciences
Appalachian Laboratory
Frostburg, MD 21532

Kenneth E. Hyer
Department of Environmental Sciences
Clark Hall, University of Virginia
Charlottesville, VA 22903

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Dept. of Environmental Sciences
Clark Hall, University of Virginia
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Dept. of Environmental Sciences
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Dept. of Environmental Sciences
Clark Hall, University of Virginia
Charlottesville, VA 22903

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Prepared by T. Dennis and A.J. Bulger
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Clark Hall, University of Virginia
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Prepared by B.J. Cosby
Dept. of Environmental Sciences
Clark Hall, University of Virginia
Charlottesville, VA 22903

Executive Summary

Prepared by
Arthur J. Bulger[1] and C. Andrew Dolloff[2]

[1]Department of Environmental Sciences
University of Virginia
Charlottesville, Virginia 22903

[2]Department of Fisheries and Wildlife
Virginia Polytechnic and State University
Blacksburg, Virginia 24061

Objectives

The objectives of SNP:FISH (Shenandoah National Park: Fish in Sensitive Habitats) were:

1) to describe the water chemistry, physical habitat, and fish communities in selected streams in the Shenandoah National Park (SNP) in Virginia;
2) to determine if and how fish communities in these streams are influenced by stream acidification; and
3) to use current physical, chemical, and biological data to predict future trends in acidification and effects on stream biota.

Narrative Summary of Findings

The SNP:FISH project was designed to account for both temporal and spatial variation in water chemistry and flow, habitat structure, and fish community response. Three streams of varying sensitivity to acidification (as measured by acid neutralizing capacity - ANC) were selected for intensive study over a three-year period. The streams and their respective ANC classes are: Paine Run, low ANC; Staunton River, medium ANC; and Piney River, high ANC. These streams drain catchments underlain by three common bedrock types in SNP (each underlying about one-third of SNP catchments):

siliciclastic, granitic, and basaltic bedrock, respectively, for Paine Run, Staunton River, and Piney River (Figure E-1, Table E-1). Five additional streams - three having low and two having medium ANC - also were sampled but at lower frequency than the three primary basins.

Table E-1. Mean values for selected water chemistry parameters from the three SNP:FISH intensive streams for the three years of the project. Means are presented (with standard deviations in parentheses) that are based on approximately 150 weekly samples for each stream. Episodic chemistry samples are not included.

	pH	**ANC μeq/L**	**Calcium μeq/L**
Paine Run	5.8 (.25)	5.9 (5.01)	31.3 (4.1)
Staunton River	6.7 (.24)	81.8 (18.5)	66.4 (6.0)
Piney River	7.1 (.16)	217.0 (67.8)	142.2 (19.0)

