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THE RELATIONSHIP OF WATER QUALITY AND FISH OCCURRENCE TO SOILS AND GEOLOGY IN AN AREA OF HIGH HYDROGEN AND SULFATE ION DEPOSITION[1]

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ABSTRACT: A survey of 61 headwater streams and their watersheds on Pennsylvania's Laurel Hill, an area of high hydrogen ion and sulfate deposition, was conducted in May and June 1983. Trout were absent from 12 or 20 percent of the streams. No fish were present in 10 streams. Thirty-three streams appeared to contain viable trout populations, 10 streams had other interferring cultural impacts and 6 streams had nonviable trout populations. Significant differences in water quality were noted among streams with and without fish. The streams having no fish as a group had significantly lower pH and alkalinity and higher dissolved aluminum than those with fish. Attempts were made to correlate soil type and geology with the presence or absence of trout. Watersheds with a major percentage of very stony land soil classifications always contained no trout or were culturally impacted. On the other hand, watersheds with a major percentage of Upshur (limestone derived) soils always supported trout. Watersheds with more than 30 percent Pocono Group bedrock supported trout in every case but two, while in every case but one, watersheds with more than 30 percent Pottsville Group bedrock did not support trout. Acid runoff episode data indicate severe transient acidification attributable to atmospheric deposition. It appears that a combination of very stony land, 30 percent Pottsville Group bedrock and high deposition of hydrogen ions and sulfate may result in transient acidification and absence of fish populations from headwater streams on Pennsylvania's Laurel Hill.
(KEY TERMS: acidification; atmospheric deposition; water quality; fish occurrence; soils; geology; headwater streams.)

INTRODUCTION

Native brook trout populations (*Salvelinus fontinalis*) are not present in many streams on the Laurel Hill. Fish kills within the past 25 years have been documented by private trout nurseries and the Pennsylvania Fish Commission (Sharpe, *et al.*, 1984). It appears acid precipitation may be responsible, since both the rain and snow falling on the Laurel Hill are very acidic (Sharpe, *et al.*, 1984; Wilson and Mohnen, 1982; Lynch, *et al.*, 1984; DeWalle and Sharpe, 1985). Four streams (Wildcat, Bear, Linn, and Card Machine Runs) were monitored on the Laurel Hill from December 1980 through April 1981. On each stream the pH dropped dramatically in response to rain and snowmelt runoff (Sharpe, *et al.*, 1984). Decreasing stream pH as a consequence of acidification can result in increased concentrations of metals (Haines, 1981). Bear, Linn, and Card Machine Runs, all poorly buffered streams without trout, had increased aluminum concentrations and decreased pH with increased discharge. Wildcat Run, a well-buffered stream with fish (*Salvelinus fontinalis, Salmo gairdnerii,* and *Cottus bairdi*) had a much smaller increase in aluminum concentrations during the same period (Sharpe, *et al.*, 1984). High aluminum concentration and low pH can cause fish mortality in acidified streams (Sharpe, *et al.*, 1983; Gagen, 1986; Baker and Schofield, 1982).

A fish and water quality survey was conducted in the spring of 1983 to determine the status of headwater fish populations on the Laurel Hill. The survey was conducted at a time of moderate-to-high stream discharge, when pH was expected to approach minimum values and dissolved aluminum concentrations to approach maximum values (Sharpe, *et al.*, 1984). Fish status was related to water quality, and available soils and geologic information.

STUDY AREA

The study area was located in the Laurel Hill region of the Allegheny Mountain System in southwestern Pennsylvania (Figure 1). Laurel Hill is an anticlinal mountain fold located approximately 80 kilometers southeast of Pittsburgh in the Appalachian Plateau Province. The mountain trends NNE to SSW and has a maximum local relief of 611 meters.

Deposition

Numerous reports and data are available (Wilson and Mohnen, 1982; Lynch, *et al.*, 1984; NRC, 1986) that show high deposition rates for hydrogen and sulfate ions in southwest Pennsylvania. However, data specific to the Laurel Hill indicate even greater deposition than that generally reported by national or statewide precipitation monitoring networks. A comparison of wet fallout and bulk loadings of hydrogen

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and sulfate ions for three locations are given in Table 1. The Peavine Hill Site is located near the top of the Laurel Hill anticline (watershed 14 in Figure 1) in Westmoreland County, Pennsylvania. The data in Table 1 clearly indicate the heavy annual loading of these ions to the study area.

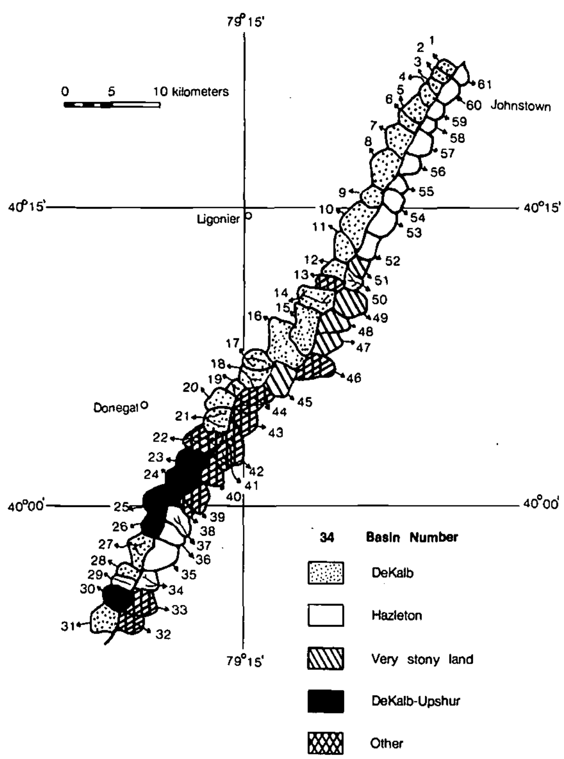

Figure 1. Distribution of Major Soil Series Among 61 Watersheds on Pennsylvania's Laurel Hill.

