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An Assessment of Aquatic Macroinvertebrates in a High-elevation Stream, Great Smoky Mountains National Park

Natural Resource Technical Report NPS/GRSM/NRTR—2012/660

ON THE COVER
Noland Divide Watershed in Great Smoky Mountains National Park
Photograph by Jim Renfro, GRSM

An Assessment of Aquatic Macroinvertebrates in a High-elevation Stream, Great Smoky Mountains National Park

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Contents

Page

Figures

Page

Tables

Page

Abstract

A small-watershed study was initiated in Great Smoky Mountains National Park within the Noland Divide Watershed (NDW) in the early 1990's to measure trends in atmospheric deposition and to examine the long-term effects on stream chemistry and on stream biota. Monitoring of macroinvertebrates was initiated in 1991 and continued through 2001. The main objectives of this monitoring were firstly, to compile long-term benthic macroinvertebrate data for Noland Creek; secondly, to determine if benthic macroinvertebrate populations in this area have been adversely influenced by acidic deposition; and thirdly, to examine the relationships among the biotic responses and ecosystem parameters measured simultaneously at the same site. Assessment of the aquatic macroinvertebrate community in the NDW over time has shown a downward trend in diversity measures, particularly in the summer and fall. This decline corresponds with both a pH decline and an ANC decline over the same time period. As regional emissions are reduced, and air quality conditions improve with stricter standards for power plants, water quality in the NDW should also improve, but at a much slower rate due to the low buffering capacity of the system. Monitoring of the aquatic macroinvertebrate community in the future will be a useful tool to assess conditions within this watershed.

1. Introduction

Benthic macroinvertebrates represent an integral part of lotic systems by processing organic matter and providing energy to higher trophic levels; therefore, an understanding of the effects of anthropogenic, as well as natural stressors on their distribution and abundance is critical for comprehensive impact assessments of streams and rivers (Carter et al. 2006). Changes in macroinvertebrate population relative abundances, life-history traits, and growth rates are sensitive indicators of perturbations and are routinely used when evaluating the impacts of pollution (Carter et al. 2006). The deleterious effects of acidic stream water, for example, are well established, primarily in terms of reduced numbers of species and individuals (Allan 1995). Direct physiological effects and mortality due to acidification and to the subsequent mobilization of toxic metals have been observed among various groups of aquatic invertebrates (Burton et al. 1985). Indirect effects of acidification also occur, through behavioral responses and alterations of food availability (Allan 1995).

In the 1980's, due to general concern about the effects of acidic deposition and the potential for forest decline, several large projects were funded to examine the relationship between atmospheric deposition and forest health. One of these projects was the Integrated Forest Study (IFS), funded primarily by the non-profit Electric Power Research Institute. The research involved monitoring deposition and nutrient cycling at 17 forested sites in North America and Europe, and included a site within the Noland Divide Watershed (NDW) in Great Smoky Mountains National Park (GRSM) (Johnson and Lindberg 1992). The IFS and related studies demonstrated that high-elevation Southern Appalachian spruce-fir forests were receiving among the highest loadings of sulfur and nitrogen measured in North America (Johnson and Lindberg 1992).

Following the IFS, the National Park Service then began a small-watershed study within the NDW in the early 1990's to measure trends in atmospheric deposition, and to examine the long-term effects of atmospheric deposition and forest changes on stream chemistry and on stream biota. Regular monitoring of macroinvertebrates was initiated in 1991 and continued through 2001. The main objectives of this monitoring were firstly, to compile long-term benthic macroinvertebrate data for Noland Creek; secondly, to determine if benthic macroinvertebrate populations in this area have been adversely influenced by acidic deposition; and thirdly, to examine the relationships among the biotic responses and ecosystem parameters measured simultaneously at the same site (Parker and Salansky 1991).