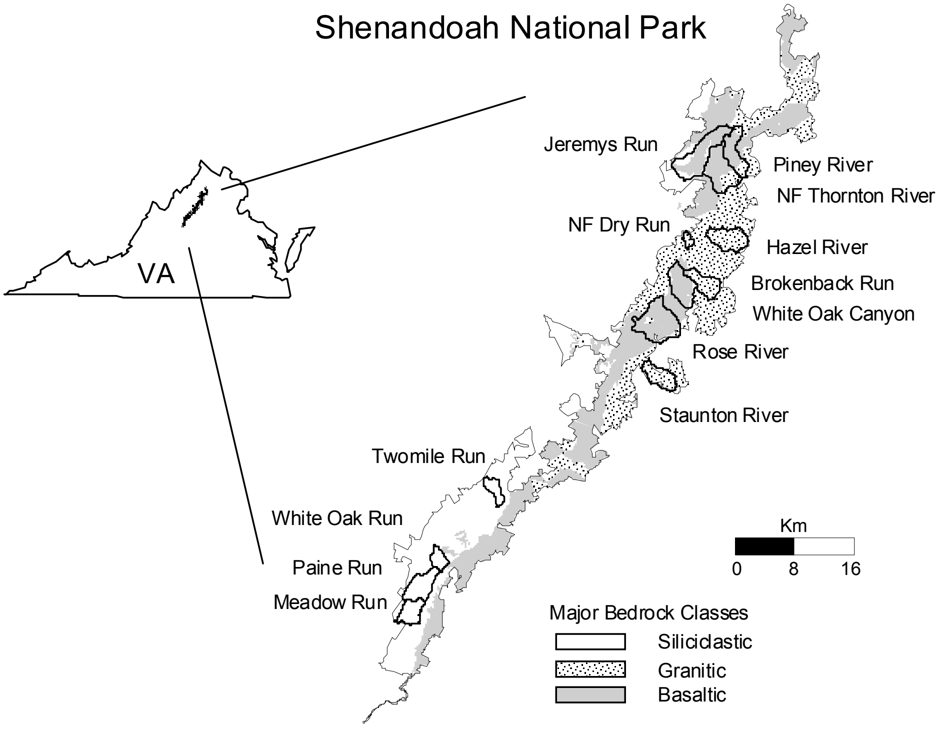


Figure E-1. Map showing streams (catchments outlined) covered in the report, and distribution of major bedrock classes in the Shenandoah national Park. Piney River (north district, high ANC), Staunton River (central district, intermediate ANC), and Paine Run (south district, low ANC) were intensively studied.

Water flow (stream discharge) was monitoring continuously, and water chemistry was monitored weekly, episodically (associated with storm events), and synoptically (twice annually at multiple sites upstream from the main sampling stations) for the three year duration of the study. Fish habitats and fish communities were inventoried using the basinwide visual estimation technique; fish populations were inventoried each spring and fall in each of the three intensively studied basins. In situ fish bioassays (trout eggs and fry; adult blacknose dace) were performed in all three basins. Fish populations, habitat, and water chemistry also were sampled but at a lower frequency in the five additional basins. These two study designs allowed comparisons both within (3-basin intensive) and among (5-basin extensive) catchments.

Compared to the Adirondack Mountains or southern Norway, where hundreds of fish populations were lost by the 1980s, SNP streams are in the early stages of stream acidification, due in part to regionally thicker soils and their sulfate retention capacity. If present levels of acid deposition persist, it is likely that the negative biological effects of acidification demonstrated by this project will worsen.

Acidification effects result from interactions of atmospheric, geological, hydrological, chemical, and biological processes. Atmospheric processes deliver acidifying pollutants (sulfur, nitrogen oxides and ammonia) throughout SNP. In catchments underlain by relatively soft bedrock such as basalt, weathering rates produce sufficient acid neutralizing capacity (ANC) in streams such that stream acidity values remain above pH 7 (acid-neutral), and no negative biological effects result under baseflow or stormflow conditions. But in catchments where siliciclastic bedrock predominates and weathering rates are low, stream ANC values are typically low or even negative, and pH values as low as 5.0 are common. Fish in these unbuffered streams suffer the effects of both chronic and episodic acidification. In extreme situations, most if not all of a year-class may be lost if an acid-episode occurs when the fish are particularly vulnerable, such as during the egg and fry life stages.

The amount of buffering is therefore critical to the long-term viability of fish populations. Buffering is a function of the type of bedrock and the acidity of rainfall. During storm events, water in streams consists of a mixture of pre-event or "old" water (ranging from poorly to well buffered) and unbuffered rain or "new" water. Simultaneous measurements of stream discharge and episode chemistry made in this project confirm that variations in flow regime were responsible for short term variations in stream water chemistry. In SNP, even episode discharge is often dominated by pre-event water, which has been buffered by weathered minerals. So episodes, while still lethal to fish, may be less intense chemically (minimum pH reached) compared to glaciated areas further north, such as the Adirondack Mountains, with thinner soils.

The thicker soils of SNP also retain larger amounts of atmospheric sulfate, producing a temporal delay in regional acidification of streams. However, the soils' ability to retain sulfate is finite, and once saturated, all sulfate inputs will contribute to episodic acidification, perhaps intensifying SNP acid episodes. Base flow ANC values are also expected to decline. Local soils are approximately 70% saturated with sulfate now.