TABLE 1. Comparison of Wet Fallout (WF) and Bulk Precipitation (BP) Deposition of Hydrogen and Sulfate Ions to Three Appalachian Mountain Sites (11/30/83–11/14/84).

	Sand Mountain		Fork Mountain		Peavine Hill	
	WF* (Kg/ha)	BP (Kg/ha)	WF (Kg/ha)	BP (Kg/ha)	WF (Kg/ha)	BP (Kg/ha)
H^+	1.01	0.98	0.99	0.91	1.52	1.42
SO_4^{2-}	37.74	56.68	43.84	59.33	61.53	75.00

*WF data for Sand and Fork Mountains were derived from NADP data for Parsons, West Virginia, and Leading Ridge, Pennsylvania, respectively. All data are from D. R. DeWalle and W. E. Sharpe, "Biogeochemistry of Three Appalachian Forest Sites in Relation to Stream Acidification," Final Report, U.S. Forest Service, Northeastern Forest Experiment Station (Cooperative Agreement 23-829).

Soils

The majority of soil associations on the Laurel Hill were typically acid, well drained, moderately deep silt loams (Taylor, *et al.*, 1968; Kopas, 1973). Soils information for Cambria and Somerset Counties was taken from unpublished advanced soil survey reports available from County Soil Conservation Service Offices. Soil family names are taken from Cunningham, *et al.* (1983). The watersheds on the eastern slope of the Laurel Hill generally contained a larger mixture of soils than the western slope. (Dekalb (Typic Dystrochrept) was the dominant soil series in all but three watersheds along the western slope. Calvin (Typic Dystrochrept) and Ernest (Aquic Fragiudult) soils were also present in significant amounts. As much as 2/3 to 3/4 of the first 12 watersheds were composed of Dekalb soils (Figure 1). Dekalb becomes less prevalent and Calvin completely disappears at watershed No. 23 (Trout Run). Ernest soils are consistently present throughout the 61 watersheds, although not in great amounts (<20 percent).

Upshur (Typic Hapludalt) series soils are present in significant amounts beginning with Trout Run (No. 23) and ending with Cranberry Glade Run (No. 33). The only other appearance of Upshur (Typic Dystrochrept) soils is on S. Fork Blue Hole Creek (No. 38).

Hazleton (Typic Dystrochrept) series soils first appear on Trout Run (No. 23) watershed and continue to appear in varying amounts in the remainder of the watersheds. Cookport (Aquic Fragiudult), Leck Kill (Typic Hapludult), and Rayne-Gilpin (Typic Hapludult) soils all occur intermittently only on the eastern slope, sometimes as the major soil types in individual watersheds.

The only other trend of apparent significance is the presence, in relatively large amounts, of very stony land in ten watersheds in Somerset County, beginning with Shafer Run (No. 44) and ending with S. Fork Bens Creek (No. 53). Very stony land is the major soil type in five of these watersheds, with as much as 44 percent of the total surface area.

Geology

The five rock groups found in the study basins vary greatly in hydrologic character and exposure on the basins (Dinicola, 1982). Pocono sandstone, the oldest formation exposed, is generally of high and uniform permeability, and deep springs are commonly emitted from the formation. The Loyalhanna Limestone formation has a very low permeability, so contact springs are often found at the top of this stratum when it is not deeply buried. Mauch Chunk shale, which lies directly over the Loyalhanna, is highly permeable when exposed to weathering, but is impermeable when deeply buried. Contact springs are found at the base of Mauch Chunk outcrops only when the formation is exposed to weathering. The Pottsville formation has two highly permeable sandstone members separated by discontinuous beds of impermeable shale and coal. Contact springs are found emerging at the tops of the impermeable beds in this formation. The Allegheny formation is composed of impermeable shales, moderately permeable sandstones, and thin, discontinuous beds of limestone and coal, with underclays. Contact springs also emerge at many places in the formation. Deep springs can occur in any of the formations due to occurrence of deep fractures. The geology of the Laurel Hill is explained in greater detail by Dinicola (1982) and later in this paper.

METHODS

Sixty-one headwater streams were surveyed between May 16, 1983, and June 16, 1983. Geologic and topographic maps were used to determine watershed boundaries. Downstream boundaries for the watersheds included groundwater inputs from the Loyalhanna Limestone (Dinicola, 1982).

Prior to electrofishing, two water quality samples were taken from each stream. One sample was filtered on site through 0.45 μm membrane filter paper and preserved with nitric acid (Baker Instra-Analyzed) for later determination of aluminum concentration. The other sample was refrigerated and returned within 72 hours to the Water Laboratory at the Institute for Research on Land and Water Resources for analysis of pH, Alkalinity (ALK), acidity and specific conductance (SPC). EPA and Standard Methods were used to analyze water samples throughout the study (Table 2).

