Banisteria, Number 14, 1999

Amphibian Diversity in Three Montane Streams with Different Levels of Acidity, Shenandoah National Park, Virginia

Joseph C. Mitchell

Department of Biology
University of Richmond
Richmond, VA 23173

INTRODUCTION

The Blue Ridge Mountains are potentially sensitive to acid deposition derived from human sources, particularly burning of fossil fuels (Galloway & Cowling, 1978; Ryan et al., 1989; Webb et al., 1989). Because acidity levels are expected to increase in the eastern United States in the foreseeable future, acid deposition may increase in this region (Galloway et al., 1983). In Shenandoah National Park (SNP), surface runoff alkalinity concentrations are generally low throughout, indicating a potential sensitivity to increases in acidic atmospheric precipitation (Lynch & Dise, 1985). The pH of precipitation during pre-industrial times was $\geq$5.0 but has since decreased to a mean annual pH of 4.2 (Camuto, 1991). Increasing acidity causes changes in the chemistry of soils and aquatic systems and can have dramatic effects on the local fauna.

Biotic responses to increases in acidity in the Blue Ridge mountains have been studied for only a few taxonomic groups. Aquatic invertebrate abundance and species richness were significantly lower in montane

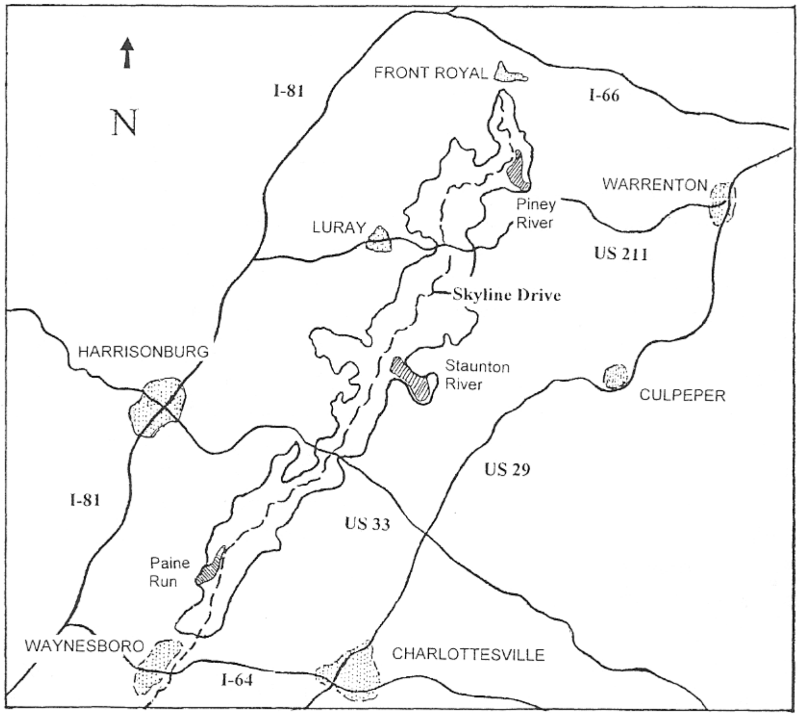

Fig. 1. Location of the three Long-Term Ecological Monitoring sites in Shenandoah National Park, Virginia.

streams in SNP with pH levels of 5.8 compared to streams with a pH of 7.1 (Feldman & Conner, 1992). The number of invertebrate taxa (generic level and above) in the acid-sensitive St. Marys River in Augusta County, Virginia, south of SNP, declined from 32 in 1936 to 17 in 1992 (Webb et al., 1989; Kauffman et al., 1999). Likewise, the number of fish species in St. Marys River declined from 12 in 1976 to 4 in 1998 due apparently to increases in stream acidity (Bugas et al., 1999).

Although the general composition of the amphibian fauna of SNP is known (Witt, 1993), the distribution of amphibians by watershed and stream has not been assessed. There are no baseline data on biotic responses of amphibians occupying those watersheds in which water chemistry and other taxa have been studied. The objective of this study was to determine species richness of amphibians in the streams and associated riparian areas in three watersheds designated as Long-term Ecological Monitoring (LTEM) sites in SNP (Ravlin et al., 1990).