Except in extreme situations, differences in fish communities in acid-sensitive versus acid-insensitive watersheds cannot automatically be attributed to water chemistry alone. Information on habitat is necessary to characterize the potential to support fish communities. As confirmed by detailed analysis of basinwide habitat data, habitat quality was similar across all three intensively studied streams. With a few important exceptions, the ANC of stream water decreased with increasing distance upstream. Thus, the weekly and episodic chemistry data collected at the Park boundary provide conservative estimates of acidification of the waters within SNP.

Low-pH water interacts with the living and non-living elements of the catchment in two critically important ways (Figure E-2). First, low pH can directly influence fish mortality by disrupting ion regulation. Second, low pH mobilizes aluminum which, although essentially non- toxic at high pH,

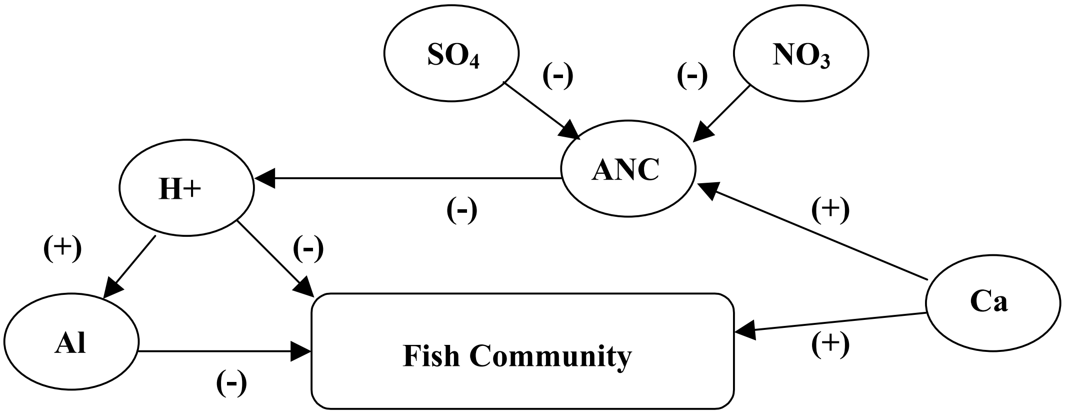


Figure E-2. Conceptual model of direct and indirect acidification effects on fish communities. As any variable increases in magnitude, it produces the indicated effect (positive or negative) on the receptor. Acidic pollutants (SO4 and NO3) lower ANC, resulting in an increase in hydrogen ion (H+) concentration (= increase acidity = lower pH) with direct toxic effects on fish. Increased H+ mobilizes aluminum (directly toxic to fish) from soils. Calcium directly counters aluminum and acid toxicity, and it elevates ANC.

is highly toxic to fish under acidic conditions. Fish in streams that drain poorly buffered soils that are high in aluminum are therefore particularly vulnerable to any increase in acidification.

Stream water calcium, which is mostly derived from mineral weathering, also interacts with the biotic and abiotic elements of the catchment in important ways. Calcium directly counters the effects of both low pH and aluminum and contributes to ANC. The physiological effects of calcium are so potent over the range of 0-150 μeq/L (within the observed range of calcium in the intensive streams) that small increases in the concentration of dissolved calcium produce dramatic increases in fish survival. At concentrations above 150 μeq/L, the effects on fish survival are less pronounced following additional increases in calcium.

Specific Findings

Mortality of brook trout eggs and fry.

During the six 1-3 month-long brook trout bioassays in each intensive stream, mortality was observed from three sources in one or more streams: drought and fungal infection (one bioassay), flood and sedimentation (three bioassays), and acidification (three bioassays). Predation on eggs, a potential source of mortality, was prevented by the bioassay design. The bioassays used large sample sizes, 1000-2000 individuals per stream per bioassay, placed into artificial gravel nests, mimicking natural gravel trout nests, which could be withdrawn at intervals without disturbing all the nests, minimizing handling stress.

Drought.

Low stream flow was the ultimate source of mortality in the fall, 1993, bioassay. Mortality in was uniformly high in all streams within seven days after placement, due to fungal infection (probably Saprolegnia), secondary to very dry conditions. This is a common source of trout egg and fry mortality when low flow prevents adequate flushing of gravel nests.