In addition, intensive water quality and stream stage measurements were made during runoff events on three watersheds during 1984. Powdermill (Figure 1, No. 4), Baldwin (Figure 1, No. 5), and Shannon (Figure 1, No. 6) Runs were monitored, since they represent watersheds with a predominance of Pocono group rocks, a rock type not represented in the earlier work of Sharpe, *et al.* (1984).

Paired t-tests, or nonparametric sign tests on differences, were used to compare the water quality in streams with and without trout. The results from the Shapiro-Wilk test indicated that pH and specific conductivity were not normally distributed. In addition, a median two-sample test comparison was made on the water quality data. These same tests were used to compare different bedrock types exposed on the streams with and without trout.

The fish populations of the 61 streams were surveyed by electrofishing. One pass was made through one 100-meter section of each stream using a 230 VAC backpack generator (Coffelt Electronics Co.) and electrodes. Previous work by the authors on Wildcat Run (Figure 1, No. 14) showed that the first pass through a stream segment was sufficient to account for 80, 82, and 49 percent of the brook trout, rainbow trout, and mottled sculpin, respectively, at prevailing November streamflow (low) conditions. At higher May streamflows, 58, 50, and 34 percent, respectively, of the population of these same three fish species were captured on the first pass. With this information in mind, it was decided that Zippen estimates were not necessary and that one pass through each stream segment would be sufficient to enumerate qualitatively the fish present in the stream segments being evaluated. Larger stream segments were sampled in two cases where no fish were found. Shorter segments were surveyed on two streams with fish (North Fork of Bens Creek and Jones Mill Run) because of equipment failure. The length of each captured fish was measured to the nearest millimeter and recorded. At least one adult and one 0-age fish of each species were retained as voucher specimens. The trout were grouped into age classes and wild or hatchery origin was determined on the basis of length frequency using histograms. Riparian vegetation, water temperature, streamflow, and stream substrate were recorded at each sampling site. Because of their small size and remoteness, the stream segments sampled are usually not stocked with fish by the Pennsylvania Fish Commission. Exceptions to this rule have been noted in the results section.

In January of 1985, four streams with trout and four streams without trout were sampled for calcium, color, and total organic carbon (TOC). Color (PCU) was measured at the time of sampling with a Hach color comparator.

RESULTS

Transient Acidification Episodes

Acidification episodes as a consequence of acid runoff to headwater streams of the Laurel Hill have been observed and

TABLE 2. Summary of Analytical Chemistry Techniques.*

Parameter	Methodology	Equipment
pH	EPA Electrometric 150.1	Orion 901 Microprocessor Ion Analyzer
Acidity	EPA Titrimetric 305.1	Orion 901 Microprocessor Ion Analyzer
Alkalinity	EPA Titrimetric 310.1	Orion 901 Microprocessor Ion Analyzer
Specific Conductance	EPA Specific Conductance 120.1	Hach Model 2510 Conductivity Bridge
Aluminum, Dissolved	EPA AA Direct Aspiration 202.1 AA Furnace 202.2	Perkin Elmer Atomic Absorption Spectrophotometer: Model 2380 with Graphite Furnace Model HGA 500
Color	Standard Methods	Hach Model CO-1 (ALPHA-Platinum-Cobalt Std.)
Total Organic Carbon	EPA 415.1	Coulometrics Coulometer Model 5020

*Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983, and Standard Methods for the Examination of Water and Wastewater, 15 Edition, American Public Health Association, Washington, D.C., 1981.

related to atmospheric deposition (Sharpe, *et al.*, 1984). Four streams (Nos. 14, 15, 16, and 51, Figure 1) were intensively monitored during the winter of 1981 to observe water quality changes subsequent to precipitation induced increases in streamflow (Sharpe, *et al.*, 1984). Three of the four streams showed major declines in pH and increases in aluminum concentrations to levels reportedly toxic to brook trout during acidification episodes.

During the winter and spring of 1984, three additional streams representing the only unmonitored major hydrogeological condition represented on the Laurel Hill (Pocono sandstone) were also intensively sampled (Nos. 4, 5, and 6, Figure 1). Figures 2 and 3 depict the changes in pH and dissolved aluminum concentrations during acid runoff episodes on these streams. The pH declines dramatically and the dissolved aluminum concentration increases in each of these streams in response to acid runoff. These results are consistent with those reported by Sharpe, *et al.* (1984).

The major differences in response of headwater streams to acid runoff would appear to be the severity and duration of water quality changes attendant to the episode. It has been hypothesized (Sharpe, *et al.*, 1984; Dinicola, 1982) that basin hydrology plays a key role in amelioration of acid runoff episodes on the Laurel Hill.

