LICHEN BIOMONITORING PROGRAM IN THE GEORGE WASHINGTON AND JEFFERSON NATIONAL FORESTS: A SURVEY OF LICHEN FLORISTICS AND ELEMENTAL STATUS

FINAL REPORT TO THE FOREST SUPERVISOR,

GEORGE WASHINGTON AND JEFFERSON NATIONAL FORESTS,

USDA-FOREST SERVICE.

CHALLENGE COST SHARE AGREEMENT NUMBER 94-19CCS

MARCH, 1996

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SUMMARY

In the summer of 1995, a lichen biomonitoring program was initiated in the George Washington (GWNF), Virginia. Five study locations were established in watersheds on the GWNF: (1) Brown's Run and (2) Fridley Gap in the Massanutten Mt. area of the Lee Ranger District (RD), (3) the Skidmore Fork watershed in the Dry River RD, (4) St. Mary's Wilderness in the Pedlar RD, and (5) the Locust Spring/Buck Run watershed in the Laurel Fork area of the Warm Springs RD. A survey of the lichen floras of these areas was conducted and the presence of pollution-sensitive species was noted. Additionally, one of the dominant lichen species in the areas, Flavoparmelia caperata, was collected and analyzed for elemental sulfur and nitrogen. This was a baseline study in these areas designed to accomplish the following objectives: (1) To characterize the lichen floras of the watersheds and note patterns characteristic of air pollution damage. (2) To establish the present sulfur and nitrogen contents in a single lichen species from these areas so that comparisons can be made with similar data from previous studies in nearby Monongahela National Forest, WV and Shenandoah National Park, VA. (3) To provide the basis upon which future resurveys of GWNF study sites can be made to document significant changes in the air quality of these areas.

In addition to the five watershed study areas in GWNF, lichens from sites in the Jefferson National Forest (JNF) were sampled to provide sulfur and nitrogen data. Samples of Flavoparmelia caperata were obtained from various elevations in the Mount Rogers National Recreation Area and the James River Face Wilderness, and these were subjected to the same elemental analysis as those from GWNF.

Lichen communities sampled in each of the watersheds on the GWNF were found to include numerous species known to be pollution-sensitive, indicating the lichen floras of these sites are not adversely affected by air pollution at the present time. A total of 84 species of corticolous (bark-inhabiting) macrolichens was observed in the study areas, the largest portion of which were found in the southernmost sites. The species observed were the same as those collected in an earlier study (Dey, 1995) of the lichen flora of the James River Face Wilderness.

At all study locations, specimens of the lichen Flavoparmelia caperata contained generally low contents of elemental sulfur and nitrogen, although certain areas exhibited higher values than others. Of the GWNF sites, those in the Massanutten Mountain area (Brown's Run and Fridley Gap) had the highest contents of both sulfur and nitrogen; of the JNF sites sampled, those from the James River Face Wilderness had the highest S and N contents. Significant correlations between the mean values of S and N were observed for all of the study areas, strongly suggesting that similar factors regulate deposition of the two elements. However, elevation did not appear to be strongly correlated with the patterns observed for either element.

It is recommended that resurveys of the lichen communities of the GWNF watersheds and JNF sites be done at five-year intervals to continue monitoring changes in the floras and the element status of test species. Such a schedule was used in the resurvey of the Otter Creek and Dolly Sods Wildernesses of the Monongahela National Forest in 1992 (Lawrey, 1993b), and results indicated significant changes after five years, especially in the element status of test lichens. It is anticipated that the lichen data contained in this report will prove most valuable in documenting possible future adverse effects on the air quality related values of the surveyed areas.

INTRODUCTION

Lichens are fungi that use captured photosynthetic cyanobacteria or green algae as a source of food. As "dual organisms", they are studied to understand the physiological and evolutionary basis of symbiosis, the intimate association of evolutionarily unrelated organisms. They are also "air plants" which obtain their water and essential element requirements from the atmosphere. Ever since the early 1950's, lichens and other "air plants" have been used as indicators of atmospheric quality around cities and various point sources of air pollution. The reasons lichens are especially useful in this regard are numerous (Stolte, et al., 1993): (1) many species are sensitive to the toxic effects of air pollutants, caused primarily by damage to the photosynthetic symbiont of the lichen; (2) the distribution of some especially pollution-tolerant species has been known to increase dramatically in polluted environments, eliminating pollution-sensitive species; (3) lichens accumulate pollutants from the atmosphere so that analysis of the element concentrations within lichens provides information about ambient air quality conditions in the habitat; (4) lichen thalli (a term for the plant body) are easily transplanted from one habitat to another, allowing collection of air quality data for prescribed locations and lengths of time; (5) lichen recolonization of formerly-polluted environments has been documented in several cases following improvements to air quality; (6) comparison of lichens collected and analyzed for pollutant elements in the past with recently-collected specimens permits a retrospective view of pollution patterns for an area.

Given their usefulness as biological monitors of air quality, the USDA-Forest Service and National Park Service have undertaken a number of lichen studies on

Federal lands (Stolte et al., 1993). Many of these studies have been done at sites designated Class I areas under the Clean Air Act Amendments of 1977. These areas are to be closely monitored to prevent significant deterioration of air quality related values (scenic beauty, vegetation, water, wildlife, odor). To date, over 30 lichen biomonitoring programs have been done in areas managed by the National Park Service; more than 25 have been done at Forest Service sites. All of these studies established baseline conditions for lichen floristics (identification and listing of species and notation of sensitivity to pollution); in addition, some included collecting elemental, physiological or transplant data, and others established permanent sampling or photographic plots.

In the summer of 1995, a baseline study of the lichen communities of five watersheds in the George Washington National Forest, Virginia, was done. These included: (1) Brown's Run and (2) Fridley Gap in the Massanutten Mountain area; (3) Skidmore Fork; (4) St. Mary's Wilderness; (5) the Locust Spring-Buck Run watershed in the Laurel Fork area. These watersheds have been inventoried and monitored for a variety of reasons during recent years by the USDA-Forest Service and others, but of the many environmental concerns, stream acidification is clearly one of the most important. It was anticipated that lichen data could contribute to a better understanding of acidic deposition patterns in these watersheds by providing evidence both of biological effects of deposition on the lichen communities directly and the uptake of sulfur and nitrogen by lichens growing at each site.

In addition to these watersheds in the George Washington National Forest, lichen samples were collected in the Jefferson National Forest from two locations: (1) the

Mount Rogers National Recreational Area and (2) the James River Face Wilderness. These areas have been the subject of previous lichen inventories; the Mount Rogers and White Top Mt. areas were surveyed by Kinsman (1990) and the James River Face Wilderness was surveyed by St. Clair (1987) and most recently by Dey (1995).

The management questions addressed by this study were similar to those of most lichen biomonitoring efforts supported by the U.S. Forest Service (Adams et al., 1991):

(1) What is the distribution and species richness of the lichen communities found?

(2) How does community distribution, species richness and relative species abundance, and the results of the elemental analysis, compare with what is expected to be found in ecologically similar areas of the eastern United States?

(3) What evidence is there that the lichen communities of the five watersheds in the GWNF are under stress?

(4) If there is evidence of stress, what factors are (or could be) contributing to this stress? Is air pollution a contributing factor? If so, are specific air pollutants involved?

(5) What evidence is there that air pollution is the cause of any observed deviation in community structure from that which is expected in an unperturbed ecosystem?

(6) What evidence is there (from species richness, community composition or elemental data) of air pollution trends over time? Is a five-year sampling schedule adequate to yield information of value to U.S. Forest Service management?

In this report, I will discuss these questions insofar as it is possible from the data obtained. In the sections that follow, I will discuss the results of three tasks:

(1) A floristic survey similar to that which was undertaken in Monongahela National Forest in 1987 (Lawrey and Hale, 1988a) and again in 1992 (Lawrey, 1993b), listing all species observed in the study areas and including an assessment of sensitivity to air pollution;

(2) Collecting specimens of Flavoparmelia caperata from systematically-established field quadrats and analyzing for sulfur and nitrogen;

(3) Comparing the floristic and element status of lichens observed in the study areas by location; comparing these areas to those studied previously in West Virginia and Viriginа.