Flood.

High flow was the source of mortality in the spring, 1995, bioassay. It was begun on 1/13/95; a massive hydrologic event occurred in all three streams two days later. It was clear from inspection after the event that the artificial gravel nests, the cages that contained them, and even the protective devices, had been agitated substantially during the flood, especially at Paine and Piney. The artificial nests had also trapped much sediment, interfering with the flow of fresh water after the flood. Steep declines in survivorship, similar at all three sites, are probably best attributed to mechanical damage plus suffocation (due to sediment in the nests) resulting from flood conditions. Flood is also regarded as a common natural source of mortality for young trout still in nests.

Acid stress.

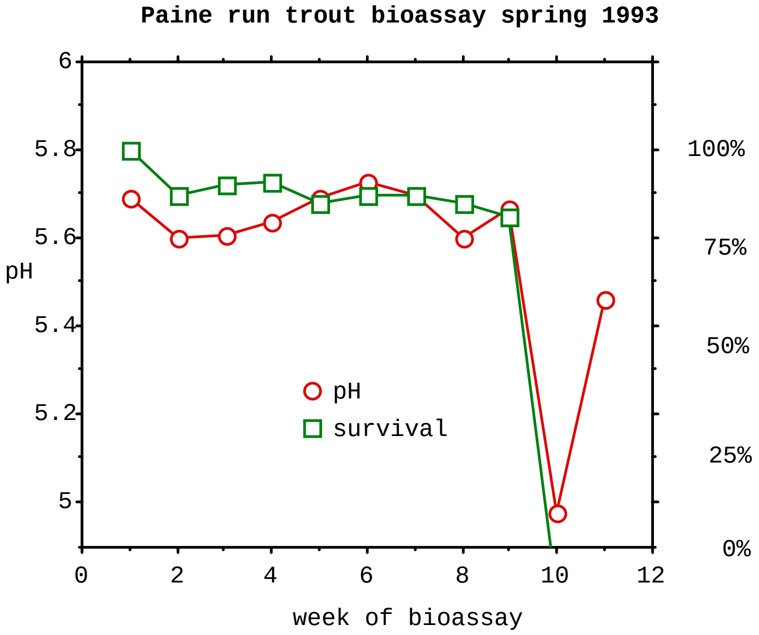
Differential mortality of trout occurred among the study streams during four of the six bioassays (fall 1992, spring 1993, spring 1994, and fall 1994). In each of these four, trout in Piney River (high-ANC) showed higher survival rates than trout in Paine Run (low-ANC). The most likely source of differential mortality in two bioassays is episodic acidification, and chronic acidification plus sedimentation in the other two bioassays. Compare the pH ranges during the two example bioassays in Figure E-3: pH remained between 5.8 and 5.6 for most of the first bioassay, followed by a sharp drop. In the second bioassay, there were no sharp drops, but pH was nearly always below 5.6. The mortality in these bioassays can be considered as acute or episodic in the first case, and chronic in the second.

Acute Acid Stress.

The spring, 1993, bioassay at Pine Run typifies acute acidification mortality (Figure E-3). The spring was fairly dry until large hydrological events occurred in all three streams, killing all remaining fry at the low-ANC stream, Paine Run, where survivorship declined sharply from 80% to 0%, coincident with the sharp drop in pH (and peak in toxic aluminum concentration, Chapter 6A). This indicates that pre-event baseflow, maintained by groundwater, was not toxic, while acidic storm flow was toxic. Trout survivorship remained high at Piney River during this bioassay, despite increased storm flow, no doubt due to the greater ANC at Piney River, which prevented the pH from dropping lower than 6.6; toxic aluminum concentrations there were below detection limits.

Chronic Acid Stress.

The spring, 1994, bioassay at Paine Run illustrates chronic acidification mortality (Figure E-3). Survivorship in Paine Run showed a steady decline and was significantly lower than that at Piney River. Four moderate hydrological events at Paine Run kept the pH between 5.6 and 5.3 for most of bioassay, with no sharp pH drops. pH increased after most of the fish had died. Mortality here may best be attributed to accumulated stress associated with acidification of streamwater.