Brook trout populations exist on watersheds 4, 5, 6, and 14 because the severity and duration of the acidification episodes are not sufficient to cause mortality. Studies on Linn Run (watershed 16) by Gagen (1986) indicate that brook trout would be expected to survive the conditions present on watersheds 4, 5, 6, and 14 during acid runoff episodes. Although only one water quality sample was obtained from most of the 61 watersheds surveyed in this study, the intensive monitoring carried out on seven of these watersheds in 1981 and 1984 should be sufficient to allow characterization of water quality on all headwater streams of the Laurel Hill. Sharpe, *et al.* (1984), and Dinicola (1982) have indicated that hydrogeologic parameters control water quality and acidification response on the Laurel Hill. The intensively monitored watersheds represent all the major geologic variables present on the 61 watersheds surveyed; consequently, the acid runoff episode chemistry of all 61 streams can be inferred from the data available and the presence or absence of fish.

Fish Survey

Out of 61 headwater streams surveyed, 12 did not contain trout and 10 had no fish whatsoever in the surveyed section. Fifty-four percent of the streams contained trout with three or more age classes represented. Another 20 percent of the streams were classified as culturally impacted (Figure 4).

With few exceptions, the water quality of the 12 streams without trout was characterized by low pH, high aluminum and minimal alkalinity. Eight streams in this category had alkalinities of <0.05 mg $CaCO_3$/ℓ at the time of sampling. The dissolved aluminum values of these streams averaged 0.45 mg/l^{-1} (Table 3). Schofield and Trojnar (1980) and Baker and Schofield (1982) reported that aluminum concentrations of 0.2 mg/ℓ or greater caused mortality of brook trout. One stream in the "no fish" category, Card Machine Run, had low dissolved aluminum concentrations and relatively high pH's at the time of sampling. However, during intensive monitoring in 1981 (Sharpe, *et al.*, 1984) Card Machine Run had a minimum pH of 4.5 and a maximum total aluminum concentration of 0.7 mg/ℓ.

The six streams classified as having a remnant fish population had intermediate water quality (Table 3) with respect to pH and aluminum at the time of sampling. Although 16 adult brook trout were found in Camp Run, it was classified as having a remnant population because all of the trout appeared to be of hatchery origin.

The dissolved aluminum values for the streams with remnant fish present were lower than the streams with no fish present. The lowest and highest dissolved aluminum values in this category were 0.018 mg/ℓ and 0.10 mg/ℓ, respectively, at the time of sampling. It is possible that streams in this category have not been impacted solely by acid precipitation. Heavy fishing pressure was evident on two of the streams and one stream may not have provided suitable habitat for fish (Camp Run).

Thirty-three (54 percent) of the streams surveyed contained fish, mostly brook trout and mottled sculpin (*Cottus bairdi*). The dissolved aluminum values for these streams were well below the 0.2 mg/ℓ brook trout *toxicity* limit. The highest dissolved Al value was 0.097 mg/ℓ. The alkalinity concentrations of these streams were variable. While the average alkalinity was 6.97, 6 of the 34 streams had alkalinities of <3.0 mg $CaCO_3$/ℓ. The pH of the streams with fish ranged from 5.99 to 7.21.

Means and median pH, alkalinity, and dissolved aluminum were compared for streams with and without fish. The null hypothesis was rejected at $\alpha = 0.01$ in each case; thus, the mean $[H^+]$, alkalinity, and dissolved aluminum concentrations were significantly different for these two classes of streams. The mean color for four streams in each of these classes was 0 and the mean calcium concentrations were not significantly different ($\alpha = 0.01$). The mean TOC concentration for eight streams sampled on January 16, 1985, was 5.7 mg/ℓ. Four of these streams had fish (mean TOC 5.8 mg/ℓ) in the 1983 survey and four did not (mean TOC 5.6 mg/ℓ).

Twelve of the 61 streams surveyed were classified as culturally impacted. These streams were impacted for various reasons, including the presence of major highways, strip mines, water supply intakes, and agriculture. Three were completely devoid of fish and six had remnant fish populations.

Soil Type

The upland soils in the Laurel Highlands have been classified as moderately sensitive to acid precipitation impacts with respect to aquatic inputs (Leibfried, 1982). Although the acid neutralization capacity of the soil is low, reduction of hydrogen ion concentration does occur in percolating waters. Three soils on the Laurel Hill (Dekalb, Calvin, and Ernest)