MATERIALS AND METHODS

Site Descriptions

The three LTER sites selected for inventories of the amphibian fauna were Paine Run, Staunton River, and Piney River (Figure 1). These three streams were selected because they represent an alkalinity gradient from low acid neutralizing capacity (ANC - Paine Run), to moderate ANC (Staunton River), to high ANC (Piney River), and because water chemistry parameters and fish and invertebrate communities have been monitored previously. Characteristics of the three watersheds are noted in Table 1.

The ANC of Paine Run has been consistently lower than the ANC in Piney and Staunton rivers (Bulger et al., 1993; Webb et al., 1993; Mitchell, 1998; J.R. Webb, pers. comm.). This is due to the lack of buffering capacity provided by the most common underlying bedrock, the Hampton formation. There are several minor tributaries and one major tributary that drain Lefthand Hollow on the north side of the watershed near the SNP boundary. The majority of the river margin in which most salamanders were found consists of an abundance of small loose rocks, bank edges with no associated rock cover, large boulders, and patches of rubble and gravel. The mainstem substrate is loose rock of small to boulder size and abundant bedrock. Several pools and seepages occur within the watershed that potentially serve as breeding locations for amphibians that avoid moving water.

Staunton River has a moderate capacity to buffer acid deposition and alkalinity readings have been consistent over the past decade (Webb et al., 1993; J.R.

Webb, pers. comm.) (Table 1). The underlying granitic bedrock (mostly Pedlar formation) provides some buffering capacity. There is one primary tributary in the lower reach of the river (Wilson Run), and two smaller tributaries join the river in the middle section. The substrate throughout the mainstem and major tributaries consisted mainly of patches of boulders, large rocks, small rocks, patches of rubble and gravel, and bank margin without cover objects. Many of the rocks were covered with mosses. Mainstem substrate consists of boulders, large rocks, and bedrock. Seepage areas and pools occur along the stream margin. The canopy was complete for nearly the entire length of the watershed until the catastrophic flood of 27 June 1995 (Smith et al., 1996; Mitchell, 1998) destroyed the lower section of the river.

Piney River has a higher capacity to buffer acid deposition. Alkalinity readings throughout the late 1980s and early 1990s show values well above the danger zone for many aquatic animals (>100 _eq/L). During 1992-1997 the lower pH levels were 6.38-6.67 (J.R. Webb, pers. comm.) (Table 1). The underlying Catoctin formation, characterized by metamorphosed basalt beds that originated as ancient lava flows (Gathright, 1976), provides high buffering capacity. There are no major tributaries. The stream margin substrate throughout much of the mainstem consists of small rock, river bank lacking cover objects, large rocks, boulders, and rubble and gravel bars. The mainstem consists of boulders, large to small rocks, and bedrock. Seepages are scattered along the mainstem and in the minor tributaries.

METHODS

Streamside salamander assemblages were inventoried in the three watersheds with three survey techniques (Heyer et al., 1994): time-constrained visual encounter surveys, randomly-placed 1-meter square quadrats along linear transects at the stream edge, and haphazard surveys during hikes through the watersheds. Surveys were conducted from September 1994 to August 1998 (Table 2). Surface objects were turned over and all microhabitats that might harbor amphibians were searched thoroughly. All individuals encountered were identified, and relative location (upper, lower reaches) and habitat (e.g., seep, tributary, mainstem) noted. Adult and immature life history stages were also recorded for most individuals. Occurrence of two species of frogs was determined from their species-specific male vocalizations (frog calls).

RESULTS

Species Richness and Diversity

A total of nine frog species and seven salamander species were documented during this study (Table 3). Fifteen amphibian species were recorded in 1995 for all three LTEM watersheds combined (7 frogs, 8 salamanders), thirteen species (6 frogs, 7 salamanders) were recorded for 1996, 10 species in 1997 (4 frogs, 6 salamanders), and 6 species in 1998 (1 frog, 5 salamanders). The highest total species richness recorded

Table 1. Characteristics of the three LTER watersheds in Shenandoah National Park, Virginia.

	Lowest pH levels (1992-1997)	Underlying bedrock	Mainstem length (km)	Elevation range (m)	Canopy
Paine Run	4.98 – 5.21	Hampton formation	5	424	mostly complete
Staunton River	6.03 – 6.17	granitic; Pedlar formation	5.5	308	complete until flood in June 1995
Piney River	6.38 – 6.67	Catoctin formation	6.5	347	complete

Table 2. Survey dates for amphibians in the three LTER watersheds in Shenandoah National Park, Virginia.