METHODS

Study Areas

Five watersheds (Fig. 1; site locations given in Appendix 1) in the George Washington National Forest were chosen for study based on the amount of previous work done on stream quality and atmospheric deposition. Within each of these study areas, lichen floristic information was collected and lichens were collected for elemental analysis. These areas were:

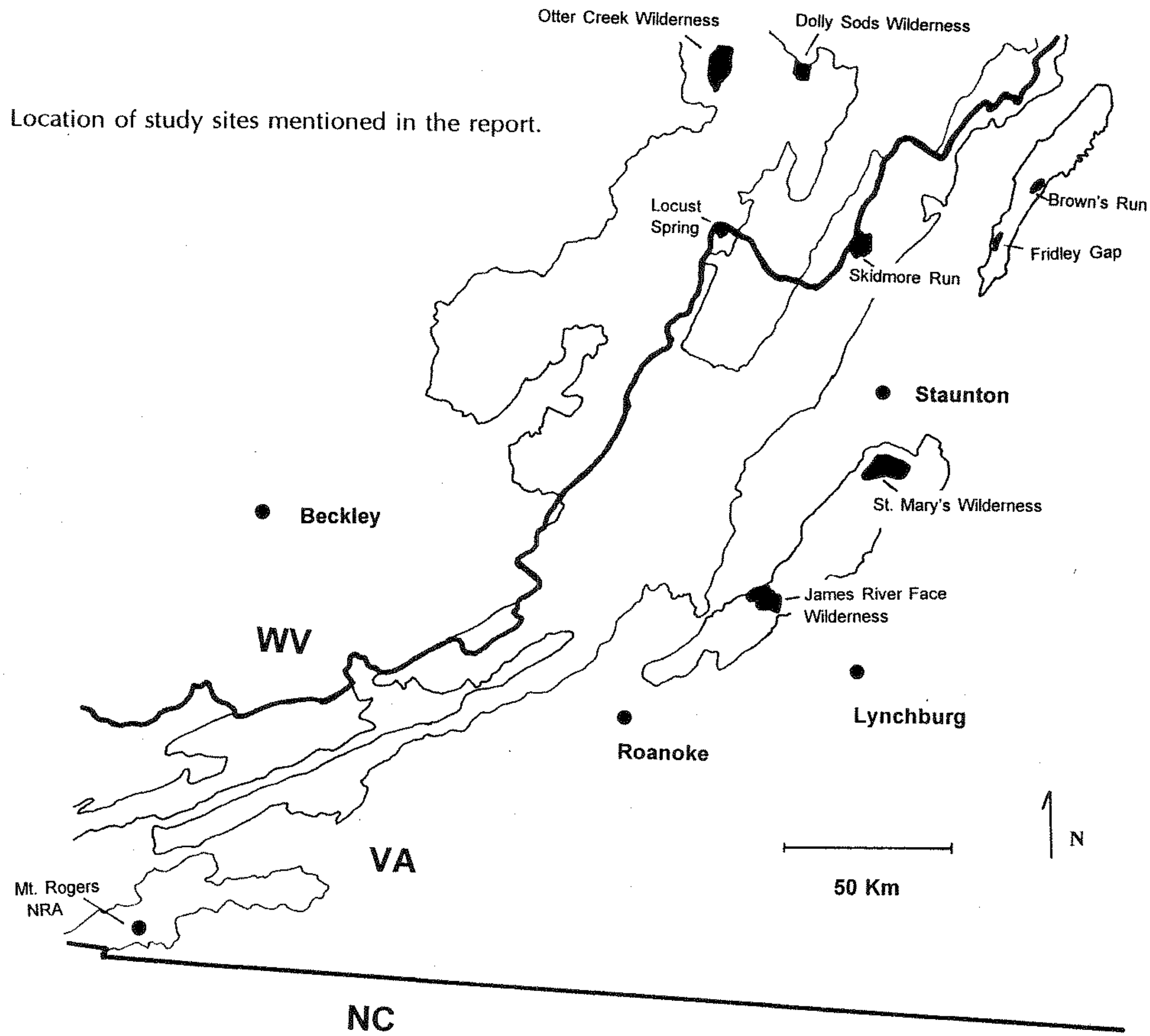
(1) Brown's Run and (2) Fridley Gap in the Massanutten Mountain area of the Lee Ranger District.

(3) Skidmore Fork on the Dry River Ranger District.

(4) St. Mary's River on the Pedlar Ranger District.

(5) Locust Spring/Buck Run in the Laurel Fork area of the Warm Springs Ranger District.

Fig. 1. Location of study sites mentioned in the report.



For all but the Laurel Fork site, the dominant vegetation covering these watersheds tended to be typical of the Shenandoah Mountain region, with a dogwood understory and an overstory of oak-hickory-pine communities on the ridges and birch-maple-hemlock communities near the streams. In the Laurel Fork area, vegetation is more typical of the high elevation Allegheny Mountains with much of the understory consisting of dense Rhododendron thickets, and the overstory made up of northern hardwood and Allegheny mixed hardwood communities. In addition, there may be separate components of oak, heath and associated species; red spruce dominates at higher elevations. There are also wetland bogs and beaver impoundments encountered throughout the Laurel Fork area.

On the Jefferson National Forest, lichens were collected for elemental analysis from two additional areas to supplement previous floristic studies by St. Clair (1987) and Dey (1995; Fig. 1). Site locations were those established for the 1994 floristic survey (Dey, 1995) and are shown in Appendix 2 & 3:

(1) Ten locations at various elevations on Mount Rogers and White Top Mountain in the Mount Rogers National Recreational Area (Appendix 2).

(2) Ten locations in the James River Face Wilderness on the Glenwood Ranger District (Appendix 3).

The forest cover of both areas is mainly Appalachian mixed hardwoods interspersed with conifers.

Floristic Field Work

All field work was done in the summer of 1995. The lichen floras of the five watershed study areas on the George Washington National Forest were assessed using methods similar to those employed earlier in the lichen biomonitoring study done on the Monongahela National Forest (Lawrey, 1993b) and the more recent floristic analysis of the James River Face Wilderness (Dey, 1995), although the latter was a more systematic survey undertaken by USDA-Forest Service personnel. Corticolous (bark-inhabiting) macrolichens (i.e., excluding crustose species) were collected throughout each watershed from all appropriate tree habitats. Following the methods of Dey (1995), the basal 0.5 m of trees and shrubs was excluded from the collections inasmuch as this portion contains a large terricolous (soil-inhabiting) lichen community. All lichens were packeted and returned to George Mason University, where they were identified, labelled and placed in the lichen collection as voucher specimens. Representative voucher specimens will be delivered to the USDA Forest Service along with this final report. Species lists were developed for each watershed. Nomenclature follows Egan (1987). Since quantitative sampling of the lichen communities was not done, the lists reflect the lichens observed, but not necessarily their commonness or rarity. Notes were made of the dominant species in each community type, however, and particular attention was given to species known (or considered) to be sensitive to atmospheric pollution.

These methods were more simplified than those used in the 1995 survey done in the JNF (Dey, 1995), which followed a methodology adopted from the National Forest Health Monitoring Program (McCune et al., 1994). This methodology employs USDA-

Forest Service field crews to collect corticolous macrolichens from field plots and record estimates of abundance for each species. The lichens are then sent to an expert lichenologist for identification. In the present survey of the GWNF watersheds, a single collector was employed and corticolous macrolichens were collected throughout the study areas, and no quantitative abundance data were recorded.

Elemental Analysis Grids in the George Washington National Forest Watersheds

Prior to the field season in 1995, grids were established systematically on 7.5 minute series topographic maps of the five study watersheds on the GWNF. Grid cells 0.5 km^2 in area were used for the three smallest watersheds (26 in Brown's Run, 36 in Fridley Gap, 47 in Locust Spring), resulting in a total of 109 sample locations. For the two larger watersheds (37 at Skidmore Fork and 39 at St. Mary's), grid cells 1.0 km^2 in area were used, for a total of 76 sample locations. Numbers for the grids are given in the site location maps (Appendix 1).

Within each grid cell, lichen material was collected for elemental analysis. Healthy, mature (at least 5.0 cm diameter) lichen thalli identified in the field as *Flavoparmelia caperata* were collected from tree bark and returned to George Mason University to be prepared for laboratory analysis. Sufficient thallus mass was collected to make up at least three 2-gram samples from each grid cell.

Lichen Collections for Elemental Analysis from the Jefferson National Forest

In the Jefferson National Forest (JNF), samples of *Flavoparmelia caperata* were collected at ten locations in each of two areas, the James River Face Wilderness and the Mount Rogers National Recreational Area (site locations given in Appendix 2 & 3). USDA-Forest Service personnel collected the lichen material, which was then labelled and sent to me to be cleaned and prepared for lab analysis. Collection methods were identical to those employed in the GWNF watershed study.

Laboratory Analysis

Lichen material collected in each sample location of the GWNF watersheds and JNF was positively identified, cleaned of tree debris and ground in a Wiley mill. Air-dry samples were then sent to the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio, for elemental analysis. Samples of reference material (peach leaves, NBS 1547) from the National Bureau of Standards were also sent to insure reliability of lab-generated results. Standard peach leaves have been used for quality control purposes in previous lichen studies (Kinsman, 1990) because they have approximately the same content of S and N as lichens. All lichen samples were analyzed at OARDC for total content of sulfur and nitrogen. Total sulfur was determined for each sample using a dry combustion method (Leco 132 Sulfur Analyzer); total nitrogen was also determined using a dry combustion method (Foss/Heraeus Nitrogen Analyzer).

RESULTS AND DISCUSSION

Floristic Analysis Summary

In total, 519 lichen specimens were collected in the 1995 survey. Many collections were duplicates, however, since 84 lichen species were identified (Table 1). Of this total, most species were from the two large watersheds (54 species from Skidmore Fork and 47 species from St. Mary's Wilderness). However, most of the collected species were not restricted to a single site, suggesting that these lichen floras are not distinct but rather part of a larger, homogeneous flora characteristic of the Massanutten and Blue Ridge Mountain region. The species observed at Locust Spring were fewest in number (30 species) and most distinctive, but the flora here is generally less diverse than that seen in the Blue Ridge area and the species observed here are characteristic of the northern Allegheny Mountains. One high-elevation species (Parmelia saxatilis) was found only in the Locust Spring area where high-elevation sites were encountered and sampled more frequently.

