THE ASSOCIATION OF WATER CHEMISTRY VARIABLES AND FISH CONDITION IN STREAMS OF SHENANDOAH NATIONAL PARK (USA)

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Abstract. As part of the "Shenandoah National Park: Fish in Sensitive Habitats" (SNP:FISH) project, the blacknose dace (*Rhinichthys atratulus*) was utilized as an indicator species to assess the susceptibility of the ichthyofaunal community of Shenandoah National Park (USA) to acidification. Water chemistry (ANC, conductivity, pH, and concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, NO_3^{-}, SO_4^{2-}, and SiO_2) was sampled every three months over the course of 3¼ years which represents the probable maximum lifetime of *R. atratulus*. *Condition factors* (K = [g/mm^3]*10^6) were calculated for samples of fish (age class 2+ yr; n = 370) from nine montane, second/third order streams representing a range of ANCs. A principle components regression was performed on factor scores from a principle components analysis of the water chemistry variables and fish condition factor. Two factors, one associated with stream water ANC and ion concentrations, and another associated with SO_4^{2-} concentration, collectively explained 84% of the variance in condition factor. The influence of variables other than water chemistry upon *R. atratulus* K is addressed. The results show that environmental chemistry is highly associated with the K of *R. atratulus*.

Keywords: *Rhinichthys atratulus*, condition factor, water chemistry, PCR, Shenandoah National Park

1. Introduction

Shenandoah National Park (SNP) receives the highest inputs of SO_4^{2-} of any national park in the USA (NADP/NTN, 1989). Although all areas of SNP receive acid deposition, only those forested catchments with thin, base-poor soils have streams with negative acid neutralizing capacity (ANC). A sample of 51 headwater streams in SNP revealed that 6% have ANCs < 0 μeq/L, 25% have ANCs < 50 μeq/L, and 59% have ANCs < 100 μeq/L (Herlihy *et al.*, 1993). ANC is expected to continue its decline in headwater streams as sulfate deposition continues (Herlihy *et al.*, 1993).

In the present study, we assess the association between an index of fish condition and stream water chemistry. Fish are often used as indicators of an ecosystem's health due to their sensitivity to environmental change and ease of study. We used the condition factor "K" of the blacknose dace (*Rhinichthys atratulus*) as an indicator of environmental stress (Le Cren, 1951). Condition factor is a ratio of weight to length; it is an indirect measure of a fish's energy reserves.

Any use of multiple regression techniques to relate some biological response variable to a suite of water chemistry variables will likely encounter the problem of multicollinearity due to correlation among the water chemistry variables. One technique that circumvents the problem of multicollinearity is *principal components regression* (PCR). PCR effectively deals with the issue of multicollinearity of independent variables because: 1) It reduces the dimensionality of the original data matrix through *principal components analysis* (PCA); 2) The derived principal components, which are linear combinations of the original variables, are by definition orthogonal to one another.

The objective of this investigation was to determine the degree of association of the principal components derived from a matrix of water chemistry variables contemporaneous with observations of condition factor from fish of nine streams of SNP.

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We wanted to determine which water chemistry variables were most closely associated with *R. atratulus* "*K*".

2. Methods

All sites were in SNP, which is located in the Blue Ridge Mountains, USA. Physical and geological characteristics of the 9 watersheds are summarized in Table I. The sites represent different degrees of acid sensitivity: *extremely sensitive* (ANC < 50 μeq/L), *sensitive* (ANC < 200 μeq/L) and *insensitive* (Lynch and Dise, 1985). None of the streams chosen have tributaries with appreciably different chemistry than that found in the mainstem where water samples were collected and fish were surveyed.

TABLE I

Physical and geological characteristics of the study sites

stream	ANC classification*	watershed area (km^2)	geology %† silici-clastic	granitic	basaltic
Meadow Run	extremely sensitive	8.86	100	0	0
Paine Run	extremely sensitive	12.41	100	0	0
Two Mile Run	extremely sensitive	5.52	100	0	0
Staunton River	sensitive	10.52	0	100	0
Brokenback Run	sensitive	9.81	0	93	7
Hazel River	insensitive	13.08	0	100	0
Rose River	insensitive	22.33	0	9	91
Piney River	insensitive	12.44	0	31	69
N. Fork Thornton River	insensitive	18.91	5	27	68

* From Lynch and Dise (1985).
† Indicates the percentage of the stream catchment underlain by this type of bedrock. Data from Gathwright (1976).