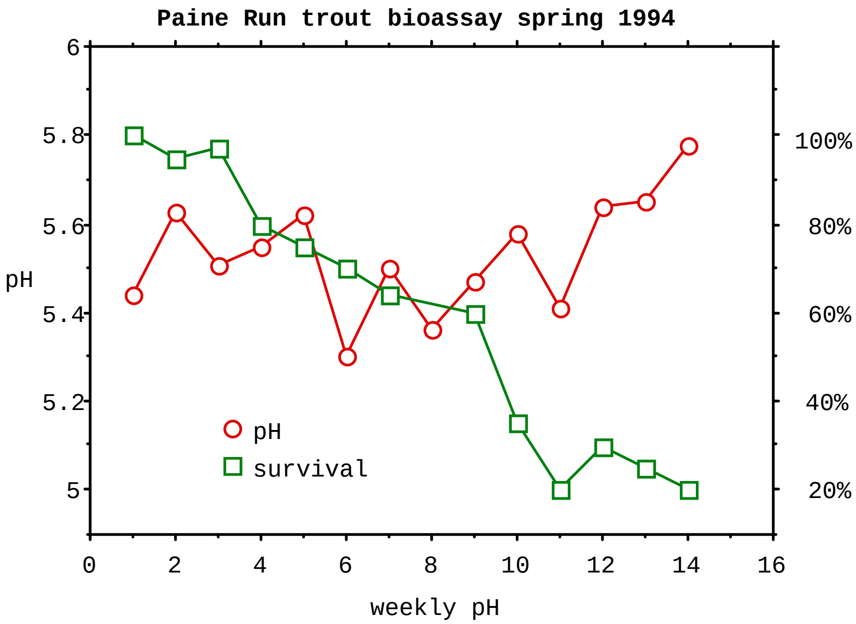


Figure E-3. Two bioassays illustrating mortality due to acute acid stress (top) and chronic acid stress (bottom). Note that in the upper example, pH stays above 5.6 until a sharp drop occurs, associated with sudden mortality, while in the lower example pH stays between 5.6 and 5.3, with no sharp drop, associated with gradual mortality. Survival is estimated by periodic removal without replacement of pairs of artificial nests from a large sample of nests, to avoid disturbing all the nests, which can cause stress. Apparent increases in survival over time are due to differences in survival among nests removed in adjacent weeks.

Chronic effects on brook trout.

Several other measures of the overall health of fish populations are derived from the fish community surveys described in Chapter 5. These integrate effects over longer time periods than the episodic responses of trout early life stages described above. Among the three intensive streams, the contrasts between brook trout in Paine Run (low ANC) versus Piney River (high-ANC) are the clearest. Paine Run trout show a combination of poor condition of individual fish, lower mean weight, lower population density and lower rate of annual production versus trout in Piney River. This suggests that poor water quality may limit trout growth in Paine Run. Since density of trout was always lower in Paine versus Piney, it does not appear that competition limits trout growth in Paine Run, and no combination of habitat characteristics appears to explain the differences.

Chronic effects on blacknose dace.

Among the three intensive streams, blacknose dace in Paine Run (low ANC) had significantly lower condition factor and mean weight, versus Piney River (high ANC) and Staunton River (mid-ANC) blacknose dace, which were similar to each other. Further, there was a very strong relationship across multiple streams in dace condition factor, which was incorporated into the predictive models in Chapter 7.

Chemical and biotic effects on blacknose dace density across an ANC gradient.

Figure E-4 shows the density of dace populations in the eight streams (three intensive and five extensive streams) plotted versus baseflow ANC, and indicates the other species present in each stream. Blacknose dace are more sensitive to acidification than brook trout; however, it is likely that blacknose dace are more tolerant to acidification than many other fish species which are absent from low-pH streams where blacknose dace are still present. Blacknose dace densities peak in the lower half of the ANC range, in the absence of both potential competitors (other members of the cyprinid family: rosyside dace, longnose dace, river chub) and in the absence of predatory American eel. It may be that dace are limited by acid water chemistry on the one hand, and biotic (competition and/or predation) factors on the other. The blacknose dace population in Meadow Run, the lowest ANC- steam of those studied, declined since the study began and is now regarded as extirpated from that stream.