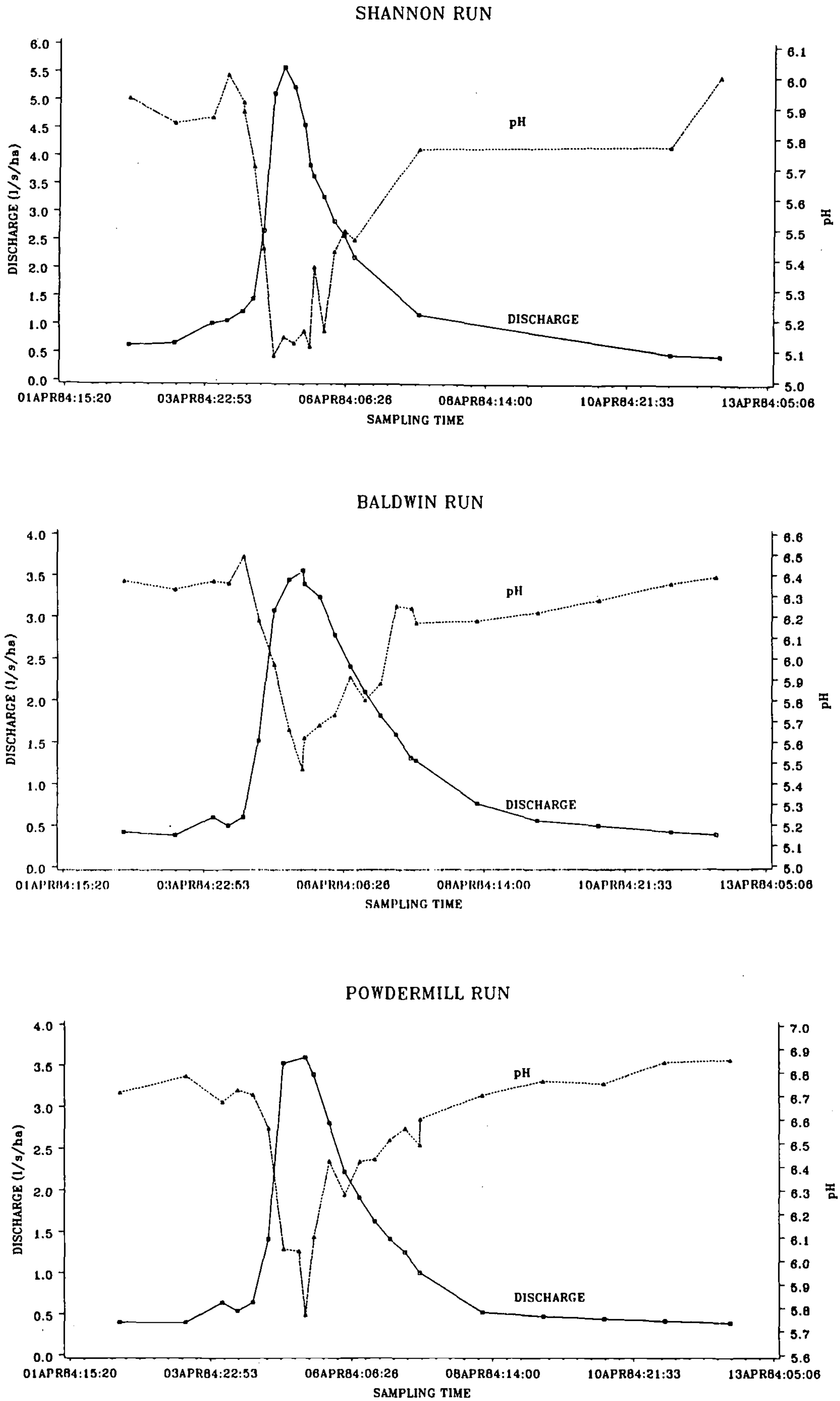

Figure 2. The pH During Acid Runoff Episodes on Three Predominantly Pocono Sandstone Watersheds on Laurel Hill.