	1994	1995	1996	1997	1998
Paine Run	9 Sep	8 May 5 & 18 Jul 28-29 Aug 6 & 12 Sep 19 Oct	17 May 17 & 25 Jun 17 Jul 5 Oct	26 Jul 4, 10, 23, & 28 Aug 10, 16, & 21 Sep	21 & 23 Jul
Staunton River	21 Sep	26 Apr 16 May 8 Jun 1 Aug 13, 19, & 20 Sep 17 Oct	7 & 13 Jun 1 & 24 Jul 25–26 Sep	6 & 29 Aug 2 & 12 Sep 15 Oct	16 & 30 Jul 16 Aug
Piney River	22 Sep	26 Apr 22 May 7 & 17 Jul 30 Aug 20 Sep	3 May 14 & 24 Jun 25 Jul	8 Aug 25 & 26 Sep 2, 6, 9, 12, & 13 Oct	4 & 13 Aug

was in Paine Run (15), whereas the lowest was in Piney River (8). Paine Run contained the highest total frog diversity with nine species. Salamander assemblages were similar among the three watersheds (Table 3). *Plethodon cylindraceus* was not found in Paine Run in the five years of this study, whereas it was recorded for the other two sites. Five *Pseudotriton ruber* were found in Paine Run and one in Staunton River. Four species of salamanders were abundant in all three rivers: *Desmognathus fuscus*, *D. monticola*, *Eurycea bislineata*, *and Gyrinophilus porphyriticus*. Together, these species comprised the majority of salamanders encountered during this study. Juveniles and/or larvae of most species of streamside salamanders were observed in all three watersheds. The number of frog species increased substantially in Staunton River that year following the catastrophic flood in June 1995 (Mitchell, 1998).

SPECIES ACCOUNTS

Frogs

Acris crepitans crepitans (Eastern cricket frog) - One adult male was observed in Paine Run on 19 October 1995.

Bufo americanus americanus (American toad) - One juvenile was observed in the lower portion of Paine Run on 12 September 1995. Two recent metamorphic individuals were found in lower Staunton River on 6 August 1997. One adult was found in upper Staunton on 2 September 1997.

Bufo fowleri (Fowler's toad) - Single juveniles of this toad were observed on the trail in the lower portion of Paine Run on 12 September 1995 and 17 June 1996. A large aggregation of tadpoles and several recent metamorphs were observed in a pool in the lower, inundated portion of Staunton River on 1 July 1996. A large adult female was found in lower Paine Run on 28 August 1997.

Hyla versicolor (Gray treefrog) - Two individual males were heard calling at the upper end of the Paine Run watershed on 17 May 1996. Numerous recently metamorphosed individuals were observed in the lower portion of the Staunton River among the stagnant and slow-movement pools adjacent to the mainstem on 1 July 1996.

Pseudacris crucifer crucifer (Spring Peeper) - One male was heard in the lower portion of Paine Run on 19 October 1995.

Rana catesbeiana (American Bullfrog) - I tentatively identified an adult frog that jumped from a rock into the upper portion of Piney River on 17 July as this species, however, since the identification is tentative; it is not included in Table 3. An immature bullfrog was caught in lower Paine Run on 5 October 1996.

Rana clamitans malanota (Northern green frog) - This species has been observed in all three LTEM sites. Tadpoles were observed in a pool near the confluence of the Staunton and Rapidan rivers on 17 October 1995. One immature was caught along the stream edge in Paine Run on 17 June 1996. Several aggregations of tadpoles containing up to three size classes (suggesting three separate egg-laying events) were recorded in lower Staunton River on 1 July 1996. An adult was observed in a pool in the Piney River floodplain on 22 May 1995. One juvenile was observed in lower Staunton on 20 August 1997 and in lower Paine Run on 28 August 1997.

Rana palustris (Pickerel frog) - This is a relatively numerous frog in Paine Run. Juveniles and adults have been caught under streamside rocks throughout the watershed between 17 June and 5 October. A single adult was caught while it was hiding in a rock crevice adjacent to the upper portion of Piney River on 17 July 1995, and

Table 3. Amphibian species encountered in the three Long-Term Ecological Monitoring watersheds in Shenandoah National Park, Virginia, during 1994-1998 based on all methods used in this study. Abbreviations: A = abundant (>20 individuals), C = common (5-19), U = uncommon (<5). Range of relative abundances refer to differences among years. Blank spaces indicate no observations.