2. Study Area

The NDW is on the North Carolina side of GRSM, about 2 km east of Clingmans Dome, and is 17.4 ha in size (Fig. 1). The elevation range within this watershed is from 1680 m to 1920 m, with the dominant vegetation type being high-elevation spruce-fir forest. The specific vegetation community is a *Picea rubens* – (*Abies fraseri*)/*Vaccinium erythrocarpum*/*Oxalis montana* – *Dryopteris campyloptera*/*Hylocomium splendens* forest (i.e., red spruce – [Fraser fir]/ highbush cranberry/common wood sorrel – mountain woodfern/stairstep moss forest) (White et al. 2003). The spruce-fir ecosystem has undergone canopy decline due to Fraser fir mortality caused by the infestation of the balsam woolly adelgid (BWA, *Adelges piceae*). This exotic insect was first detected in the southern Appalachians in the 1950's (Nodvin et al. 1995).

The mean annual air temperature in the NDW is 8.5°C, ranging from an average of -2°C in January to +18°C in July (Van Miegroet et al. 2007). Mean annual precipitation is approximately 230 cm, ranging from 150 to 300 cm, and is fairly evenly distributed throughout the year. The soils of the study area are poorly buffered inceptisols, formed from the underlying Thunderhead Sandstone (King et al. 1968, Johnson et al. 1991), and are acidic with high organic matter content and high nitrogen mineralization and nitrification capacity (Johnson et al. 1991).

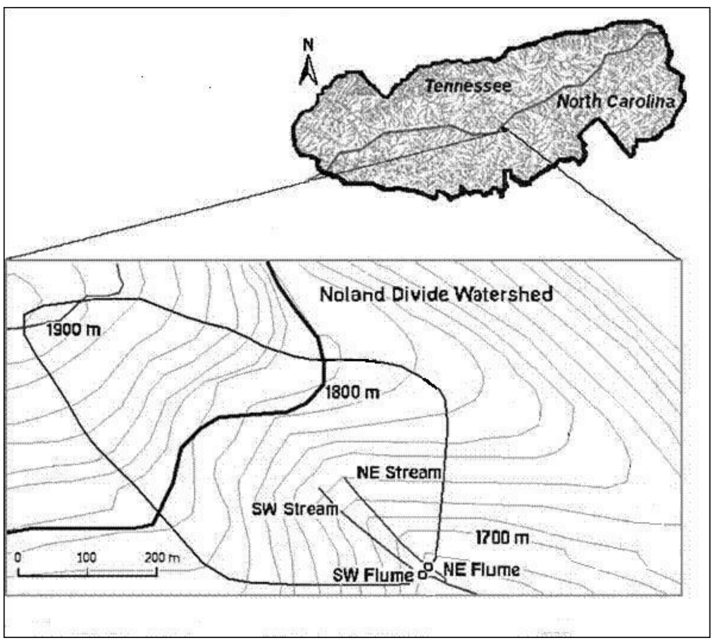

Figure 1. Noland Divide Watershed. (from Cai et al. 2010)

Watershed nitrate export was shown to be extremely high during the period from 1991-1994, whereas stream acid neutralizing capacity values were extremely low, due to low uptake by vegetation in the watershed. The system was determined to be highly nitrogen saturated; a condition which promotes both chronic and episodic stream acidification (Nodvin et al. 1995). More recent research has shown that stream nitrate export has significantly declined from 1991-2007, with more inorganic nitrogen being retained within the watershed, presumably due to forest regeneration since the initial BWA infestation and subsequent increased uptake of nitrogen

(Cai et al. 2011). emporal trend analysis and model predictions show that the NDW streams remain in an acidified condition with stream pH consistently being about 5.8 (Cai et al. 2011).

Within the NDW, two first-order perennial headwater streams (southwest [SW] streamlet, northeast [NE] streamlet) merge and form Noland Creek, which then flows generally south. The collection site for long-term monitoring of benthic macroinvertebrates was on the SW streamlet (17S, 275231E, 3938502N [NAD 83]), just above the flume, at an elevation of 1697 m (Fig. 1). The SW streamlet has an average width of <1 m and a very steep average gradient (16%). The substrate is composed of boulders, cobbles, and large gravel with accumulations of finer particles, silt, and organic debris in depositional areas (Fig. 2).