A total of 28 lichens with known sensitivities to air pollution (Wetmore, 1983; McCune et al., 1994) were observed in the five watersheds (Table 2); the greatest diversity was observed in Skidmore and St. Mary's, but these also had the most diverse lichen floras generally. The relatively large number of sensitive species indicates that the lichen communities of the watersheds are not presently experiencing stress caused by air pollution.

This conclusion is similar to that reached by Dey (1995) in a survey of the lichen flora of the James River Face Wilderness and the Mount Rogers National Recreation Area

Table 1. List of all corticolous macrolichens collected in the five study areas during 1995 in the George Washington National Forest.

Species	Brown's Run	Fridley Gap	Skidmore	St. Mary's	Locust Spring
Anaptychia palmatula	X	X	X	X	
Bryoria furcellata			X	X	
Candelaria concolor			X		
Candelaria fibrosa		X			
Cetrelia chicitae	X	X			
Cetrelia olivetorum		X	X	X	X
Cladonia coniocraea	X	X	X	X	X
Cladonia polycarpoides	X				
Cladonia squamulosa					
Collema conglomeratum			X		
Collema furfuraceum		X	X	X	
Collema nigrescens		X			
Dermatocarpon fluviatile	X				
Flavoparmelia baltimorensis	X	X	X	X	X
Flavoparmelia caperata	X	X	X	X	X
Flavopunctelia flaventior	X	X	X	X	X
Heterodermia appalachensis	X		X	X	
Heterodermia casarettiana	X	X			
Heterodermia granulifera		X	X	X	
Heterodermia hypoleuca		X			
Heterodermia leucomelos			X	X	
Heterodermia obscurata				X	
Heterodermia speciosa			X		
Heterodermia squamulosa		X	X	X	X
Hypogymnia physodes	X	X	X	X	X
Hypotrachyna livida			X		
Imshaugia aleurites		X	X		
Imshaugia placarodia				X	

Leptogium corticola		X			
Leptogium cyanescens	X	X	X	X	
Lobaria pulmonaria			X		
Lobaria ravenelii			X		
Lobaria quercizans		X	X	X	
Melanelia halei			X		X
Melanelia subaurifera		X	X	X	X
Myelochroa aurulenta		X	X	X	X
Myelochroa galbina	X	X	X	X	X
Pannaria tavaresii			X		
Pannaria rubiginosa		X	X		
Parmelia saxatilis					X
Parmelia squarrosa		X			X
Parmelia sulcata	X	X	X	X	X
Parmelinopsis minarum	X			X	
Parmeliopsis aleurites	X				
Parmotrema arnoldii			X		
Parmotrema crinitum			X		
Parmotrema hypotropum	X		X	X	
Parmotrema louisianae		X			
Parmotrema marginatum			X		
Parmotrema perlata			X	X	
Parmotrema rampoddense				X	
Parmotrema reticulatum	X		X	X	
Parmotrema stuppeum	X	X			
Parmotrema xanthinum	X				
Peltigera canina	X	X	X	X	X
Peltigera praetextata	X				
Phaeophyscia adiastola	X				
Phaeophyscia pusilloides	X	X			
Phaeophyscia rubropulchra	X	X	X	X	X
Physcia americana	X				

Physcia millegrana	X			X	
Physcia stellaris	X	X	X	X	X
Physcia subtilis		X			X
Physciopsis syncolla		X			
Physconia enteroxantha	X	X	X		X
Platismatia glauca			X		
Platismatia tuckermanii			X	X	
Pseudevernia consocians	X	X	X	X	X
Pseudevernia cladonia			X	X	
Punctelia appalachensis		X		X	X
Punctelia rudecta	X	X	X	X	X
Punctelia subrudecta	X	X	X	X	X
Pyxine caesiopruinosa	X	X			
Ramalina americana		X	X	X	X
Ramalina stenospora				X	
Sticta weigelii		X	X	X	
Tuckermannopsis ciliaris		X	X	X	X
Tuckermannopsis oakesiana	X	X	X	X	X
Usnea ceratina			X	X	X
Usnea dasypoga				X	X
Usnea mutabilis			X	X	
Usnea rubicunda	X	X	X	X	X
Usnea strigosa			X	X	
Usnea subfloridana			X	X	X
Total (All sites = 84)	35	44	54	47	30

Table 2. Some pollution-sensitive corticolous macrolichens collected in the five study areas during 1995 in the George Washington National Forest. Sensitivity based on Wetmore (1983) and McCune et al. (1994).

Sensitive Species	Brown's Run	Fridley Gap	Skidmore	St. Mary's	Locust Spring
Bryoria furcellata			X	X	
Heterodermia obscurata				X	
Hypotrachyna livida			X		
Lobaria pulmonaria			X		
Parmelia squarrosa		X			X
Parmelinopsis minarum	X			X	
Parmotrema reticulatum	X		X	X	
Punctelia rudecta	X	X	X	X	X
Ramalina americana		X	X	X	X
Usnea mutabilis			X	X	
Usnea strigosa			X	X	

in 1994. He identified a total of 103 corticolous macrolichen species in 20 plots within the areas, and commented that this was a relatively high diversity, one which would probably not be expected in areas experiencing adverse effects of atmospheric pollution. The methods used to sample the floras of the James River Face Wilderness and the Mount Rogers National Recreation Area were different from those used in the present study. However, inasmuch as many of the species identified in the present study were identical to those found by Dey (1995), the differences do not seem important in this particular effort. It is recommended that periodic resurveys (approximately every five years) be done in all of the sites (the five watersheds in GWNF and the two sites in JNF) using a single collecting protocol. This will help to document changes in the lichen floras indicative of pollution damage. Given the pollution sensitivity of many of lichens presently inhabiting the study areas, surveys that focus particular attention on these species would be especially desirable.

Elemental Analysis Grids in the George Washington National Forest: Elemental Analysis of Test Lichens

Analysis of Flavoparmelia caperata specimens collected from elemental analysis grids established in the five watersheds from the George Washington National Forest (GWNF; 109 from 0.5 km^2 grids and 76 from 1.0 km^2 grids) yielded total percent dry weight values for two elements, sulfur and nitrogen (summary in Table 3; all element data are provided in Appendix 4).

Table 3. Range and mean values of total sulfur and total nitrogen content measured in thalli of Flavoparmelia caperata collected from sampling grids in each experimental watershed in the George Washington National Forest in 1995.

	Mean Percent Dry Weight ± S.E.[1]	
Site	S	N
Brown's Run (78)[2]	0.188 ± 0.002 (0.14 - 0.24)	1.763 ± 0.017 (1.14 - 2.35)
Fridley Gap (108)	0.170 ± 0.001 (0.10 - 0.23)	1.694 ± 0.017 (1.20 - 2.10)
Skidmore Fork (111)	0.154 ± 0.028 (0.09 - 0.24)	1.432 ± 0.204 (1.00 - 2.00)
St. Mary's River (117)	0.148 ± 0.033 (0.09 - 0.24)	1.398 ± 0.270 (1.00 - 2.20)
Locust Spring (141)	0.138 ± 0.032 (0.07 - 0.32)	1.224 ± 0.205 (0.80 - 1.90)

[1] Values of S and N mean percent dry wt. ± the standard error of the mean. Numbers in parenthesis are ranges for each watershed.

[2] Numbers in parentheses are sample sizes for each elemental analysis sample at each watershed.

In general, the contents of S and N are relatively low and reflect good to moderate air quality conditions. The Massanutten sites (Brown's Run and Fridley Gap) exhibited the highest values of both S and N. The remaining sites on the GWNF exhibited relatively low values of both elements, although there were generally wide ranges in both N and (especially) S. The highest N content (2.35%) was observed at site number 8 in Brown's Run and the highest S content (0.32%) was observed at site 140 in the Locust Spring watershed. This particular S value may not be representative of site 140, however, since two of the three replicates from that site had values below 0.2% S (Appendix 4).

The spatial distribution of lichens containing the highest contents of sulfur (mean values exceeding 0.20%) and nitrogen (mean values exceeding 2.0%; Figs. 2-4) indicates that a number of "hot spots" exist for these two elements in the five watersheds in GWNF. In the smaller watersheds where lichens were sampled from 0.5 km^2 grids (Fig. 2), Brown's Run exhibited the greatest number of hot spots for both S (9 of 26 grids, 34.6%) and N (4 of 26 grids, 15.4%); Fridley Gap had 4 of 36 (11.1%) hot spots and Locust Spring had only 2 of 47 (4.2%). In the larger watersheds where 1 km^2 grids were sampled, Skidmore Run (Fig. 3) had only 2 of 37 hot spots (5.4%), while St. Mary's (Fig. 4) had 3 of 39 (7.7%). Except for the fact that the Massanutten sites had the highest frequency of sites with high contents of S and N, there is no discernible distribution pattern suggesting a single pollution source.