Species	Paine Run	Staunton River	Piney River
Frogs:			
Acris crepitans	U		
Bufo americanus	U	U	
Bufo fowleri	U	A	
Hyla versicolor	U	A	
Pseudacris crucifer	U		
Rana catesbeiana	U		
Rana clamitans	U	A-U	U
Rana palustris	C-U	U	U
Rana sylvatica	C-U	U	
Salamanders:			
Desmognathus fuscus	A-C	A-C	A-U
Desmognathus monticola	A-C	A-U	A-C
Eurycea bislineata	A-U	A-C	A-C
Gyrinophilus porphyriticus	A-C	A-U	C-U
Plethodon cinereus	C-U	C-U	C-U
Plethodon cylindraceus		U	U
Pseudotriton ruber	C-U	U	
Total no. frog species	7	4	2
Total no. salamander species	6	6	6
Total no. of species	15	13	8

one was found under a rock 10 m from the stream edge on 3 May 1996. In 1997, adult pickerel frogs were observed in lower Paine Run on 4 and 28 August, in lower Staunton River on 6 August, and in lower Piney River on 8 August. One adult was observed in Piney River on 4 August 1998.

Rana sylvatica (Wood frog) - This species as was numerous in Paine Run as pickerel frogs. Adults and juveniles were caught in both upper and lower portions between 28 August and 5 October; most of the individuals observed in fall months were juveniles. A single recently-metamorphosed individual was caught in the inundated portion of the Staunton River on 1 July 1996, indicating at least one breeding event in this watershed that year.

Salamanders

Desmognathus fuscus fuscus (Northern dusky salamander) - This is a widespread salamander and is a common inhabitant of mountain streams and tributaries. It occurs in shallower water than the seal salamander and less often in flowing water. It was found in seepage areas in the watersheds instead of mainstream habitats. This species ranked third to fourth in relative abundance in the three LTEM sites 1995-1998. Only once did it rank second, in upper Piney River in 1997, by the quadrat method.

Desmognathus monticola (Seal salamander) - It is the first- to second-most abundant streamside salamander in this study. It was commonly encountered throughout each of the watersheds along the stream edge in all years of study and less so in seepage areas. All age classes were observed in each of the years of study.

Eurycea bislineata (Northern two-lined salamander) - This species was formerly known as *E. b. bislineata* but was elevated to species level by Jacobs (1987). It is the ecological equivalent to the southern two-lined salamander (*Eurycea cirrigera*). Distributional limits of these sibling species have been delineated by Mitchell & Reay (1999) and SNP populations are referable to *E. bislineata*. Two-lined salamanders were frequently recorded as the second-most abundant species in the three watersheds. It was abundant in each of the streams in all years of study. Adults and juveniles were found primarily within the small rocky microhabitat along stream edges. They appeared to tolerate lower surface moisture conditions than either of the *Desmognathus*, but this physical property was not quantified.

Gyrinophilus porphyriticus porphyriticus (Northern spring salamander) - This is an important predator of all other streamside salamanders. It was the third or fourth abundant species encountered in the LTEM sites during 1995-1998. Most individuals (adults and larvae) were found in flowing water under rocks.

Plethodon cinereus (Red-backed salamander) - Red-backed salamanders are usually the most abundant terrestrial salamander in Appalachian and Blue Ridge forests. They were encountered incidental to searches for streamside salamanders. We found them only in 1995 and 1996 in each of the watersheds.

Plethodon cylindraceus (White-spotted slimy salamander) - This is the larger of the two completely terrestrial species. It was recorded incidentally during searches focusing on the streamside salamanders. Slimy salamanders were found in Staunton River and Piney River watersheds, but not the Paine Run watershed.

Pseudotriton ruber ruber (Northern red salamander) - Adults of this species were observed twice in Paine Run in 1995 and 1998, and once in lower Paine Run on 10 September 1997. One individual was observed in lower Staunton River on 6 August 1997. None was found in the Piney River watershed during any year of the study. It was the rarest of the streamside salamanders observed in these watersheds.