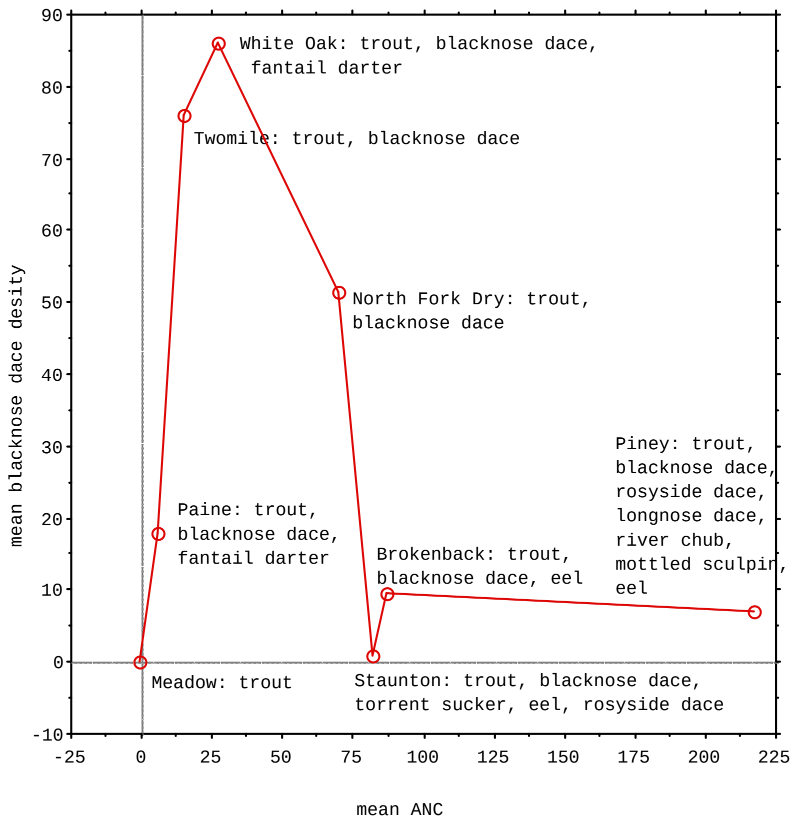


Figure E-4. Blacknose dace density (number of individuals per 100 m^2 of habitat) in the FISH project's three intensive and five extensive streams, versus mean ANC. Other fish species present in each stream are shown after the stream name on the graph.

Acid sensitivity of blacknose dace versus brook trout.

The differences between these two species is less clear-cut than often depicted. Brook trout adults are more tolerant of acidification effects than blacknose dace adults; in both species the young are regarded as more sensitive than adults. Yet this study has shown that brook trout young are more sensitive than blacknose dace adults: during the fall 1994 bioassay in Paine Run, significant mortality occurred among brook trout fry, while, simultaneously, blacknose dace maintained in cages nearby showed 100% survival.

Blacknose dace spawn in the summer, when ANC often peaks in SNP, so eggs and very young fry are not present in spring and fall when acid episodes are worst. Thus, in the early stages of regional acidification, when through reproductive timing, blacknose dace young are isolated from the worst acid events and survive, there may already be negative effects on brook trout young; thus, the presence of the more sensitive species (blacknose dace) does not necessarily mean that the more tolerant species (brook trout) is still unaffected. Furthermore, the blacknose dace is often represented as an acid-sensitive species; the relationships in Figure E-4 suggest that in fact blacknose dace is one of the more acid-tolerant species SNP, since they are present in low-ANC streams where other fish species are absent.

Rapid hydrochemical and biological responses in episodes.