When these frequencies are compared to those observed in previous studies in the nearby Monongahela National Forest and Shenandoah National Park, it appears that

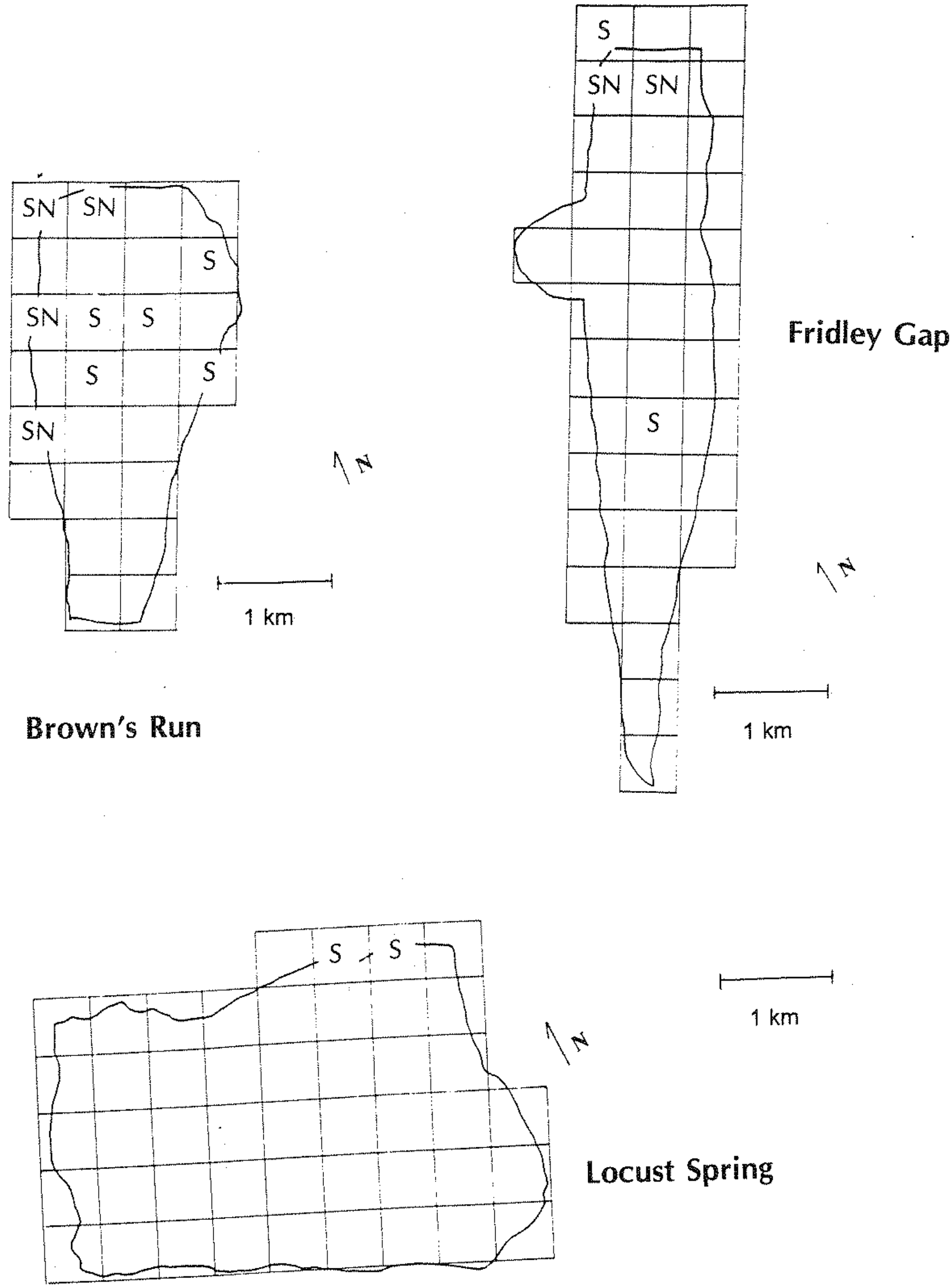


Fig. 2. Locations of 0.5 km² grids with lichens containing high sulfur (≥ 0.2% sulfur by wt., S) or nitrogen (≥ 2.0% nitrogen by wt., N) content.

Fig. 3. Locations of 1.0 km^2 grids in the Skidmore Fork watershed with lichens containing high sulfur ($\geq$ 0.2% sulfur by wt., S) or nitrogen ($\geq$ 2.0% nitrogen by wt., N) content.

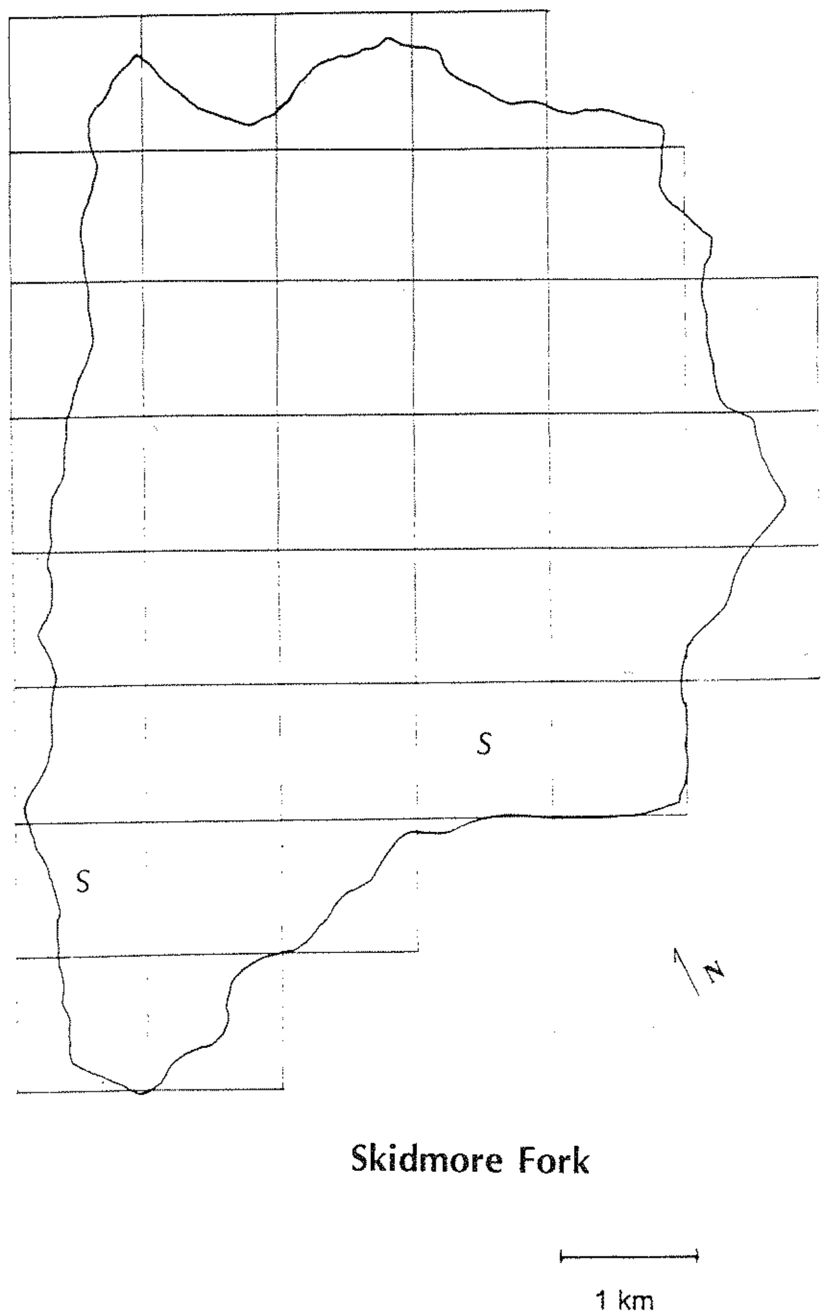
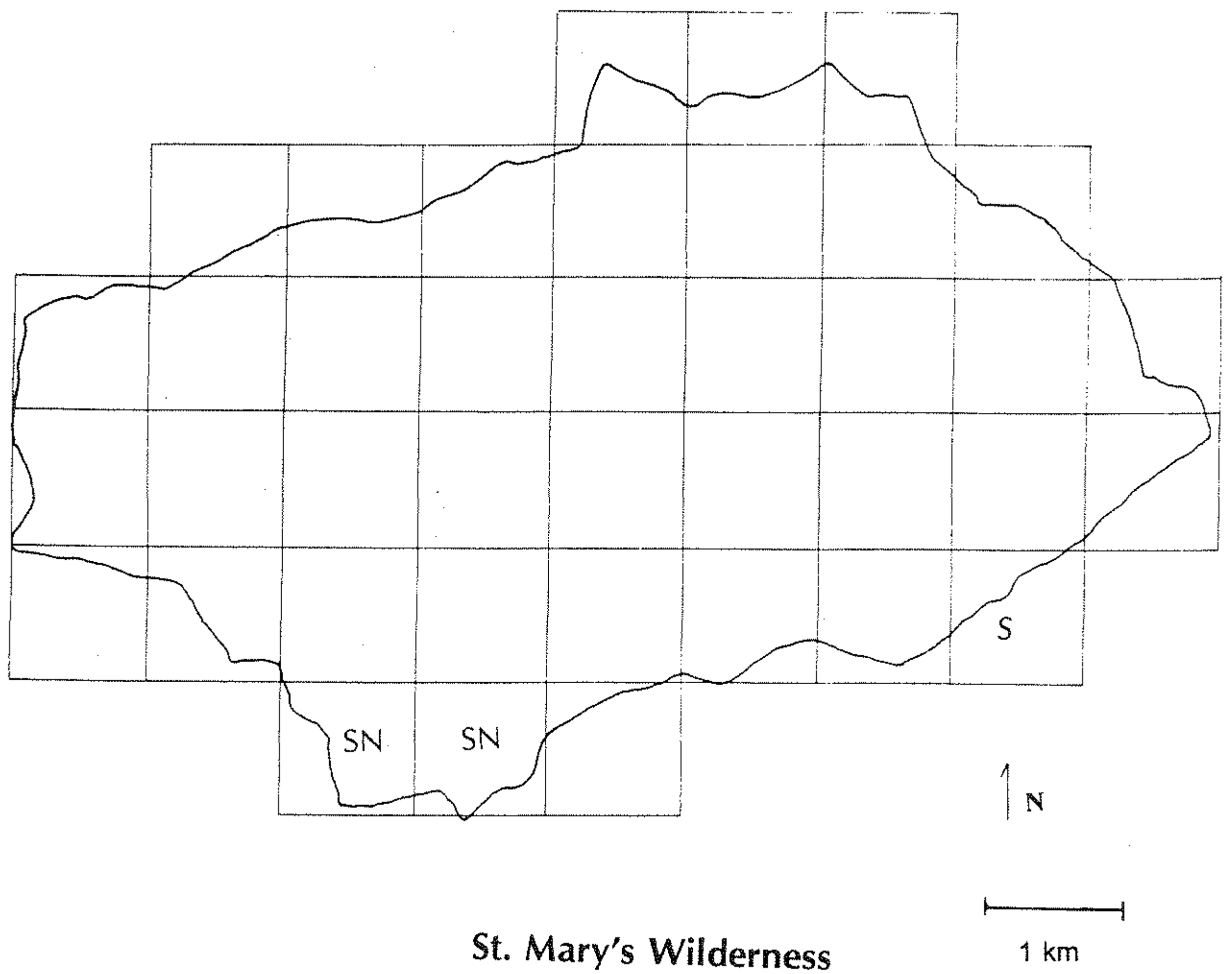