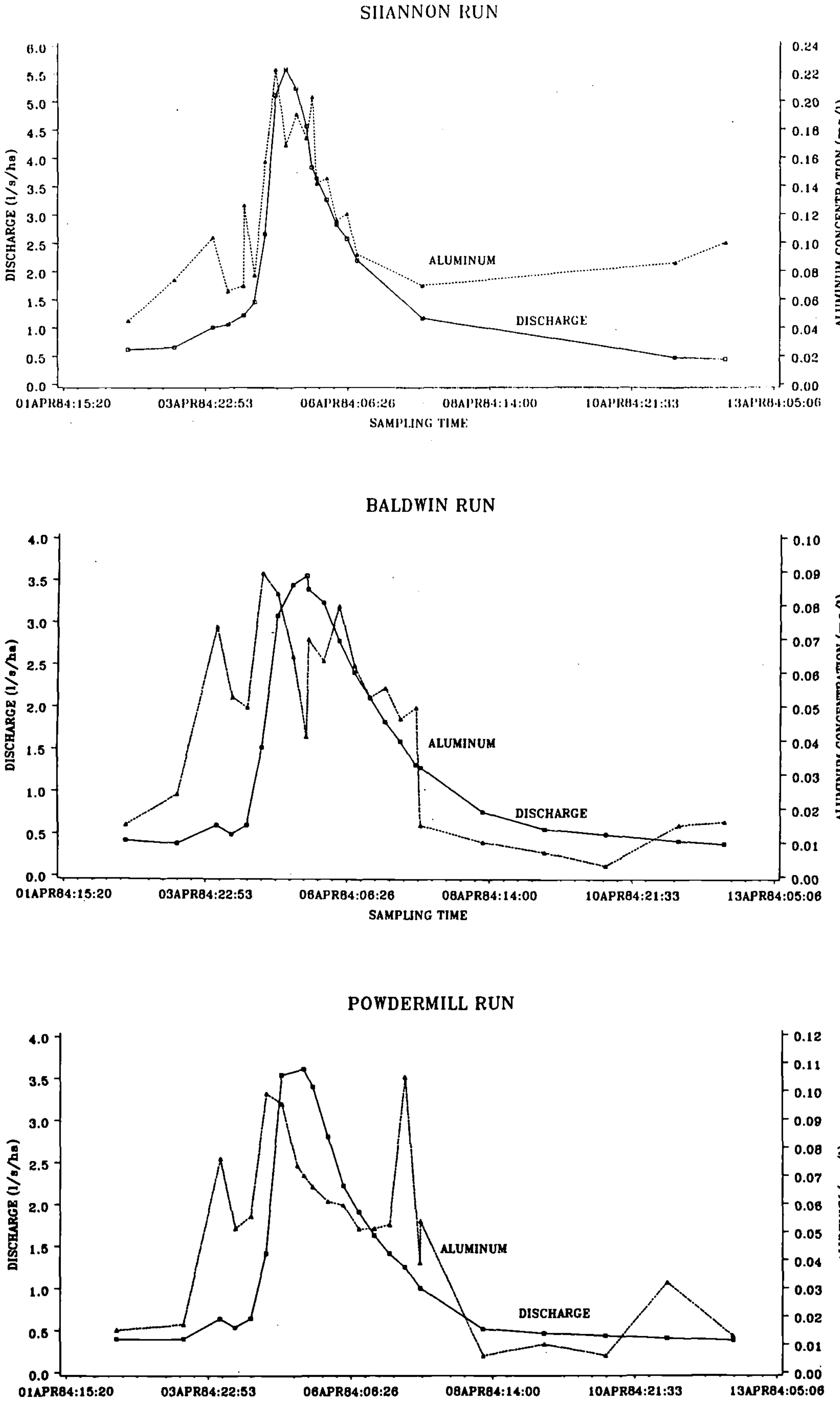

Figure 3. Aluminum Concentrations During Acid Runoff Episodes on Three Predominantly Pocono Sandstone Watersheds on Laurel Hill.

TABLE 3. Selected Geologic, Water Chemistry, and Fish Population Characteristics of the Study Watersheds.

	Water Quality		Bedrock		Fish Presence (No.)		
Stream Name	pH	Al (µg/ℓ)	L. Limestone (percent)	Pottsville (percent)	Brook Trout	Mottled Sculpin	Others
			FISH PRESENT				
1. N. Fork Sugar Run	6.82	8	7.3	7.7	39	0	0
2. S. Fork Sugar Run	6.97	10	7.3	15.6	45	0	0
4. Powdermill Run	6.79	18	8.4	0.0	37	0	0
5. Baldwin Creek	6.34	7	5.2	0.0	24	0	0
7. Lick Run	6.94	14	6.6	6.3	55	35	0
8. Tubmill Run	6.63	5	6.7	3.4	30	28	0
9. N. Fork Mill Creek	6.46	34	5.2	2.9	44	22	0
10. M. Ford Mill Creek	7.01	12	4.5	2.4	31	34	0
11. S. Fork Furnace Run	6.71	5	10.2	6.3	27	6	0
12. N. Fork Furnace Run	6.57	9	15.9	5.6	37	21	0
14. Wildcat Run	7.12	24	3.8	12.0	13	28	12[6]
17. Powdermill Run S.	6.57	18	7.5	38.1	43	4	0
19. Little Run	6.97	16	13.9	0.0	38	30	0
22. Roaring Run S.	7.20	11	17.0	5.2	60	68	0
23. Trout Run[1]	7.21	10	18.9	3.6	13	13	0
24. Neals Run[1]	7.06	9	9.7	6.2	28	26	0
25. Laurel Run[1]	7.07	20	4.7	14.4	57	33	0
26. Middle Fork[1] Laurel Run	6.86	51	9.7	21.3	31	13	0
27. Buck Run	6.74	36	9.8	12.4	32	34	0
28. Clay Run	7.13	17	15.9	18.8	47	0	0
29. Mill Run	6.65	17	22.1	11.6	44	0	0
30. Fulton Run[1]	6.76	10	23.5	7.1	35	35	0
31. Bear Run S.	6.68	24	24.5	1.7	44	0	0
32. Little Glade Run[1]	6.14	97	33.7	8.9	38	0	7[3]
41. S. Fork Jones Mill Rn	6.95	20	24.6	0.0	41	48	0
42. N. Fork Jones Mill Run	7.05	30	13.5	10.6	30	22	0
44. Shafer Run	6.96	13	9.8	5.4	33	86	0
52. Roaring Run N.	6.20	41	9.0	12.5	62	6	0
54. N. Branch Bens Crk	6.61	10	7.5	8.0	36	45	0
55. N. Fork Bens Crk	6.47	27	6.7	0.0	10	0	0
57. Dalton Run	5.99	16	6.0	0.0	20	0	0
58. Mill Creek	6.52	8	5.4	4.4	66	3	0
59. Little Mill Creek	6.10	40	7.7	4.1	42	0	0
	$\bar{X}$=6.73	$\bar{X}$=20	$\bar{X}$=11.6	$\bar{X}$=7.8	$\bar{X}$=37.3	$\bar{X}$=19.4	$\bar{X}$=0.2
			FISH ABSENT				
15. Bear Run (North)	5.18	400	2.4	29.8	0	0	0
16. Linn Run	4.97	500	1.8	33.7	0	0	0
34. S. Fork Sandy Run	4.62	500	3.0	31.3	0	0	0
36. Ansell Run	4.73	500	0.0	55.4	0	0	0
37. Fall Run	4.83	400	3.3	41.7	0	0	0
39. N. Fork Blue Hole Run	4.54	500	0.0	39.3	0	0	0
46. N. Branch Quemahoning Creek	4.46	500	0.0	32.2	0	0	0
47. Beams Run[2]	4.37	800	0.0	53.5	0	0	0
48. Spruce Run[2]	4.29	1,000	0.0	79.4	0	0	0
51. Card Machine Run[2]	5.96	15	10.7	1.1	0	0	0
	$\bar{X}$=4.80	$\bar{X}$=512	$\bar{X}$=2.12	$\bar{X}$=39.7	$\bar{X}$=0	$\bar{X}$=0	$\bar{X}$=0
			REMNANT FISH POPULATION				
20. Camp Run	7.06	42	18.8	0.0	16	0	0
35. N. Fork Sandy Run	5.49	300	0.0	58.8	4	0	0
38. S. Fork Blue Hole Run	5.66	100	0.0	65.5	6	4	0
49. Beaverdam Run[2]	6.22	37	0.0	60.9	2	0	0
53. S. Fork Bens Creek	6.45	34	5.2	1.1	8	23	0
60. Gray Run	6.27	18	0.0	0.0	7	0	0
	$\bar{X}$=6.19	$\bar{X}$=88	$\bar{X}$=4.0	$\bar{X}$=31.0	$\bar{X}$=6.0	$\bar{X}$=4.5	$\bar{X}$=0