The last figures in this section (Figures E-5 and E-6) illustrate the rapid responses to hydrologic episodes. In the absence of high-frequency sampling, it would be difficult to interpret the sudden mortality of brook trout during the bioassay. In Figure E-5, note the rapid response of toxic aluminum to discharge, and that the episode signals (discharge and aluminum peaks) last only about two days. In Figure E-6, note that the ANC troughs lag only very slightly behind the discharge peaks.

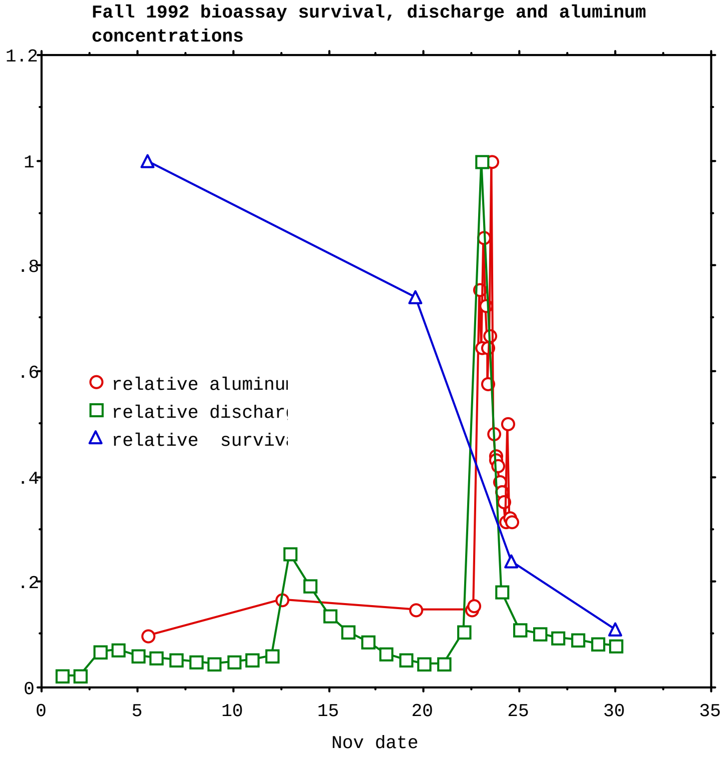


Figure E-5. Fall, 1992 bioassay trout survival, discharge and aluminum concentrations. Since the variables have very different ranges, values for each are shown as relative to the maximum value for each variable. Note the rapid response of both toxic aluminum concentrations and mortality to discharge.