Figure 2. Noland Creek, SW streamlet, upstream of the flume (left), and downstream of the flume (right).

3. Methods

High-elevation, low-order streams are fragile ecosystems subject to considerable environmental extremes; therefore, a non-disruptive sampling technique was desired for use in the NDW. Drift-net sampling was determined to be the most appropriate for this site, as it is a simple, reliable, quantitative technique that provides detailed information on invertebrates in the stream (Parker and Salansky 1991). Drift-net sampling is a technique not often used for long-term monitoring; however, it overcomes the limitations of quadrat samplers (i.e., Surber samplers) in that a drift-net can be placed at any location in the stream having sufficient flow to carry material into the net, and it does not disrupt the habitat.

The drift-net used for this study is constructed of Nitex® nylon with a mesh size of 363 µm and a net mouth opening of 30.5 cm by 45.7 cm, and a net length of 101.6 cm. The net was placed in the same position in the stream each time it was installed, using stream boulders and a section of rebar as support. Once the net was in the water and fully opened with the dolphin bucket (removable collection container) on the downstream end, water depth and temperature were recorded. After a 24-hour period, the net was retrieved, and the contents removed and placed in 95% ethyl alcohol.

At the beginning of this project in 1991, drift-net samples were collected over a 24-hour period each week in the Noland Creek SW streamlet. Weekly sampling allows for intensive study of the relative abundances, growth, emergence, flight periods, and other characteristics of drifting species; however, it also requires considerable time and is nearly impossible to maintain indefinitely. Therefore, after ~4 years of weekly sampling, the frequency was decreased to monthly until 2001, when sampling ceased. Even under a monthly schedule, samples frequently could not be collected, due to extreme weather, lack of personnel, equipment breakdown, etc., and as a result, there are gaps in the data.

The drift-net collects all coarse particles in the water column including aquatic and terrestrial invertebrates, leaves, sticks, and sand. In the laboratory, the invertebrates in the sample were quantified and the inorganic matter was disregarded. The entire drift-net samples, or sub-sampled portions of it, were thoroughly "picked" to remove all organisms, and specimens were identified to the lowest taxonomic level possible.

4. Results

Over the course of this study, 245 samples were collected from June 1991 through October 2001, with a total of 79 macroinvertebrate species recorded (Table 1). The EPT orders (i.e., Ephemeroptera, Plecoptera, Trichoptera) were the most frequently collected and the most abundant in all samples. The mayflies (Ephemeroptera) were represented by 12 species, stoneflies (Plecoptera) by 21 species, and caddisflies (Trichoptera) by 29 species. The remainder of the Noland Creek community was made up of isopods, midges, crane flies, black flies, other flies, and a few beetles (Table 1).

The most frequently collected taxa throughout the study period (Fig. 3) are common inhabitants of lower-order, cool, fast-flowing streams. *Tallaperla* sp., a stonefly genus in the family Peltoperlidae with nymphs that are shredders feeding primarily on detritus and diatoms, was encountered the most frequently (149 times) over the 10-year period of this study. The next most-frequent taxon was *Lepidostoma* sp. (129 times), a caddisfly in the family Lepidostomatidae which also is a shredder, feeding primarily on detritus, and constructing its case of bark and leaves. *Parapsyche apicalis*, a filter-feeding species of caddisfly in the family Hydropsychidae, was observed on 106 sampling occasions. It feeds primarily on suspended detritus and animal material in small, cold streams. Other species of mostly stoneflies and caddisflies made up the remainder of the most-frequently collected taxa.

When examining aquatic community responses to changes in the environment, the assignment of tolerance values to specific taxa is a valuable tool. Tolerance values range from 0 - 10 and indicate the ability of a taxon to withstand pollution and ecosystem stress: 0 denotes very high intolerance and 10 denotes extreme tolerance. These values have been derived from hundreds of samples taken in diverse water quality conditions across the state of North Carolina (Lenat 1988), and represent the best available assessments of tolerances for the taxa found in the park. Seventy-three percent of all species collected in Noland Creek have tolerance values of 3 or less (Table 1), indicating that the community is quite sensitive to perturbations.