TABLE 3. Selected Geologic, Water Chemistry, and Fish Population Characteristics of the Study Watersheds (cont'd.).

Stream Name	Water Quality		Bedrock		Fish Presence (No.)		
	pH	Al ($\mu g/\ell$)	L. Limestone (percent)	Pottsville (percent)	Brook Trout	Mottled Sculpin	Others
			CULTURALLY IMPACTED				
3. Poplar Run	5.31	63	4.6	0.0	0	0	0
6. Shannon Run	6.15	17	8.3	0.0	23	0	0
13. S. Fork Furnace Run	7.47	7	24.7	18.8	2	0	0
18. Indian Creek	7.33	46	7.2	38.6	3	25	14[4]
21. Pike Run	6.83	18	14.6	0.0	0	0	0
33. Cranberry Glade Run	7.09	29	1.3	28.8	0	0	16[5]
40. Allen Run	7.17	3	19.8	0.5	0	35	0
43. Kooser Run	6.92	19	24.4	0.0	0	16	0
45. Clear Run	6.54	58	0.0	49.7	1	0	0
50. Pickings Run	6.71	16	15.8	5.0	1	0	0
56. Allwine Creek	6.64	70	6.1	0.0	22	0	0
61. Strayer Run	6.71	16	0.0	35.0	0	0	0
	$\bar{X}$=6.74	$\bar{X}$=30	$\bar{X}$=10.6	$\bar{X}$=14.7	$\bar{X}$=4.3	$\bar{X}$=6.3	$\bar{X}$=2.5

[1]Upshur soils present.
[2]Major percentage "very stony land."
[3]Seven black nosed dace.
[4]Ten creek chubs, 4 black nosed dace.
[5]One creek chub, 15 black nosed dace.
[6]Rainbow trout.

were found to alter the chemical composition of water infiltrating through them (Leibfried, 1982). These soils reduced the $[H^+]$ activity of infiltrating snowmelt and rain. The amount of chemical interaction in the soil was influenced by the size of the snowmelt or rain event. Events that produced large volumes of soil leachate were least altered chemically.

Using the soil survey information (Figure 1) and the fish population data (Table 3), an attempt was made to discover any possible relationships between major soil types in the watersheds and the streams' ability to support fish. Soils appear to play a role in determining the presence or absence of fish in streams on the Laurel Hill. Soils classified as very stony land comprised the major soil type on five watersheds in the central region of the Laurel Hill. All of these streams were without fish of any kind. Four streams were in the "no fish" category, while Clear Run which was placed in the culturally impacted category also did not contain any fish. Watershed numbers 23-26, 30, 32, and 33 had Upshur soil series present and all of these watersheds contained streams with fish (Figure 4). Cranberry Glade Run was determined to be culturally impacted. Upshur soil is associated with limestone bedrock and the possible role of limestone bedrock is discussed in the next section.

It would appear that the presence of large amounts of very stony land may predispose a watershed to acidification, while the presence of limestone derived Upshur soils indicate resistance to acidification. The soils on each watershed may need to be examined individually in order to determine more specifically the role of soil in determining stream chemistry, especially during stormflow, when rapidly-moving soil water is expected to contribute to streamflow.

Geology

The results from the fish survey indicate a correlation between bedrock type and the presence or absence of fish (Table 3).

A greater percent of Pottsville and Allegheny bedrock was found in the watersheds without fish, and a greater percent of Pocono and Loyalhanna Limestone was found in the watersheds that contained salmonids. Dinicola (1982) found that the pH of waters originating in Loyalhanna Limestone, Pocono, and Mauch Chunk formations was significantly greater than the mean pH of Pottsville or Allegheny waters. The mean alkalinity of water from Loyalhanna Limestone, Pocono, and Mauch Chunk rock units was greater and the mean acidity was less than the mean alkalinities and acidities of waters from the Allegheny or Pottsville rock units.

The mean and median percent of bedrock by type were compared for the fish status groupings. The Pocono, Loyalhanna Limestone, Allegheny, and Pottsville groups were significantly different (α = 0.05) for streams that did and did not contain a viable fish population. The Mauch Chunk formation was present in almost all the watersheds and there was no significant difference in percent bedrock between the fish and no-fish streams.