DISCUSSION

Streamside salamander faunas throughout the northern Blue Ridge Mountains are similar to those studied in the three watersheds in SNP. The fauna of Laurel Ridge Stream, Nelson County, in September 1995 and 1996 consisted of the following species (in decreasing rank order based relative abundance): *D. monticola*, *D. fuscus*, *E. bislineata*, *G. porphyriticus* (Mitchell, unpublished). *Plethodon cinereus*, *P. cylindraceus*, and *Notophthalmus viridescens* occurred in the adjacent forest. Rank order of streamside salamanders in St. Marys River in Augusta County differed between years (*D. fuscus*, 1997 - 21%, 1998 - 6%, respectively; *D. monticola*, 39%, 40%; *E. cirrigera*, 17%, 0%; *G. porphyriticus*, 22%, 4%;) but was otherwise similar to the faunas of the three streams in SNP (Kirk & Mitchell, 1999). Comparisons among frog faunas in Blue Ridge Mountain streams cannot be made because of the lack of published studies.

Despite the fact that Paine Run has low ANC and the lowest pH values of the three LTEM watersheds, it supported the highest amphibian species richness of all three areas studied in SNP. The low pH values are apparently within the tolerance limits of the salamander species. Juveniles, hatchlings, and/or larvae of most of the salamanders were observed, indicating that these species were maintaining reproducing populations in these watersheds during the study period. We do not know if all of the frog populations reproduce successfully in each watershed but the presence of eggs, tadpoles, and metamorphs of some species suggests that they also tolerate acid levels currently present in Paine Run. In addition, no abnormal individuals or other indications of unhealthy animals, environmental contamination, or genetic damage were noted during this study. Kirk & Mitchell (1999) found no significant difference between overall salamander densities in samples taken in 1998 and those obtained in 1936 and 1937 from St. Marys River. Thus, acid deposition and the lack of buffering capacity in Paine Run compared to Staunton River and Piney River appears to have had little detrimental affect on the amphibian communities in the three LTEM watersheds in SNP during the 1994-1998 study period.

Although salamander populations have apparently not been affected directly by acid precipitation, they may be altered in other ways (e.g., physiologically, reproductively, growth rates, survivorship) or through indirect effects on invertebrate prey and their nutrient sources (see Kirk & Mitchell, 1999, for literature). Fish densities and distribution may have greater effects, as they prey on salamander eggs, juveniles, and adults. Fish, especially brook trout (*Salvelinus fontinalis*) are known to affect the structure of streamside salamander communities in the Appalachian Mountains (Resetarits, 1991, 1995). Fish effects on frogs are unknown but are likely to be less important because most anurans breed in shallow pools left over from declining water levels and may encounter fish less often. The structure and diversity of amphibian populations and communities in montane streams in the Blue Ridge is likely to be dynamic because of all of the factors discussed above. Productive future research in these montane streams could focus on age structure and microdistribution of all species present relative to predators, prey, and acidity in microhabitats.

Although I did not quantify results from the three techniques used in this study here (but see Mitchell, 1998), there were differences among methods. Time-constrained visual encounter surveys and searches of randomly-placed quadrats along the stream edge yielded similar results. Nearly all of the species encountered were salamanders because these techniques were limited to the stream course. Haphazard surveys included searching trails and terrestrial habitats, in addition to the stream. This method yields more species than the other two. Nearly all the results for anurans were derived from this technique. Species richness surveys of other watersheds in SNP would benefit most from the use of the haphazard technique.

ACKNOWLEDGMENTS

This project would have not been successful without the help of many people. For administrative and logistic support of the proposal and grant process, I thank Randy Ferrin, John Karish, and Tonnie Maniero (NPS), Jewel Simmons (Military District of Washington), and Jackie Howard (DoD Legacy office). Personnel in Shenandoah National Park, Jim Atkinson, Tom Blount, Bob Krumenaker, and Julie Thomas assisted in various ways. The following people assisted in the field: Jim Atkinson, Tonnie Maniero, Julie Thomas, Matt Mulder, and Chris Wells. Todd Georgel was a primary field assistant during most of the project period (1995-1997). I thank T.K. Pauley and R.B. Smith for reviewing the manuscript. The University of Richmond grants office (especially Diana Vincelli) worked hard to make the funding possible. I thank the coordinators of the U.S. Department of Defense's Legacy Resource Management Program for funding this project.

LITERATURE CITED

Bugas, P.E., Jr., L.O. Mohn, & J.W. Kauffman. 1999. Impacts of acid deposition on fish populations in St. Marys River, Augusta County, Virginia. Banisteria 13:191-200.

Bulger, A.J., B.J. Cosby, K.N. Eshleman, J.N. Galloway, & J.R. Webb. 1993. Shenandoah National Park: Fish in sensitive habitats. Unpublished Report to Shenandoah National Park, Luray, VA. 49 pp.