Fig. 4. Locations of 1.0 km² grids in the St. Mary's Wilderness with lichens containing high sulfur (≥ 0.2% sulfur by wt., S) or nitrogen (≥ 2.0% nitrogen by wt., N) content.



the numbers from the GWNF watersheds (excluding Brown's Run) are relatively low. This is especially true when data from the northern district of Shenandoah National Park (SNP) in Virginia (Lawrey, 1987) are used for comparison. When this area was surveyed in 1986 (Lawrey, 1987), 49 of 185 1 km^2 sites (26.5%) were found to have elevated sulfur contents. The fact that Brown's Run (and the northern half of Fridley Gap, which exhibited 3 hot spots) is closest to the northern district of SNP would suggest that pollution sources affecting Brown's (and perhaps Fridley) are similar to those that are known to be influencing the air quality of SNP.

In the Dolly Sods and Otter Creek Wildernesses of the Monongahela National Forest, two surveys (Lawrey & Hale, 1988a; Lawrey, 1993b) yielded frequencies (for sulfur only) of 4 "hot spot" 1 km^2 grids out of a total of 120 (3.3%) in 1987 and 8 of 120 (6.6%) in 1992, indicating a relatively low background level for S in these two areas but a trend over time toward higher contents.

It is not possible at present to determine the sulfur deposition patterns necessary to produce elevated (> 0.20% dry weight) sulfur contents in Flavoparmelia caperata samples. However, it is clear from values obtained from the literature (Table 4) that lichen sulfur values exceeding 0.20% dry wt. are seen only in regions receiving elevated sulfur pollution. Furthermore, elevated values of N are always associated with elevated values of S. It is interesting that many of the locations in Virginia with F. caperata lichens containing high sulfur have been high-elevation sites.

The idea that sulfur contents in lichens are associated with the elevation of the collecting site is based on previous studies done in Shenandoah National Park (Lawrey,

Table 4. Selected total sulfur values reported from lichens sampled from various environments.

Species and Location	S, % dry wt.	Source
Cladina mitis		
Sudbury, Ontario	0.10	Tomassini, 1976
Cladina stellaris		
Sudbury, Ontario	0.09	Tomassini, 1976
Rural northern Finland	0.07	Kauppi, 1976
Transplant, urban center, Oulu, Finland	0.21	"
Transplant, fertilizer factory, Finland	0.29	"
Flavoparmelia caperata		
Northern district, Shenandoah National Park	0.085-0.29	Lawrey, 1987
Otter Creek and Dolly Sods Wildernesses, WV, 1987	0.078-0.20	Lawrey & Hale, 1988a
Otter Creek and Dolly Sods Wildernesses, WV, 1992	0.082-0.211	Lawrey, 1993b
Whitetop Mountain, Virginia	0.096-0.222	Kinsman, 1990
Potomac River Basin, 1988	0.186-0.207	Lawrey, 1993a
Potomac River Basin, 1992	0.156-0.180	"
Hypogymnia physodes		
Western Finland, near industrial complex	0.19	Laaksovirta & Olkkonen, 1977
Transplant to chlor-alkali plant, Norway	0.30	Steinnes & Krog, 1977
Transplant to aluminum smelter, Poland	0.14	Swieboda & Kalemba, 1978
Norway	0.14	Solberg, 1967
Fertilizer plant, central Finland	0.19-0.28	Tynnyrinen et al., 1992
Xanthoparmelia chlorochroa		
Powder River Basin, Wyoming and Montana	0.07	Erdman & Gough, 1977
Xanthoparmelia conspersa		
Sendai City, Japan	0.16	Saeki et al., 1977
Xanthoparmelia conspersa		
Flat Tops, Colorado	0.11-0.16	Hale, 1982
Umbilicaria deusta		
Sudbury, Ontario	0.25	Nieboer et al., 1977
Usnea sp.		
Flat Tops, Colorado	0.13-0.15	Hale, 1982

1987; Lawrey & Hale, 1988b; Lawrey, 1993a) and Monongahela National Forest (Lawrey & Hale, 1988a; Lawrey, 1993b), which yielded significant positive correlations between S content in F. caperata and elevation of the collecting site. This tendency for high-elevation lichens to have increased contents of sulfur appeared to implicate long-distance transport of sulfur from a variety of sources.

To test the hypothesis that lichens from high elevation sites were accumulating the highest contents of S and N in the GWNF, a series of nonparametric correlation tests were done for each watershed. Results (Table 5) indicate few significant correlations with elevation for either S or N content in lichens. This lack of correlation between S and elevation in the GWNF may be the result of a lower elevation gradient in the GWNF sites than in sites previously studied in Monongahela National Forest. It may also be because no elevational differences in S and N deposition exist at these sites, as they appear to do in Shenandoah National Park (SNP) and Monongahela National Forest (MNF). If this is true, then the GWNF sites may differ significantly from SNP and MNF in terms of sources of S and N or deposition patterns. In any event, the present results indicate a need for further substantiation of these patterns.

Despite a lack of correlation between S or N and elevation, however, highly significant correlations were found between S and N content in each watershed, indicating that the processes regulating the uptake of each element are generally similar in the watersheds.

A comparison of the results from the present study with results from previous studies done in nearby study locations (Table 6) indicates that the mean element values

Table 5. Values of Kendall's tau (a nonparametric correlation statistic) for various pairwise correlations between either sulfur (S) and nitrogen (N) content of Flavoparmelia caperata from various locations and elevation. Also given are values indicating the level of correlation between S and N at each location. Significant correlations are indicated with alpha values.

Location	Pairwise tests	Kendall's tau	Alpha
Brown's Run	S vs Elevation	0.126	
	N vs Elevation	0.080	
	S vs N	0.652	0.001
Fridley Gap	S vs Elevation	-0.228	0.05
	N vs Elevation	-0.173	
	S vs N	0.590	0.001
Skidmore	S vs Elevation	0.096	
	N vs Elevation	-0.166	
	S vs N	0.383	0.01
St. Mary's	S vs Elevation	0.295	0.01
	N vs Elevation	0.015	
	S vs N	0.331	0.001
Laurel Fork	S vs Elevation	0.035	
	N vs Elevation	0.024	
	S vs N	0.485	0.001
James R. Face	S vs Elevation	0.311	
	N vs Elevation	0.289	
	S vs N	0.711	0.001
Mt. Rogers	S vs Elevation	-0.178	
	N vs Elevation	-0.060	
	S vs N	0.711	0.001
GWNF (all sites)	S vs Elevation	-0.228	0.05
	N vs Elevation	-0.365	0.01
	S vs N	0.558	0.001
JNF (all sites)	S vs Elevation	-0.447	0.01
	N vs Elevation	-0.221	
	S vs N	0.626	0.001

Table 6. Mean sulfur and nitrogen values for Flavoparmelia caperata specimens collected in the present study compared with values for the same lichen species obtained from previous studies done on in the eastern United States.