The streams that do not contain fish are grouped in two different regions on the Laurel Hill (Figure 4). One region is located within a saddle along the anticlinal axis. The other area is along the eastern slope in the southern section of the Laurel Hill. These are the only two sections on the hill where Pottsville is the predominant rock unit. As seen in Table 3, every stream that has 30 percent or more Pottsville exposed on its watershed does not contain fish, with the exception of Powdermill Run South. The majority of the younger formations have eroded on the Powdermill Run South watershed. A large percent of Mauch Chunk and Loyalhanna Limestone is exposed. The limestone also dips towards the stream channel at an angle smaller than the surface slope, causing seeps to emerge at the top of the Loyalhanna Limestone. These seeps provide a significant amount of alkaline groundwater to Powdermill Run South, which probably accounts for the presence of fish in this stream.

Conversely, the streams with fish generally contained a larger percentage of Pocono and Loyalhanna Limestone units on their watersheds, although the direct influence of the Loyalhanna Limestone was not clearcut. Thirty-two of the 34 streams with more than 30 percent Pocono contained fish. The two exceptions were Card Machine Run and Strayer Run. The Laurel Hill anticline in the vicinity of Card Machine Run has the greatest average dip; therefore, erosion has exposed the Pocono group in 72 percent of the basin. Because the dip of the bedrock is also greater than the average surface slope, there are no seeps emerging at rock unit contacts on the basin. In addition, very stony land comprises a major percentage of Card Machine Run soils. Strayer Run was considered to be culturally impacted. It would appear that a combination of very stony land and/or more than 30 percent Pottsville rock on the watershed indicates extreme acidification resulting in fish absence.

SUMMARY AND CONCLUSIONS

The fish populations of 61 headwater streams on Pennsylvania's Laurel Hill were surveyed in the spring of 1983 (Figure 4). Water quality samples were taken at the time of the survey and edaphic and geologic information was compiled from existing sources.

As a result of this survey the headwaters of 10 streams were found to be without viable fish populations and six others had only remnant populations. The streams devoid of fish populations were highly acidified at the time of sampling, as evidenced by low pH, and high dissolved aluminum concentrations.

The percentage of Pottsville Group rocks on the watershed seemed to relate best to the absence of fish, with those watersheds having 30 percent or greater of this rock type being devoid of fish with only one exception. On the other hand, those streams with greater than 30 percent Pocono Group rocks generally had fish, and acid runoff episode data for these streams indicated that water chemistry toxic to brook trout was of insufficient magnitude or duration to cause mortality.

Soil type did not seem to be as important as rock type in determining the presence or absence of fish. However, all watersheds with limestone-derived Upshur soils had fish. All watersheds with major amounts of very stony land were devoid of fish, including one watershed that was culturally impacted. All of those watersheds having either a major amount of very stony land or 30 percent Pottsville rock or both were devoid of fish (except No. 17).

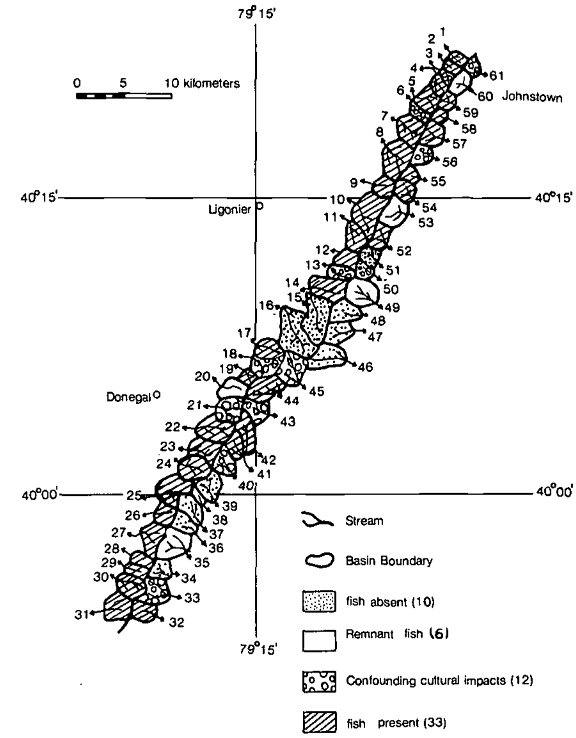

Figure 4. *Fish Distribution in the Headwater Segments of 61 Streams on Pennsylvania's Laurel Hill.*

It would appear that where sensitive soils and acidic bedrock predominate in the study area, severe transient stream acidification is present and fish are absent.

The presence of no other overriding cultural impacts on the watersheds without fish, the lack of any plausible natural cause of the acidification observed and the results of intensive monitoring of seven of the study streams indicate that acidification and subsequent fish absence in the study area are the result of acidification episodes subsequent to precipitation and/or snowmelt runoff. It has been shown (Sharpe, *et al.*, 1984) that acid precipitation is the most likely cause of these events. If remnant and fishless streams are added, 26 percent of the headwater streams on the Laurel Hill are severely impacted by acidification episodes. The extent of damage to other headwater streams where Pottsville rock occurs requires further investigation. Streams with low alkalinities and sensitive bedrock and soils may also be at future risk with continued acid deposition.

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