The blacknose dace, *Rhinichthys atratulus* (family Cyprinidae), was used as the test species due to its widespread distribution within SNP's streams, and sensitivity to acidification. Refer to Dennis and Bulger (this volume) for methods of fish capture, measurement, and calculation of condition factor. All streams were censused during a two-week period beginning in the last week of July, 1994. This period was considered to be sufficiently brief to avoid confounding effects due to seasonal change of "*K*". A length-frequency histogram of 695 *R. atratulus* assayed during June 1993 (Dennis, unpublished) from three SNP streams indicated that fish 62 mm and larger were at least two years of age. This finding is substantiated by Reed and Moulton (1973), who reported that 2 yr *R. atratulus* averaged 54 mm total length. Fish of 2+ yr were utilized in this study in order to attempt to control for the confounding effect of variation in condition factor due to age class differences (via allometric growth; see Le Cren, 1951). The number of fish surveyed from each stream ranged from 28 to 51.

ANC, conductivity, pH, and the concentrations of potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), nitrate (NO_3^-) sulfate (SO_4^{2-}) and silica (SiO_2) were for this analysis. See Ryan *et. al.* (1985) for analytical techniques. Because *R. atratulus* usually mature at age 2 yr and maximum longevity is slightly longer than 3 yr (Reed and Moulton 1973) only those records from dates that would have occurred during the life of adult fish were utilized in the analysis. Water samples included in this study were collected quarterly, from January, 1991 through April, 1994; a total of 13 records was collected for each water chemistry variable.

The Statistical Program for the Social Sciences (SPSS®) for Windows™ Release 6.1 was used for statistical analyses. "*K*" values standardized for length differences were calculated using the GENERAL FACTORAL ANOVA procedure. A principal components analysis (PCA) was conducted on the (9) streams *x* (11) water chemistry variables *x* (13) temporal observations data set. Three principal components had eigenvalues greater than one, and were retained. Factor scores were calculated for each principal component for each water chemistry observation. "*K*" factors for fish from the 9 streams (total number of fish = 370) were then regressed against the median factor scores (stratified by stream) for each principal component.

3. Results

PCA identified 3 factors explaining a total of 89% of the data set variance (Table II). For a full discussion of the interpretation of PCA in the context of acidification and fish effects, see Bulger *et al.*, (1993). Factor 1 (F1; explaining 61% of the water chemistry variance) represents the strong positive intercorrelation among Ca^{2+}, ANC, Na^+, conductivity, Mg^{2+}, SiO_2, pH, and Cl^-, as well as a weaker negative correlation of these variables with K^+. The physical basis for these relationships is the generally increasing availability of ions and buffering capacity in catchments along a gradient in bedrock geology, from silici-clastic through granitic to basaltic (as sampled in this data set), plus the elevated K^+ in silici-clastic minerals in SNP (Gathright, 1976).

SO_4^{2-} is most strongly loaded on F2 (explaining 18% of the chemistry variance), which also identifies an additional source of variance for K^+. Because PCA identifies independent sources of variance ("factors") in the data set, this factor is best interpreted as a sulfate "signal" which varies independently from the bedrock geology factor (F1), and reflects the primarily atmospheric origin of SO_4^{2-} in the region (Herlihy, et al., 1993). The positive correlation between SO_4^{2-} and K^+ identified by F2 may reflect the greater availability of K^+ for co-transport to streams in silici-clastic catchments which have less SO_4^{2-} retention capacity: where SO_4^{2-} is highest in streamwater, K^+ tends to be high as well.

F3 explained only 10 % of the variance in stream water chemistry. F3 represents the variance in NO_3^-, which apparently varies independently from the other variables in the data set. SNP has been invaded in recent years by an exotic insect pest, the gypsy moth (*Lymantria dispar*), which defoliates many trees, resulting in elevated stream NO_3^- in affected catchments; because NO_3^- is an acid anion, it may also contribute to pH depressions (Webb, et al., 1996). The variance in stream NO_3^- represented by this factor is most likely due to the patchy distribution of gypsy moth defoliations.

