THE "SHENANDOAH NATIONAL PARK: FISH IN SENSITIVE HABITATS" (SNP: FISH) PROJECT. AN INTEGRATED ASSESSMENT OF FISH COMMUNITY RESPONSES TO STREAM ACIDIFICATION.

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Abstract. The "Shenandoah National Park: Fish in Sensitive Habitats" (SNP:FISH) project is a response to declining pH and acid neutralizing capacity in Shenandoah National Park (SNP) streams. SNP receives more atmospheric sulfate than any other USA national park, and pH had decreased to the point where early negative effects on fish were expected. SNP provides the opportunity to study the early stages of acidification effects on fish. Three different classes of geological formations yield streams with low-ANC (0 μEq/L), intermediate-ANC (60-100 μEq/L) or high-ANC (150-200 μEq/L) waters in SNP. This allows a comparison of responses across a water quality gradient in a small geographic area receiving similar deposition. Both chronic and episodic acidification occur in SNP streams. Biological effects are apparent in fish species richness, population density, condition factor, age, size, and bioassay survival. A primary project objective was to provide the necessary data for development and testing models for forecasting changes in fish communities resulting from changes in stream chemistry. Monitored variables include several which are predictive of acidification effects on SNP fish communities.

Keywords: acidification, Virginia, fish response

1. Introduction

Diverse bedrock geology in Shenandoah National Park, Virginia, USA (SNP), yields surface waters (~50 streams) ranging in acid neutralizing capacity (ANC) at baseflow from 0- 200 μEq/L. SNP receives more sulfate deposition than any other USA national park (~25 kg/ha/yr in wet deposition; NADP, 1986-91) and provides the opportunity to observe the early stages of acidification effects across a gradient in stream sensitivity in a relatively small geographic area.

SNP hosts 27 fish species; 46 streams host 1-13 species; over half the streams host 1-3 species. A few streams host only brook trout *(Salvelinus fontinalis)*. The brook trout fishery is one of SNP's most valuable resources, and the only harvestable resource.

The "Shenandoah National Park: Fish in Sensitive Habitats" (SNP: FISH) project was initiated in 1992 as a response to a significant decline in pH and ANC in SNP streams since 1979 (Webb et al. 1989); early negative effects on fish populations can now be expected. Fish populations typically decline during acidification because increased acid and aluminum levels interfere with ion regulation (Rosseland et al., 1990; Bulger et al., 1993). The USA National Park Service is required by law to "preserve unimpaired" the resources in national parks, so the study was motivated by the desire to determine if negative effects on SNP fish populations have occurred, and to provide the scientific

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basis for a monitoring system in SNP. The same information will be used to develop models to predict effects on SNP fish populations under various acidification scenarios.

2. Study Design and Study Streams

Representation of SNP stream characteristics was obtained through a nested approach of data collection at differing levels of detail within the three bedrock-ANC classes. The primary objective of the streamwater data collection program was to relate the geochemical environment to observations of fish community characteristics. The location of the streams for which data were collected for the FISH project are identified in Figure 1.

2.1. TEMPORAL VARIATION

The SNP: FISH project was designed to collect information on temporal variation in stream chemistry and fish responses by studying 3 streams intensively (continuous stream stage recording; hydrograph separation and rating curves; weekly grab samples for water chemistry, plus stage-activated automated samplers for episodic water chemistry samples; complete habitat surveys and multiple fish community surveys; and bioassays for chronic and episodic lethal and sublethal effects on fish). Each of these *"intensive sites"* was located in one of the three major classes of geological formations in SNP. Silici-clastic formations yield streams with low-ANC (0 μEq/L), granitic bedrock yields intermediate-ANC (60-100 μEq/L) streamwaters, and basaltic bedrock yields relatively high-ANC (150-200 μEq/L) waters in SNP. The three streams were, in order of increasing baseflow ANC, Paine Run, Staunton River and Piney River. The area of the three catchments ranged from 10.5 to 12.4 km^2. The criteria for the selection of the three "intensive sites" included the presence of at least two species of fish common to all three streams to allow fish population comparisons; these two species were brook trout, which is relatively acid-tolerant (at least in the adult stage), and blacknose dace *(Rhinichthys atratulus)*, which is regarded as acid-sensitive. Other criteria included a) the presence of appropriate fish habitat (Newman and Dolloff, 1996a) to minimize habitat as a source of variation among the streams; and b) the presence of natural controls on stream channels so that gaging and rating curves could be developed to estimate discharge without weirs in this natural area.