The Shannon Diversity Index (H') is an index that is commonly used to characterize species diversity in a community, accounting for both abundance and evenness of the species present. Biologically realistic H' values range from 0 (low species richness and evenness) to about 4.5 (high species evenness and richness; species are relatively evenly distributed) (Magurran 1988). In general, it is thought that more disturbed and less stable environments should have lower H' values. For this data set, Shannon Diversity Indices were calculated for each month. In years where samples were collected on a weekly basis, taxa lists and abundances were combined for a monthly total. Indices were then plotted over time to determine if there were any long-term trends in overall monthly diversity (Fig. 4). The trend line for these data is declining; however, the R^2 value is very low ($R^2 = 0.12$), indicating highly variable data. Data then were further grouped, by season (i.e., spring, summer, fall, winter). When these data were plotted, two seasons had trend lines with a much better fit (i.e., summer [$R^2 = 0.41$], and fall [$R^2 = 0.65$]) (Fig. 5). In both cases, the trend was downward, indicating that overall diversity was declining over the years in the summer season, and much more sharply in the fall season.

Table 1. Cumulative list of benthic macroinvertebrates collected at Noland Creek, Great Smoky Mountains National Park, from 1991-2001, with known tolerance values (TV).

Taxon	TV
Isopoda	
Asellidae	
Lirceus sp.	7.4
Ephemeroptera	
Ameletidae	
Ameletus cryptostimulus	
Baetidae	
Baetis brunneicolor	
Baetis intercalaris	5.0
Baetis tricaudatus	1.5
Ephemerellidae	
Ephemerella catawba	0.0
Ephemerella excrucians	
Eurylophella sp.	4.0
Serratella serrata	1.4
Heptageniidae	
Epeorus dispar	1.0
Epeorus pleuralis	1.5
Maccaffertium carlsoni	2.1
Maccaffertium meririvulanum	0.5
Trichoptera	
Brachycentridae	
Micrasema sp.	0.8
Goeridae	
Goera fuscula	0.7
Goerita flinti	0.7
Goerita semata	0.7
Hydropsychidae	
Arctopsyche irrorata	0.0
Hydropsyche sp.	
Parapsyche apicalis	
Parapsyche cardis	0.0
Hydroptilidae	
Palaeagapetus celsus	
Lepidostomatidae	
Lepidostoma sp.	1.0
Theliopsyche sp.	
Limnephilidae	
Hydatophylax argus	2.4
Pseudostenophylax uniformis	
Pycnopsyche antica	2.5
Pycnopsyche flavata	2.5
Pycnopsyche gentilis	1.8
Philopotamidae	
Dolophilodes distincta	1.0
Plecoptera	
Capniidae	
Allocapnia sp.	3.3
Paracapnia angulata	
Chloroperlidae	
Alloperla sp.	1.0
Suwallia sp.	2.6
Sweltsa lateralis	0.2
Leuctridae	
Leuctra ferruginea	1.5
Leuctra sibleyi	1.5
Nemouridae	
Amphinemura nigritta	3.8
Amphinemura wui	3.8
Soyedina carolinensis	
Zapada sp.	
Peltoperlidae	
Tallaperla sp.	1.3
Perlidae	
Acroneuria sp.	1.9
Beloneuria sp.	0.0
Perlodidae	
Clioperla clio	5.2
Isoperla sp.	3.2
Malirekus hastatus	1.0
Yugus sp.	
Taeniopterygidae	
Oemopteryx contorta	
Strophopteryx limata	3.3
Taenionema atlanticum	
Coleoptera	
Dytiscidae	
Copelatus glyphicus	10.0
Copelatus punctulatus	10.0
Diptera	
Blephariceridae	
Blepharicera sp.	0.0
Ceratopogonidae	
Forcipomyia sp.	
Chironomidae	
Dixidae	
Dixa sp.	2.5
Empididae	
Limoniidae	
Hexatoma sp.	3.5

Table 1. Cumulative list of benthic macroinvertebrates collected at Noland Creek, Great Smoky Mountains National Park, from 1991-2001, with known tolerance values (TV) (continued).