Three regression analyses were performed using dace condition (*"K"*) and the factor scores from the PCA (PCR, Table III). Regressions with F1, F1 plus F2, and with all three factors, explained 67%, 84%, and 84% of the variance in *"K"*, respectively. Because F3 improved the coefficient of multiple determination very little, we suggest that the following equation, based only on F1 and F2, is an adequate representation of the relationship between *"K"* and streamwater chemistry in the SNP streams in this investigation.

$$"K" = 0.75(F1) - 0.31(F2) + 9.29$$

A plot of median *"K"* and the median factor scores for the first two factors (F1 and F2) for each of the 9 streams (Figure 1) shows a clustering of the streams underlain by silici-clastic bedrock (Paine, Twomile, and Meadow Runs) *versus* the other 6 streams underlain by granitic or basaltic bedrock.

TABLE II

Component matrix

Variables	Matrix of factor (F) loadings			
	F1	F2	F3	Communalities
Ca^{2+}	**0.976**[a]	0.112	0.014	0.966
ANC	**0.964**	-0.017	-0.218	0.977
Na^{+}	**0.954**	-0.177	-0.119	0.959
conductivity	**0.916**	0.360	-0.090	0.978
Mg^{2+}	**0.899**	0.408	-0.079	0.980
SiO_2	**0.897**	-0.260	-0.095	0.882
pH	**0.827**	-0.289	0.148	0.788
Cl^{-}	**0.684**	-0.334	0.177	0.611
SO_4^{2-}	-0.061	**0.928**	-0.055	0.869
K^{+}	**-0.565**	**0.621**	-0.384	0.852
NO_3^{-}	0.094	0.319	**0.900**	0.921
eigenvalue	6.732	1.951	1.099	
% variation explained	61.2	17.7	10.0	
cumulative %	61.2	78.9	88.9	

[a]Bold type indicates factor loadings with an absolute value greater than 0.5

4. Discussion

Blacknose dace from streams with higher ionic strength, buffering capacity, and pH (F1, Tables II and III) have the highest condition factor *"K"* in samples from 9 streams in SNP, and F1 was the best predictor of *"K"* in these streams. Several important variables can influence *"K"*, including stream productivity, competition, fish density, habitat quality, and genetic differences among populations; it is also possible that ionic strength and acidification status of streams may be linked to *"K"* directly.

TABLE III

Multiple regression results for principal components on condition factor

variable(s)	(multiple) R	adjusted R^2	b	s.e. b	*Beta*	Signif. F
factor 1	0.818	0.668	0.0.719	0.026	0.818	$p < 0.0000$
(constant)			9.310	0.022		
factor s 1 & 2	0.916	0.839				$p < 0.0000$
factor 1			0.749	0.018	0.852	
factor 2			-0.305	0.015	-0.415	
(constant)			9.286	0.015		
factors 1,2, & 3	0.918	0.841				$p < 0.0000$
factor 1			0.755	0.019	0.859	
factor 2			-0.314	0.016	-0.426	
factor 3			-0.050	0.022	-0.050	
(constant)			9.286	0.015		

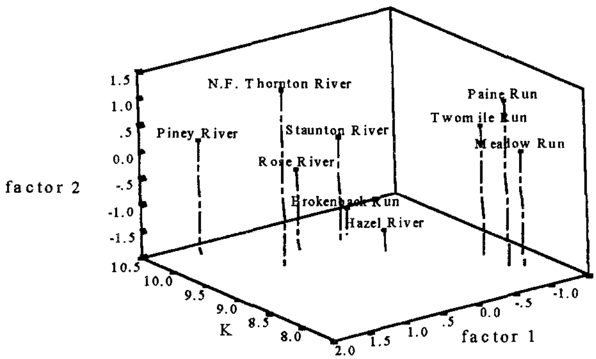

Fig. 1. Graphical representation of the first two factors (principal components) and condition factor, *"K"*.

Ion-regulation in low-ionic strength, low-ANC streams may be more metabolically costly for fish because of steeper ion concentration gradients across which ions must be actively transported into the body fluids. Also, both hydrogen ion and aluminum in solution in acid conditions interfere with ion-regulation (Bulger et al., 1993). Chronic sub-lethal stress in poorly buffered water therefore represents a double burden for ion-regulation, which can be a substantial part of a fish's energy budget even under less stressful conditions (Jobling, 1993). Thus, dace may divert energy from growth to ion-regulation, resulting in lower *"K"*.