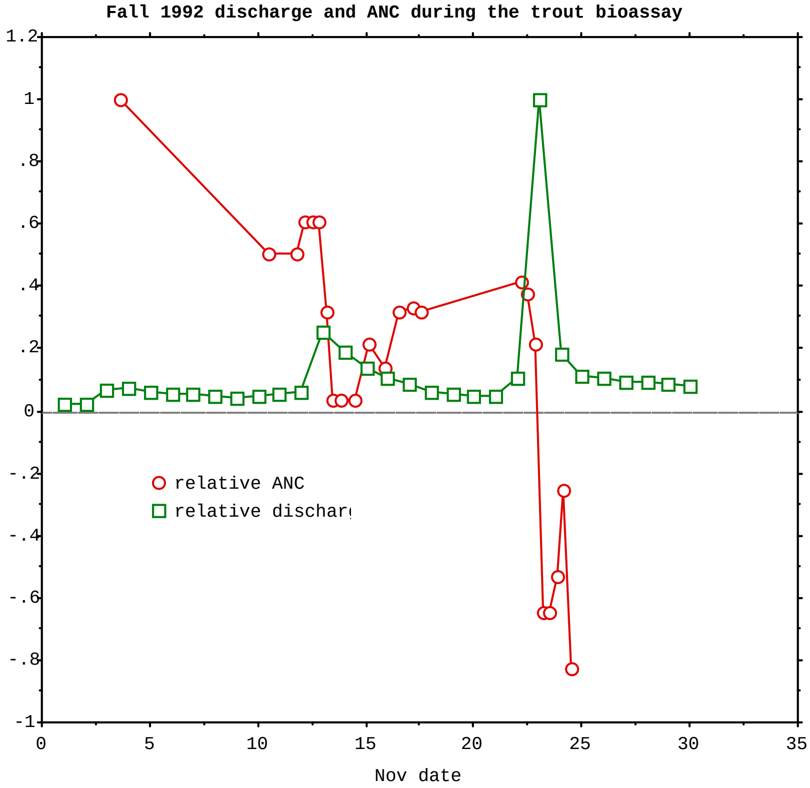


Figure E-6. Fall, 1992 discharge and ANC during the trout bioassay in Paine Run. Since the variables have very different ranges, values for each are shown as relative to the maximum value for each variable. Note that ANC troughs lag slightly behind discharge peaks.

Differences in fish species richness.

Fish species differ in their tolerance to acid conditions. Acidification has been shown to reduce fish species richness (defined simply as the number of species in a defined area) by eliminating sensitive species from fish communities.

Since SNP contains streams with low ANC, and receives substantial acid deposition, the fish species richness of at least some of its streams may have been lowered by acidification. However, the fish community records of SNP streams are too recent (begun in the 1980s) to demonstrate loss of species from streams. There is, nevertheless, a very strong relationship between the number of fish species present in streams now and their acid-base status, such that streams with low ANC host fewer species (Figure E-7). This relationship suggests, that if stream ANC is lowered in SNP, species will disappear from SNP streams. The first recorded is the blacknose dace population in Meadow Run (Figure E-4).

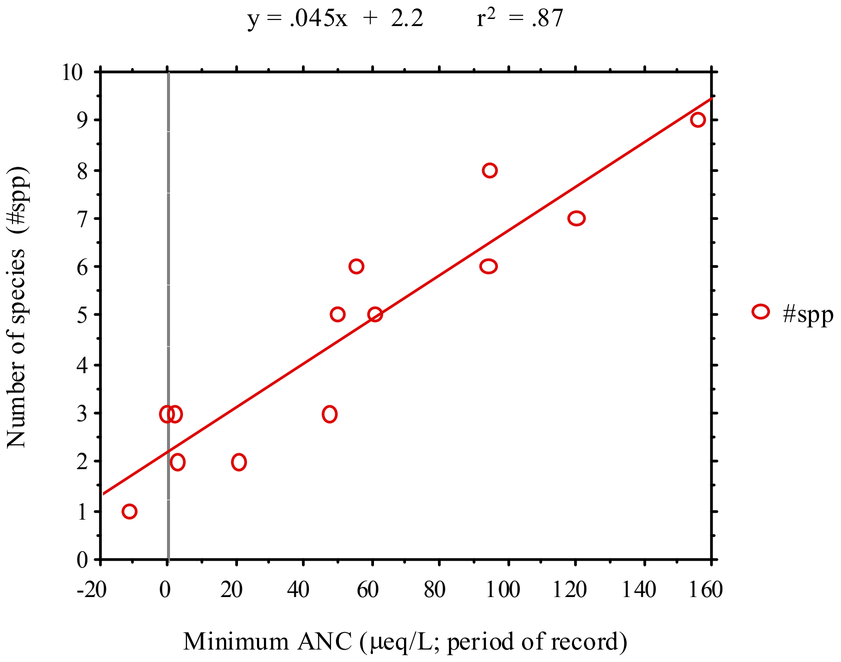


Figure E-7. Relationship between number of fish species (#spp) and Minimum ANC recorded in SNP streams; data derived from SNP Fisheries Management Plan (FMP) and the FISH project.

This last result, the strong dependence of fish species richness on the acid-base status of stream water, may be the most important finding of the SNP:FISH project. Fish diversity in the Southern Appalachians is high. Of the approximately 950 species of freshwater fish in North America, about 485 species are found in the Southeast. The total numbers of freshwater fish species per state in the region range from 107 in Maryland, to 307 in Tennessee. That species richness in SNP approaches zero as minimum stream ANC become slightly negative is cause for grave concern within the park. If this result holds for the rest of the southern Appalachian region as well, the potential (or currently realized) loss of biodiversity in fish communities due to acidification may be significant.