2.2. SPATIAL VARIATION

To incorporate spatial variation in addition to temporal variation, 5 additional sites were established to gather more extensive information on stream chemistry and fish communities in SNP. These *"extensive sites"* were sampled either quarterly (2 streams) or weekly (3 streams) for water chemistry, and had one habitat survey and one fish community survey performed. Three "extensive sites" were in the low-ANC category, and 2 were in the intermediate-ANC category. There was no additional "extensive site" in the highest ANC category. Although the distribution of the "extensive sites" resulted in an unbalanced design with respect to representation of ANC categories, it was decided that, given limited resources, the benefit of placing more sites in the most responsive category outweighed any disadvantage resulting from the unbalanced design. These "extensive streams" also were characterized by at least one spatially intensive synoptic sampling survey (water samples were taken at 25-40 sites in each stream).

2.3. PREVIOUS WATER CHEMISTRY RECORDS IN *SNP* AND SCOPE OF THE *SNP:FISH* PROJECT

Water chemistry from 7 additional streams (sampled either quarterly or weekly) was available to the SNP:FISH project from the Shenandoah Watershed Study (SWAS) operating since 1979; SWAS also previously collected water chemistry data on the 8 streams in the SNP:FISH project; thus, water chemistry from 15 SNP streams was available, some with 16 years of weekly or quarterly chemistry data; as part of the SNP:FISH project, 8 of these now have had complete habitat and fish community surveys; 3 of the 8 have had *in situ* bioassays, continuous discharge records, and weekly plus episodic water chemistry data.

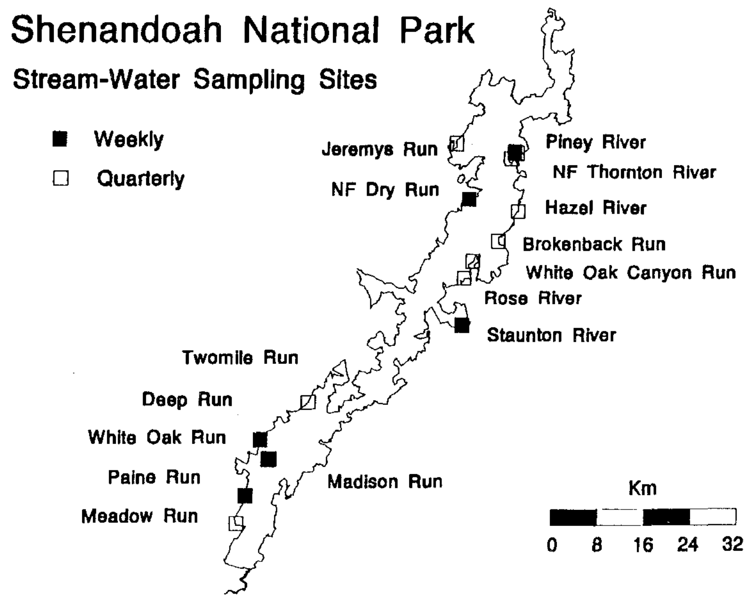

Figure 1. The location of quarterly and weekly stream-water sampling sites in Shenandoah National Park, Virginia.

2.4. CHEMISTRY AND HYDROLOGY METHODS

The sampling and analysis methods for the weekly, quarterly, and synoptic stream-water sampling during the FISH project conform to the methods described for the SWAS program by Ryan et al., (1989). The analysis included electrometric determination of pH, determination of ANC by two-point gran titration, base cations by atomic adsorption spectrophotometry, anions by ion chromatography, and silica by colorimetric determination. Stormflow samples were collected by ISCO automatic collectors; stormflow samples were also analyzed for monomeric aluminum by colorimetry. Hydrological methods are described in Eshleman (1988), and Eshleman et al., (1995, 1996).

2.5. HABITAT STRUCTURE, BIOASSAY, AND FISH COMMUNITY SURVEYS.

Habitat structure and fish community surveys were performed using the basinwide estimate techniques of Hankin and Reeves (Newman and Dolloff, 1996a). The bioassay methods are described in MacAvoy and Bulger (1996).

2.6. MODELING

A primary objective of the project is to provide the necessary data for development and testing methods for forecasting changes in fish status expected from changes in stream chemistry. We have coupled a long-term, geochemical model which predicts base-flow stream chemistry (MAGIC, Cosby et al., 1985) with a pair of short-term episodic chemical response models in order to produce predicted stream chemistries under a variety of flow conditions. The two episode models are: 1) an empirical regression model predicting minimum storm event streamwater ANC from antecedent streamwater ANC, and 2) a two-component mixing model (Eshleman et al. 1995) which calculates stream chemistry for a given mixing ratio of projected baseflow stream and precipitation chemistry. The simulated chemistry generated by the coupled models is, in turn, used as input to a number of empirical fish response models that relate water chemistry to fish responses (e.g., condition factor, species richness, acute survival during episodes).