Wormaldia sp.	2.4	*Limnophila* sp.	
Psychomyiidae		Pediciidae	
Lype diversa	3.9	*Dicranota* sp.	0.0
Rhyacophilidae		*Pedicia* sp.	
Rhyacophila carolina group	0.4	Simuliidae	
Rhyacophila fuscula	1.6	*Cnephia mutata*	
Rhyacophila glaberrima		*Prosimulium* sp.	4.5
Rhyacophila nigrita group	0.0	Thaumaleidae	
Rhyacophila torva	1.5	*Thaumalea* sp.	
Uenoidae		Tipulidae	
Neophylax aniqua		*Tipula* sp.	7.5
Neophylax consimilis	0.3	*Triogma* sp.	
Neophylax mitchelli	0.0		
Neophylax oligius	2.4		
Neophylax ornatus	1.3		

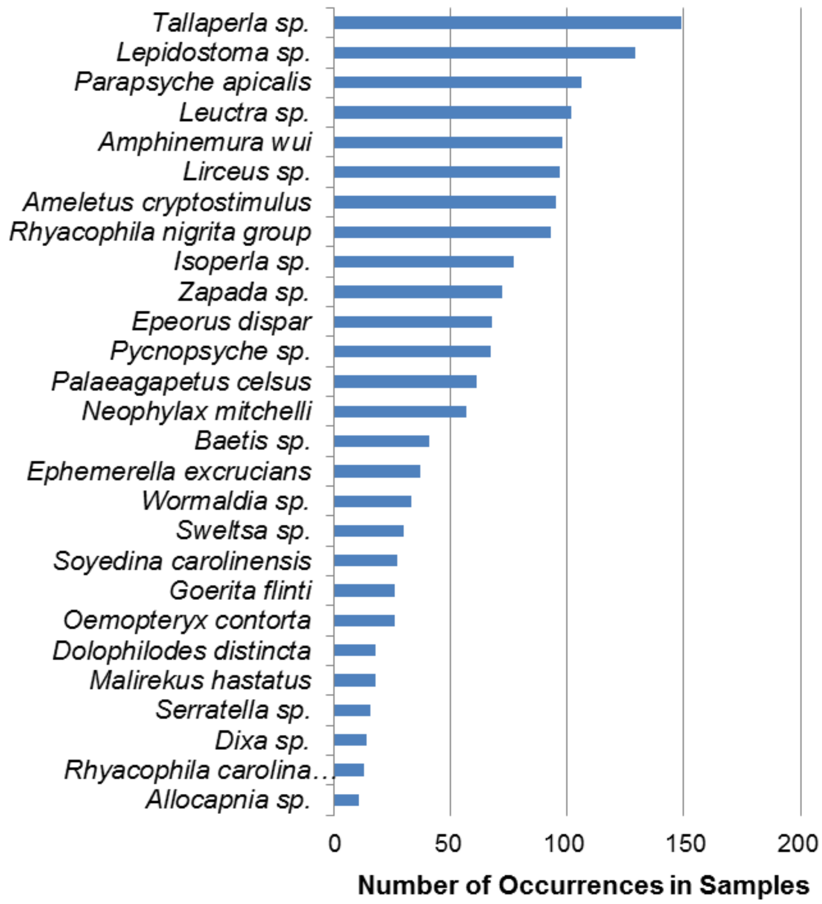

Figure 3. Number of samples in which a given species occurred during the period 1991-2001 in Noland Creek, GRSM. Some species within a genus have been grouped due to the high number of specimens unidentifiable to the species level (e.g., *Leuctra* sp., *Baetis* sp.). Species occurring in less than 10 samples are not shown.