Location	Date	Source	Element Content[1] S	N
Shenandoah NP, VA Northern District	1983	Lawrey, 1984	0.210 ± 0.005	-
Shenandoah NP, VA Central District	1983	Lawrey, 1984	0.187 ± 0.003	-
Shenandoah NP, VA Southern District	1983	Lawrey, 1984	0.169 ± 0.004	-
Otter Creek Wilderness, Monongahela NF, WV	1987	Lawrey & Hale, 1988a	0.124 ± 0.002	-
same	1992	Lawrey, 1993b	0.145 ± 0.002	1.347 ± 0.024
Dolly Sods Wilderness, Monongahela NF, WV	1987	Lawrey & Hale, 1988a	0.147 ± 0.003	-
same	1992	Lawrey, 1993b	0.157 ± 0.003	1.450 ± 0.031
Brown's Run, George Washington NF, VA	1995	present study	0.188 ± 0.002	1.763 ± 0.029
Fridley Gap, George Washington National Forest, VA	1995	present study	0.170 ± 0.001	1.694 ± 0.017
Skidmore Fork, George Washington NF, VA	1995	present study	0.154 ± 0.028	1.432 ± 0.204
St. Mary's Wilderness, George Washington NF, VA	1995	present study	0.148 ± 0.033	1.398 ± 0.270
Laurel Fork Area, George Washington NF, VA	1995	present study	0.138 ± 0.032	1.224 ± 0.205
James River Face Wilderness, Jefferson NF, VA	1987	St. Clair, 1987	0.21 ± 0.044	-
same	1995	present study	0.177 ± 0.002	1.446 ± 0.024
Whitetop Mountain, Jefferson NF, VA	1990	Kinsman, 1990	0.150 ± 0.025	1.180 ± 0.210
Mt. Rogers/Whitetop Mt., Jefferson NF, VA	1995	present study	0.135 ± 0.001	1.223 ± 0.007

of S and N in the Massanutten watersheds are similar to those observed previously in the Shenandoah National Park in 1983. The remaining sites exhibited element levels most similar to those observed in the Otter Creek and Dolly Sods Wildernesses of the Monongahela National Forest in 1987.

It is anticipated that continued monitoring of the lichen elemental status in the watersheds will permit increased resolution of the spatial patterns in pollutant deposition observed in this survey. Since these trends may be caused by long-distance transport of pollution from a variety of sources, it is expected that they will continue in the future, and an objective study of their effects requires a monitoring protocol that can be continued in the future. Therefore, results of lichen biomonitoring efforts like this one, combined with information from mechanical air quality monitoring, provide a continuous and relatively inexpensive information base upon which USDA-Forest Service land managers can rely to make decisions affecting all areas in the George Washington National Forest.

Element Analysis of Test Lichens from the Jefferson National Forest

The twenty locations yielding samples from the Jefferson National Forest (10 locations each in the James River Face Wilderness and the Mount Rogers National Recreational Area) provided a reasonable amount of data for assessing the background levels for S and N in these areas. However, the samples were not collected in grids. Results (Table 7, all data in Appendix 4) indicated that James River Face sites (site locations in Appendix 2) had the highest mean values of both S and N, comparable to

Table 7. Range and mean values of total sulfur and total nitrogen measured in thalli of Flavoparmelia caperata collected from ten sampling locations in the James River Face Wilderness and the Mount Rogers National Recreational Area of the Jefferson National Forest in 1995.

	Mean Percent Dry Weight ± S.E.[1]	
Site	S	N
James River Face (30)[2] Wilderness	0.177 ± 0.002 (0.14 - 0.20)	1.446 ± 0.024 (1.26 - 1.76)
Mount Rogers National (30) Recreational Area	0.135 ± 0.001 (0.11 - 0.16)	1.223 ± 0.007 (0.87 - 1.60)

[1] Values of S and N mean percent dry wt. ± the standard error of the mean. Numbers in parenthesis are ranges for each site.

[2] Numbers in parentheses are sample sizes for each elemental analysis sample at each location.

those of the the Massanutten sites in the GWNF. However, only one of the ten locations in the James River Face Wilderness (#6; site locations in Appendix 2) exhibited a mean sulfur content above 0.2%. None of the Mt. Rogers/Whitetop sites (site locations in Appendix 3) had mean values of S exceeding 0.2%, and no sites from the JNF had N values above 2.0% in the present study.

Although fewer comparable data exist for these JNF locations (Table 6), it is possible to give a preliminary assessment of these values for the establishment of baseline conditions. St. Clair (1987) found some relatively high values of S in Flavoparmelia caperata in his survey of the James River Face Wilderness in 1987. He found that three of five sampling locations had mean values of S exceeding 0.2% (and one had a value exceeding 0.3%). Other lichens (Tuckermannopsis halei, Parmotrema stuppeum, and Lasallia papulosa) also exhibited mean values of S exceeding 0.2%. The Mount Rogers/Whitetop Mountain area, however, appears to have lower sulfur inputs. This assumption is based on a previous lichen survey done in the Whitetop area by Kinsman (1990), who obtained an overall mean value of 0.15% $\pm$ 0.025 (S.E. of the mean, N = 26), a value which compares favorably with sulfur values obtained from the GWNF watersheds exhibiting low background levels of N and S. A comparably low N value was also obtained by Kinsman for the Whitetop survey (mean N of 1.18% $\pm$ 0.21 SE, N = 26), although it should be pointed out that an analytical technique (microkjedahl) different from that employed in the present study (dry combustion) was used to obtain this value. Given the data available in the literature and the present study, one must conclude that the James River Face Wilderness is receiving more inputs of S than the Mt. Rogers Recreational Area. It is recommended that additional surveys of these areas be done at five year intervals, and that additional sampling sites be established in each area, perhaps using a grid system as was done in the GWNF watersheds. This will yield a greater quantity of data for these areas and permit a closer comparison of these sites with the GWNF sites.

CONCLUSIONS

A baseline survey of the lichens of the George Washington (GWNF) and Jefferson National Forests (JNF) yielded a number of important findings.

(1) The lichen floras of the five watersheds of the GWNF (and previously sampled from the JNF) exhibit a species richness and community composition expected for natural areas undisturbed by air pollution. Numerous pollution-sensitive species are observed in good condition throughout all of the surveyed areas, and no sites exhibit reductions in diversity that would be expected in pollution-damaged areas.

(2) Mean values of sulfur and nitrogen measured in test lichens indicate generally good air quality throughout the areas surveyed. However, mean S and N values are elevated in the Massanutten area of the GWNF and the James River Face Wilderness of the JNF; these conclusions are supported by data from previous studies in these areas or nearby to these study areas.

(3) In the GWNF watersheds, the proportion of sampling grids with elevated sulfur (0.20% and higher) or nitrogen (2.0% or higher) is highest in the Brown's Run watershed

(where 34.6% of the grids have excessive S or N or both), but is relatively low in all other study areas.

(4) Significant positive correlations between mean S and mean N at each site were obtained for all sampling locations in both the GWNF and the JNF, indicating that atmospheric inputs of both elements may be regulated by similar processes.

(5) In general, the element data provide the most objective basis for assessing the effects of air quality changes in the study areas. "Hot spots" of sulfur and nitrogen evident from the lichen elemental analysis are undoubtedly due to air pollution effects; however, there are no noticeable effects on the lichen flora. This suggests that the continued monitoring of lichen elemental status will provide useful and important "early warning" of impacts to air quality related values in the study areas of both GWNF and JNF.

RECOMMENDATIONS

Based on the results of this study, the following recommendations can be made:

(1) Follow-up floristic analysis should be done in five years to document any changes in lichen species presence/absence; this will also add to the present lichen species list for the study areas. It is recommended that a similar protocol (the method used by Dey, 1995) be used to assess floristics in the five watersheds. This effort could perhaps involve USDA-Forest Service personnel who have been trained to do this kind of assessment.

(2) Elemental analysis grids in the GWNF watersheds should be resampled in five years to collect F. caperata samples for element analysis. Element data collected in these

permanent sites can then be compared with data collected in 1995 to continue to resolve some of the important trends evident from the present study. These samples could be collected by USDA-Forest Service personnel.

(3) A grid system similar to that used in the GWNF watersheds should be established on the JNF sites presently under study (Mount Rogers National Recreational Area and James River Face Wilderness). This will permit a more direct comparison of these sites with those from GWNF and will generate more S and N sampling locations from the JNF sites.

(4) New studies may be initiated to document changes in lichen community structure caused by air pollution effects. Such changes might be expected as a consequence of gradual changes in pollution levels and would not be evident from florisitics data consisting of presence/absence only. Community studies should target sites especially sensitive to pollution and focus on the long-term effects of air quality changes to sensitive species (especially Usnea species). For example, total biomass of Usnea species along elevational gradients in the five watersheds could be sampled to establish a baseline for future resurveys. Since future resurveys of lichen floristics and elemental status are probably most valuable, these new studies would only be done if additional resources are available.