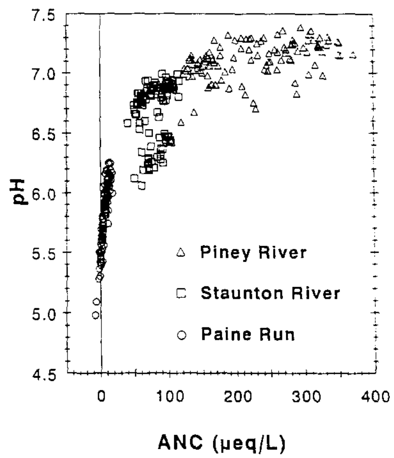

Figure 2. Stream-water pH-ANC relationship for FISH study catchments associated with basaltic (Piney R.), granitic (Staunton R.), and siliciclastic (Paine R.) bedrock classes. The plotted points represent weekly samples collected from 1992 to 1994. All points below ANC = 30 come from Paine R.

3. Results and Discussion

Major findings of the SNP:FISH project are summarized here. Detailed results and methods are described in several reports in this volume, and are cited below. Figure 2 shows the pH-ANC relationship for the three intensive study streams. The differing sensitivity among these streams and bedrock classes is indicated by the differences in ANC and pH, and by the differing slope in pH *versus* ANC change among the streams.

1. Trout embryo survivorship is significantly affected by water chemistry in SNP. A total of 6 season-long *in situ* bioassays involving 20,000 hatchery-stock brook trout eyed-eggs will be completed in the study. In 3 of 4 bioassays so far analyzed, survivorship was significantly greater in the high-ANC *versus* the low-ANC stream; episodic mortality occurred in two bioassays, and chronic mortality in one. (Drought resulted in poor survivorship in all 3 streams in one bioassay). Survivorship was variable in the intermediate-ANC stream (MacAvoy and Bulger, 1996).

2. Trout population structure is affected by water chemistry in SNP. Among the three intensively studied streams, the trout population in the low-ANC stream is dominated by older, larger individuals; only in this low-ANC stream is there a missing year-class (1992). (Newman and Dolloff, 1996a).

3. Annual production and density of trout is lower in low-ANC waters in SNP. In the three "intensive" streams, annual trout production and density are lowest in the low-ANC stream, and are highest in the high-ANC stream; differences among the streams in fish habitat are not significant. (Newman and Dolloff, 1996a).

4. Blacknose dace condition factor is strongly related to water chemistry in SNP. Condition factor (K) indicates the health of the individuals in a population, and integrates environmental conditions over seasonal time scales. Based on an analysis of over 1200 individuals, blacknose dace in low-ANC streams are significantly smaller (lower K) than conspecifics in intermediate-ANC and high-ANC streams.

5. Fish species richness is strongly related to water chemistry in SNP. A stepwise multiple regression relating number of fish species to water chemistry variables indicates that the minimum ANC observed in a seven-year record explains over 80% of the variance in fish species number in a sample of 11 SNP streams.

6. Both brook trout and blacknose dace actively avoid simulated acid pulses. In a laboratory paired-stream system, both fish species actively avoided simulated acid episodes and sought high-ANC refugia (Newman and Dolloff, 1996b).

7. Episodic acidification (as ANC loss) occurs in SNP streams. Analysis of 40 episodes during the 3-year study shows that the magnitude of ANC depressions during episodes is a linear function of antecedent baseflow ANC.

8. The "intensity" of episodic acidification in SNP is lower than in some other parts of the world. Analysis suggests that 70-90% of peak stormflow is relatively well-buffered pre-event water. Only in the low-ANC stream, where pH falls below 5.0 episodically, did total monomeric aluminum values exceed 100 µg/L. (Hyer et al.,1996). While events are less intense than elsewhere, they are still sometimes lethal to brook trout embryos (MacAvoy and Bulger, 1996).

9. A introduced insect worsens streamwater acidification in SNP. The gypsy moth *(Lymantria dispar),* causes massive tree defoliation, and results in substantial [nitrate] increases in some streams. This worsens episodic ANC depressions in low-ANC streams, and accelerates base cation export from such catchments.

The major findings of the SNP:FISH project (1992-1995) so far analyzed indicate that early acidification effects are detectable on fish in SNP. Brook trout and blacknose dace persist in many streams, but individual and population effects suggest that acidification contributes to marginal status in low-ANC streams. The effects on brook trout and blacknose dace are understandable results of temporal and spatial hydrochemistry patterns, which in turn are related to bedrock geology. SNP has provided a rare opportunity to observe incipient acidification, without having to reconstruct biological responses. Since several fish response variables appear sensitive to water chemistry (e.g., condition factor, density, species richness, annual production), modelling efforts will be undertaken to predict the future status of fish populations in SNP.

Acknowledgments

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