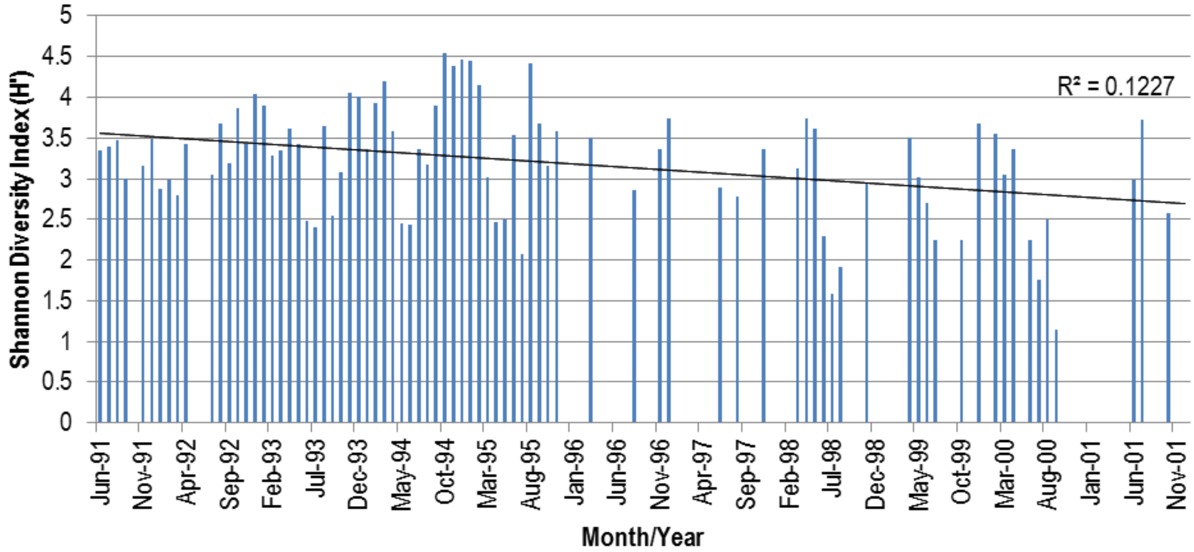

Figure 4. Diversity indices for monthly samples of benthic macroinvertebrates from Noland Creek, GRSM.