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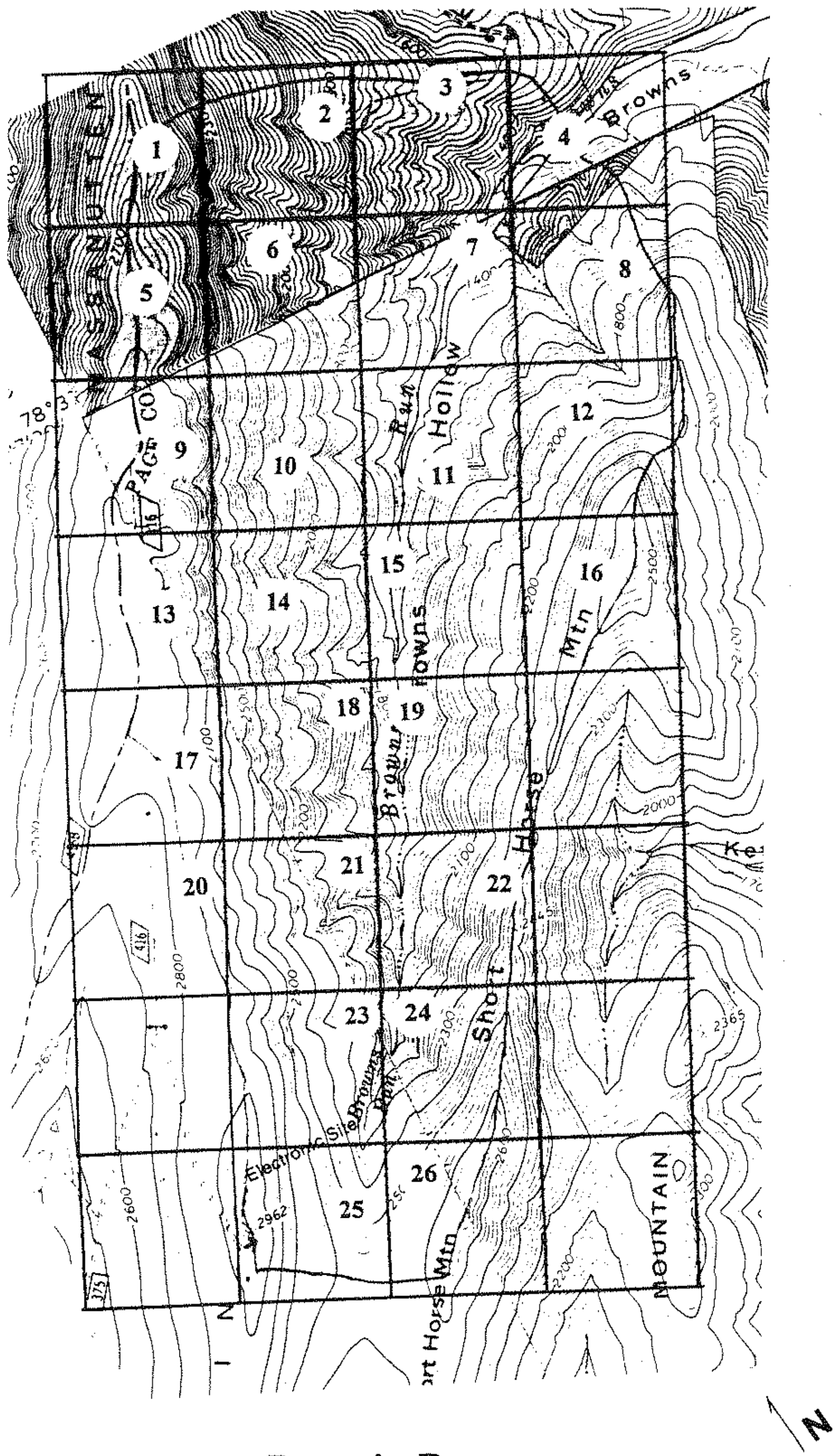
APPENDIX 1. Locations of elemental analysis grids in the five watersheds of the George Washington National Forest. Numbers indicate the grid numbers and the locations of the numbers on the base maps indicate the sites from which lichen samples were collected for elemental analysis. All base maps are USGS 7.5 minute series maps. Sites 1-26 are for Brown's Run (base maps Tenth Legion, Stanley and Hamburg Quads), sites 27-62 are for Fridley Gap (base maps Elkton and Tenth Legion Quads), sites 63-99 are for Skidmore Fork (base map Brandywine Quad), sites 100-138 are for St. Mary's Wilderness (base maps Vesuvius and Big Levels Quads), sites 139-185 are for Locust Spring/Buck Run (base maps Thornwood and Snowy Mt. Quads). Scale 1:24,000.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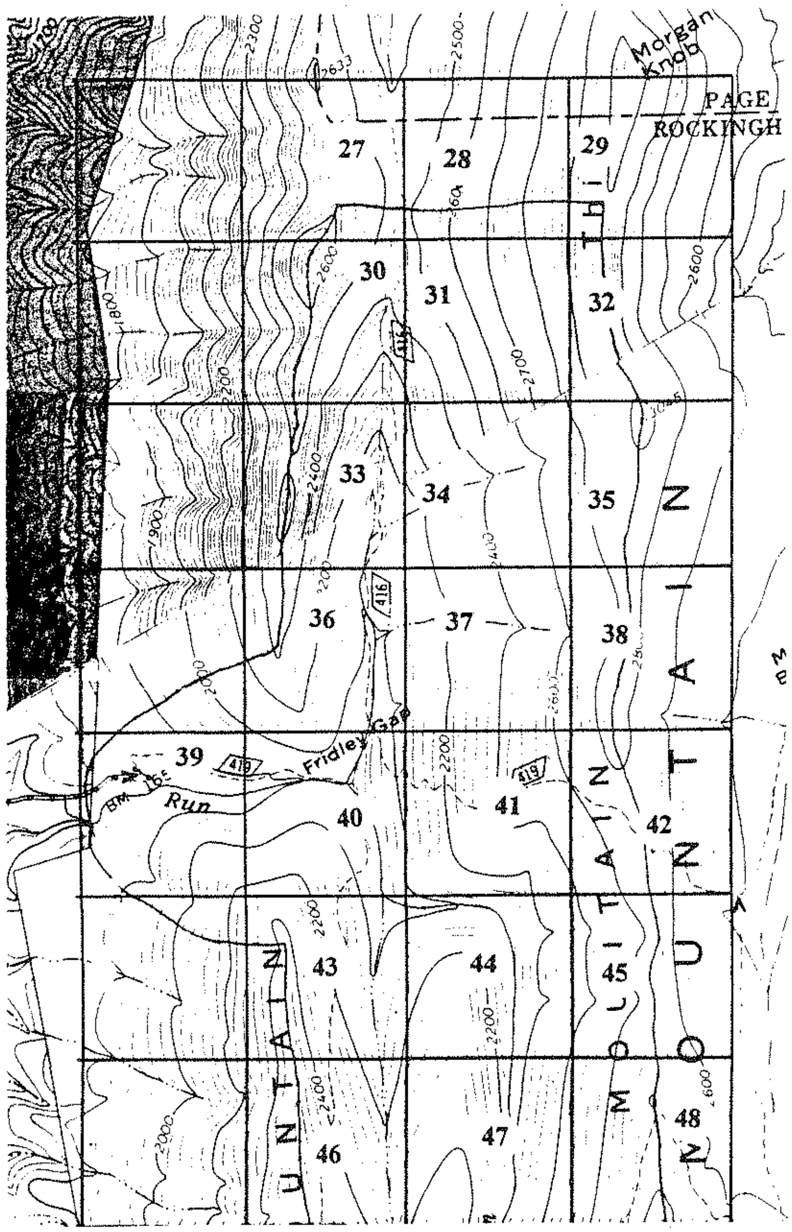
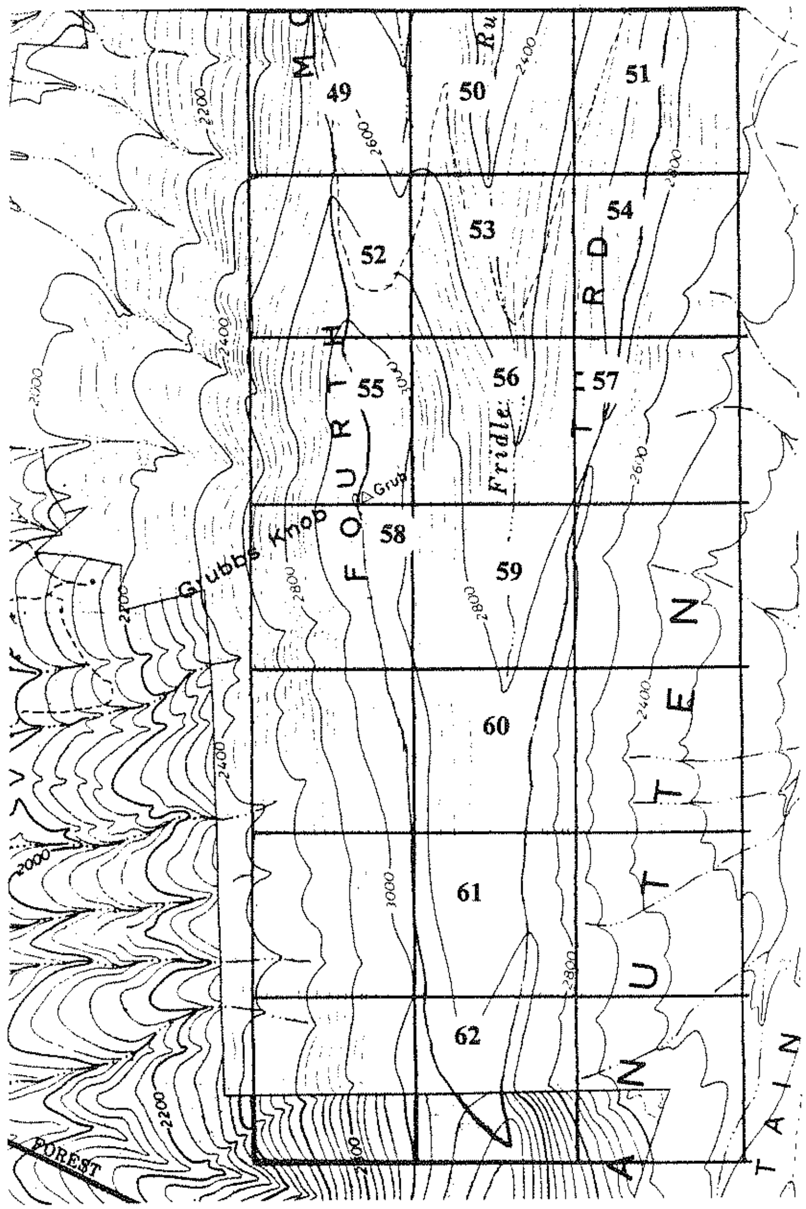
Brown's Run