The other variables which might affect *"K"* in these streams are currently under investigation; preliminary comments about some of them can be made now. Primary production is unlikely to be reduced by lower pH over the range of pH values in the current study (Baker et al., 1990; the low-pH streams have baseflow pH values typically above 5.0). Habitat quality differences among the streams does not appear to limit dace numbers in the low-ANC versus the high-ANC streams (Newman, 1995). There are fewer species in the low-ANC versus the high-ANC streams, so interspecific competition seems unlikely to explain lower "*K*" in the low-ANC streams. Dace density is similar in the high- and low-ANC streams, so intraspecific competition might not be a factor lowering "*K*" in low-ANC streams; however, we do not yet have good estimates of total fish biomass for comparisons (Newman, 1995).

This study, together with Dennis and Bulger (1996), demonstrates that dace in low-ANC/ionic strength streams have lower "*K*" than dace in higher ionic strength/ANC streams. Water chemistry, or variables correlated with water chemistry, may be responsible for this difference. We provide a plausible mechanism for water chemistry effects on dace "*K*" through metabolic costs of ion-regulation, although other factors may also contribute to the phenomenon. Dace, spawned in the summer, are not exposed to acidic episodes until several months of age in the fall. Consequently, recruitment failure due to acidification may be less important as a population controlling factor than in salmonids, where fish are exposed to poor water quality as vulnerable embryos or fry. Consequently, chronic sub-lethal stress affecting ion-regulation may lead to a reduction in the average size of dace, rather than to an increase in the average size of individuals in a population due to the absence of young fish, as in salmonids, during the early stages of acidification effects.

References

Baker, J.P. and Christensen, S.W.: 1991, "Effects of Acidification on Biological Communities", In D.F. Charles, ed. in *Acidic Deposition and Aquatic Ecosystems*. Springer-Verlag, New York, 83-106.

Baker, J.P., and 11 co-authors.: 1990, Biological effects of changes in surface water acid-base chemistry. NAPAP Report 13. In: National Acid Precipitation Assessment Program, Acidic Deposition: State of Science and Technology. Volume II.

Bulger, A.J., Lien, L., Cosby, J. and Henriksen, A.: 1993, Can. J. Fish. Aquat. Sci. **50**, 575-585.

Dennis, T.E., and Bulger, A.J.: 1996, Water, Air, Soil, Pollut., (this volume).

Gathwright, T.M.: 1976, "Geology of Shenandoah National Park, Virginia". Bull. **86**., Va. Div. of Mineral Resources, 93 pp.

Herlihy, A.T., Kaufmann, P.R., Church, M.R., Wigington, P.J., Webb, J.R., and Sale, M.J.: 1993, Wat. Resour. Res., **29**, 2687-2703.

Jobling, M.: 1993, Bioenergetics: feed intake and energy partitioning. In: Rankin, J.C. and Jensen, F.B., eds., Fish Ecophysiology. Chapman and Hall, London. 421pp.

LeCren, E.D.: 1951, J. Anim. Ecol., **20**, 201-219.

Lynch, D.D., and Dise, N.B.: 1985, "Sensitivity of Stream Basins In Shenandoah National Park to Acid Deposition", U.S. Geological Survey, Water-Resources Investigations Report 85-4115.

NADP/NTN 1989, "National Atmospheric Deposition Program (IR-7) / National Trends Network. March 8,1989, NADP/NTN Coordination Office, Natural Resources Ecology Laboratory, Colorado State University, Fort Collins, CO 80523.

Newman, K.E.: 1995, Response of Brook Char (*Salvelinus fontinalis*) and Blacknose Dace (*Rhinichthys atratulus*) to Acidic Episodes in Three Headwater Streams Within the Shenandoah National Park, Virginia. M.S. Thesis. The Virginia Polytechnic Institute and State University.

Reed, R.J., and Moulton, J.C.: 1973, Am. Mid. Nat., 90, 206-210.

Webb, J.R., Cosby, B.J., Deviney, F.A., Eshleman, K.N., and Galloway, J.N.: 1996, Water, Air, Soil Pollut., (this volume).