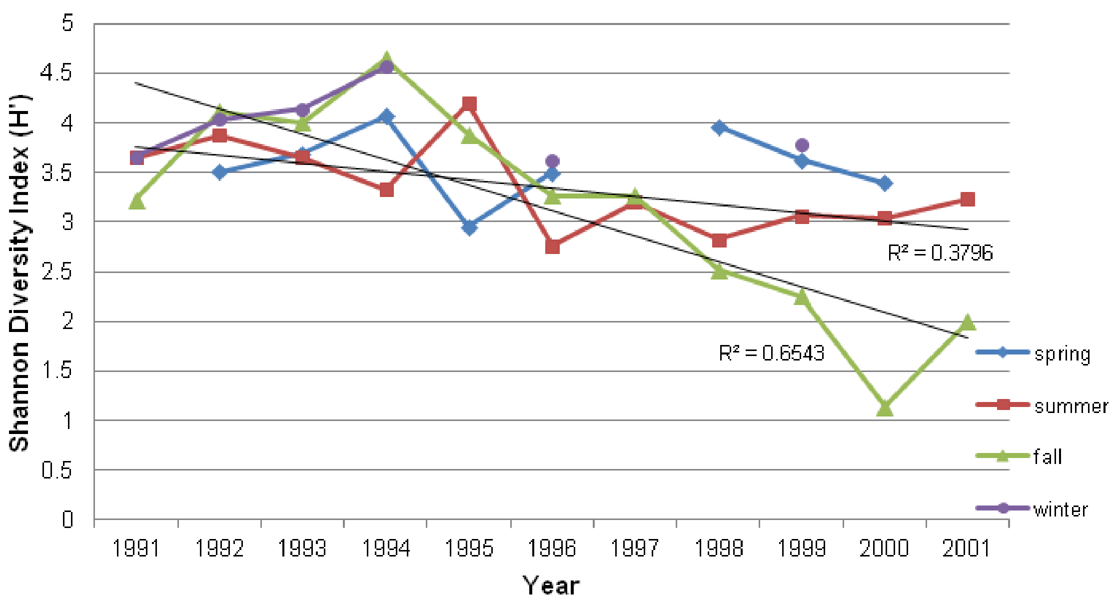

Figure 5. Diversity indices per season, and per year, for samples of benthic macroinvertebrates from Noland Creek, GRSM.

The NDW has been shown to be chronically acidified during certain time periods (e.g., 1991-2007 [Cai et al. 2011]). The pH over the span of this project, from 1991-2001 (Fig. 6), illustrates this as well, with monthly averages of pH ranging from 5.1 to 5.9 (raw values ranged from 4.9 to 6.3), and with a declining trend. The trend for diversity indices of aquatic macroinvertebrates follows the pH trend line fairly closely, but both have low R^2 values.

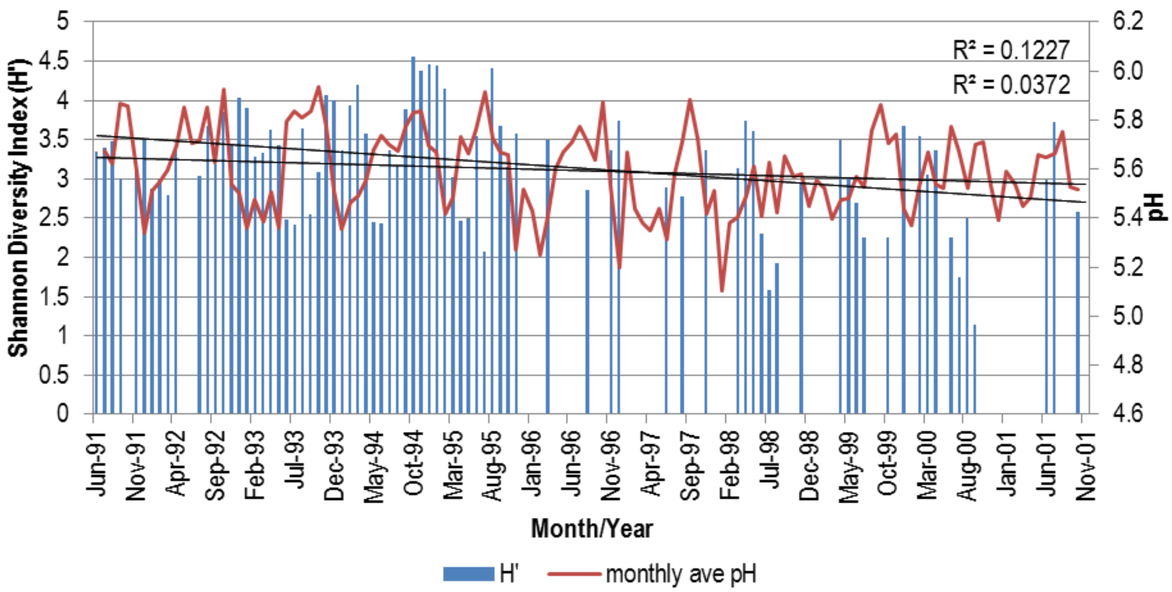

Figure 6. Diversity indices per month, with average monthly pH in the SW streamlet of Noland Creek, GRSM.