Camuto, C. 1991. Dropping acid in the southern Appalachians: a wild trout resource at considerable risk. Trout (Magazine) Winter, pp. 16-39.

Feldman, R.S., & E.F. Conner. 1992. The relationship between pH and community structure of invertebrates in streams of the Shenandoah National Park, Virginia, U.S.A. Freshwater Biology 27:261-276.

Galloway, J.N., & E.B. Cowling 1978. The effects of precipitation on aquatic and terrestrial ecosystems – a proposed precipitation chemistry network. Journal of the Air Pollution Control Association 28:229-235.

Galloway, J.N., S.A. Norton, & M.R. Church. 1983.

Freshwater acidification from atmospheric deposition of sulfuric acid: a conceptual model. Environmental Science & Technology 17:541A-545A.

Gathright, T.M., II. 1976. Geology of the Shenandoah National Park. Virginia Division of Mineral Resources Bulletin 86:1-93.

Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, & M.S. Foster (eds.). 1994. Measuring and Monitoring Biological Diversity, Standard Methods for Amphibians. Smithsonian Institution Press, Washington, DC 364 pp.

Jacobs, J.F. 1987. A preliminary investigation of geographic genetic variation and systematics of the two-lined salamander, *Eurycea bislineata* (Green). Herpetologica 43:423-446.

Kauffman, J.W., L.O. Mohn, & P.E. Bugas, Jr. 1999. Effects of acidification on benthic fauna in St. Marys River, Augusta County, Virginia. Banisteria 13:183-190.

Kirk, D.M., & J.C. Mitchell. 1999. Streamside salamanders in an acidic Blue Ridge Mountain stream: historical comparisons and relative abundance. Banisteria 13:201-207.

Lynch, D.D., & N.B. Dise. 1985. Sensitivity of stream basins in Shenandoah National Park to acid deposition. U.S. Geological Survey, Water-Resources Investigations Report 85-4115, Richmond, VA. 61 pp.

Mitchell, J.C. 1998. Amphibian decline in the mid-Atlantic region: monitoring and management of a sensitive resource. Final Report to the Legacy Resource Management Program, U.S. Department of Defense, Arlington, VA. 144 pp.

Mitchell, J.C., & K.K. Reay. 1999. Atlas of amphibians and reptiles of Virginia. Special Publication Number 1, Virginia Department of Game and Inland Fisheries, Richmond, VA. 122 pp.

Ravlin, F.W., J.R. Voshell, Jr., D.W. Smith, S.L. Rutherford, S.W. Hiner, & D.A. Haskell. 1990. Shenandoah National Park Long-term Ecological Monitoring System User Manuals. U.S. Department of the Interior, National Park Service, NPS/NRSHEN/ NRTR-90/02, Luray, VA.

Resetarits, W.J., Jr. 1991. Ecological interactions among predators in experimental stream communities. Ecology 72:1782-1793.

Resetarits, W.J., Jr. 1995. Competitive asymmetry and coexistence in size-structured populations of brook trout and spring salamanders. Oikos 73:188-198.

Ryan, P.F., G.M. Hornberger, B.J. Cosby, J.N. Galloway, J.R. Webb, & E.B. Rastetter. 1989. Changes in the chemical composition of stream water in two catchments in the Shenandoah National Park, VA, in response to atmospheric deposition of sulfur. Water Resources Research 25:2091-2099.

Smith, J.A., M.L. Baeck, M. Steiner, & A.J. Miller. 1996. Catastrophic rainfall from an upslope thunderstorm in the central Appalachians: the Rapidan storm of June 27, 1995. Water Resources Research 32:3099-3113.

Webb, J.R., P.E. Bugas, B.J. Cosby, J.N. Galloway, G.M. Hornberger, J.W. Kauffman, L.O. Mohn, P.F. Ryan, & P.P. Smith. 1989. Acidic deposition and the status of Virginia's wild trout resource. Pp. 228-233 In F. Richardson and R.H. Hamre (eds.), Wild Trout IV, Proceedings of the Symposium, Yellowstone National Park.

Webb, J.R., J.N. Galloway, & F.A. Deviney. 1993. Shenandoah watershed study program evaluation. Unpublished report, Dept. of Environmental Sciences, University of Virginia, Charlottesville, VA. 50 pp.

Witt, W.L. 1993. Annotated checklist of the amphibians and reptiles of Shenandoah National Park, Virginia. Catesbeiana 13:26-35.