Large precipitation events, which are common in this high-elevation watershed, have been shown to cause a flux in sulfate (SO_4^{2-}), leading to declines in pH and ANC (Cai et al. 2010). Additionally, a reduction in base cations (e.g., Ca^{2+}, Mg^{2+}, Na^{+}), which normally moderate acidification, also reduce stream ANC, leading to a sustained acidified condition. In the NDW, net export of base cations has been shown to occur and long-term cation depletion from the soils could limit recovery potential in stream water quality (Cai et al. 2010). Because the long-term trend of ANC has been downward (Fig. 7), it appears that the ability of the system to recover from low and/or declining pH continues to diminish. Recent analyses utilizing biogeochemical models suggest watershed recovery from acidic deposition may take several decades, governed mostly by nitrogen cycling dynamics and limited base cation supply (Sullivan et al. 2008).

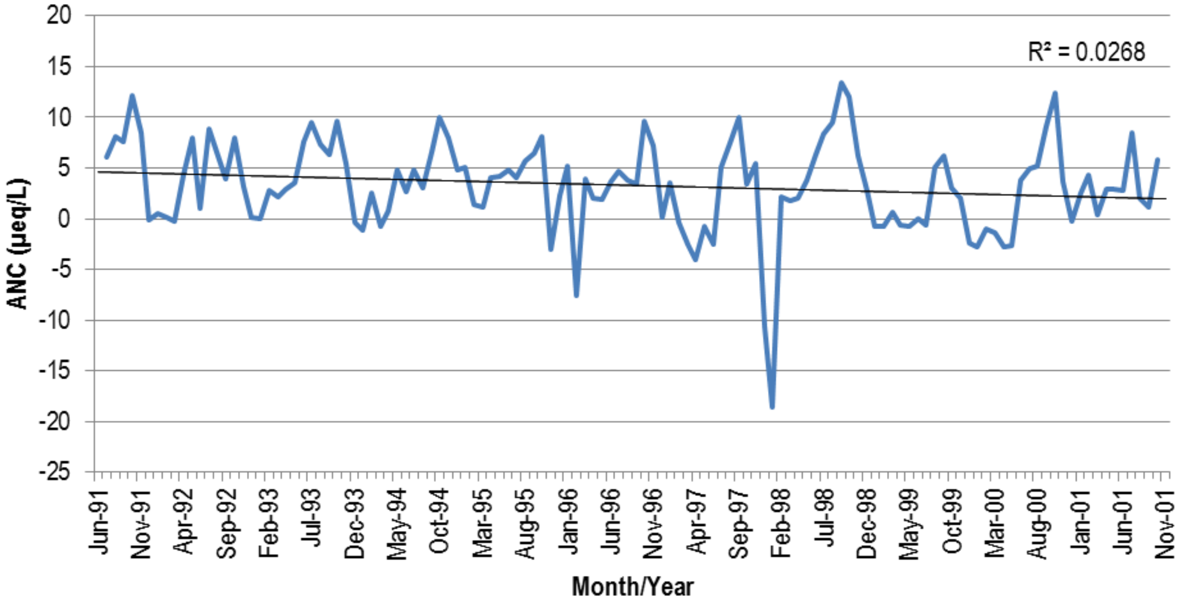

Figure 7. Average monthly ANC in the SW streamlet of Noland Creek, GRSM.

5. Discussion

Benthic macroinvertebrate populations and the benthic community display sensitivity to several types of environmental disturbance; therefore, they are useful for monitoring ecosystem deterioration. During this study, a decline in diversity was observed over time, corresponding to a long-term decline in stream water pH, and sensitive groups (e.g., some EPT's) showed the highest impact. As the invertebrate community responds, they greatly influence the rest of the ecosystem by altering decomposition and, consequently, nutrient cycles, or by disrupting trophic relationships via extinction or emigration.

Chemical and physical measurements often are used to evaluate water quality; however, these parameters primarily reflect conditions that exist when the sample is taken. In contrast, biological monitoring provides information on past and present conditions, and hence, a more spatially and temporally integrated measure of ecosystem condition (Carter et al. 2006). Long-term monitoring of acid deposition, stream water chemistry, and the responses of stream biota in the NDW will all be critically important in the future, in order to better understand the potential influences of forest succession, reduced sulfate emissions, and potential climate changes.

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