Fridley Gap, N half



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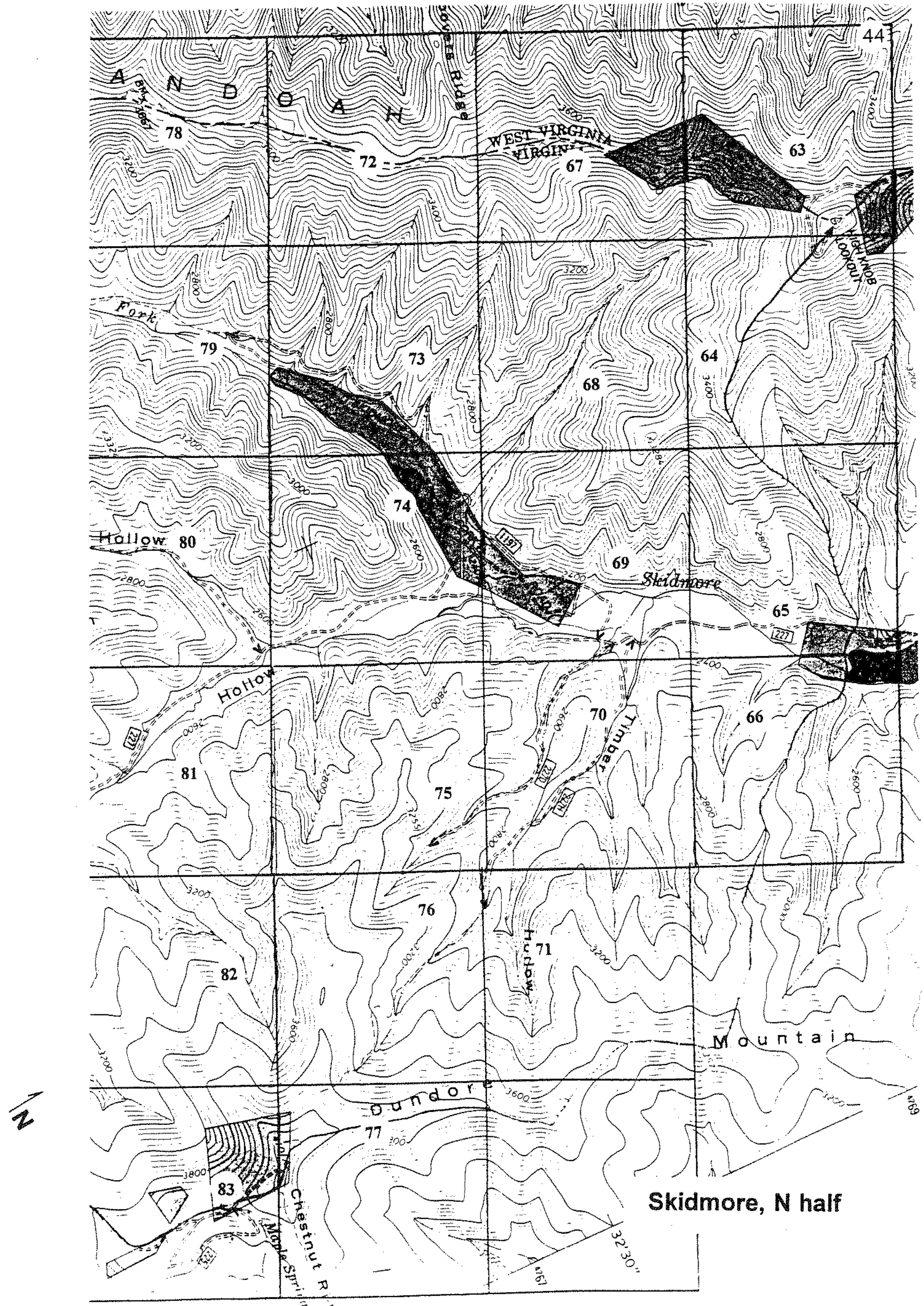

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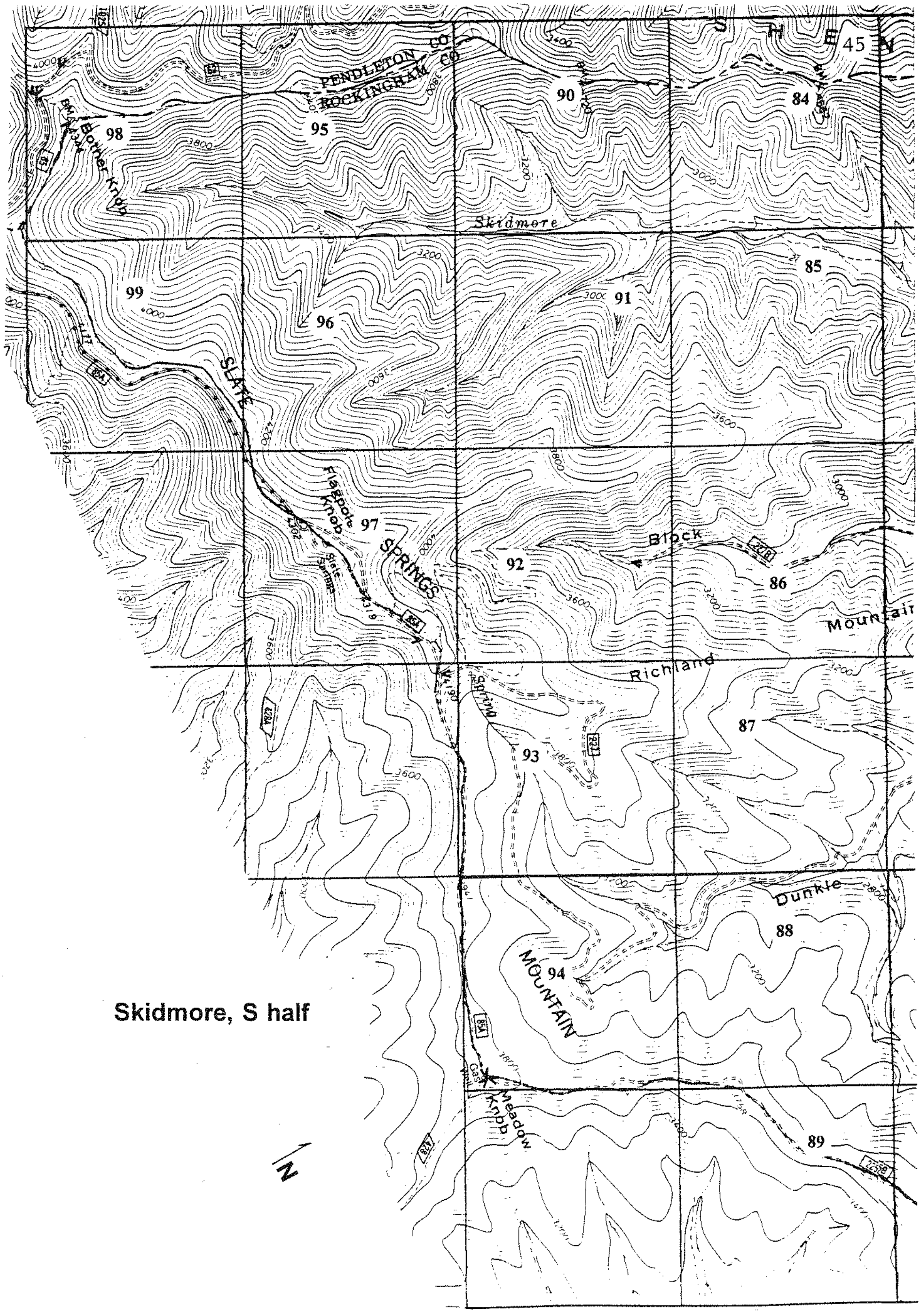

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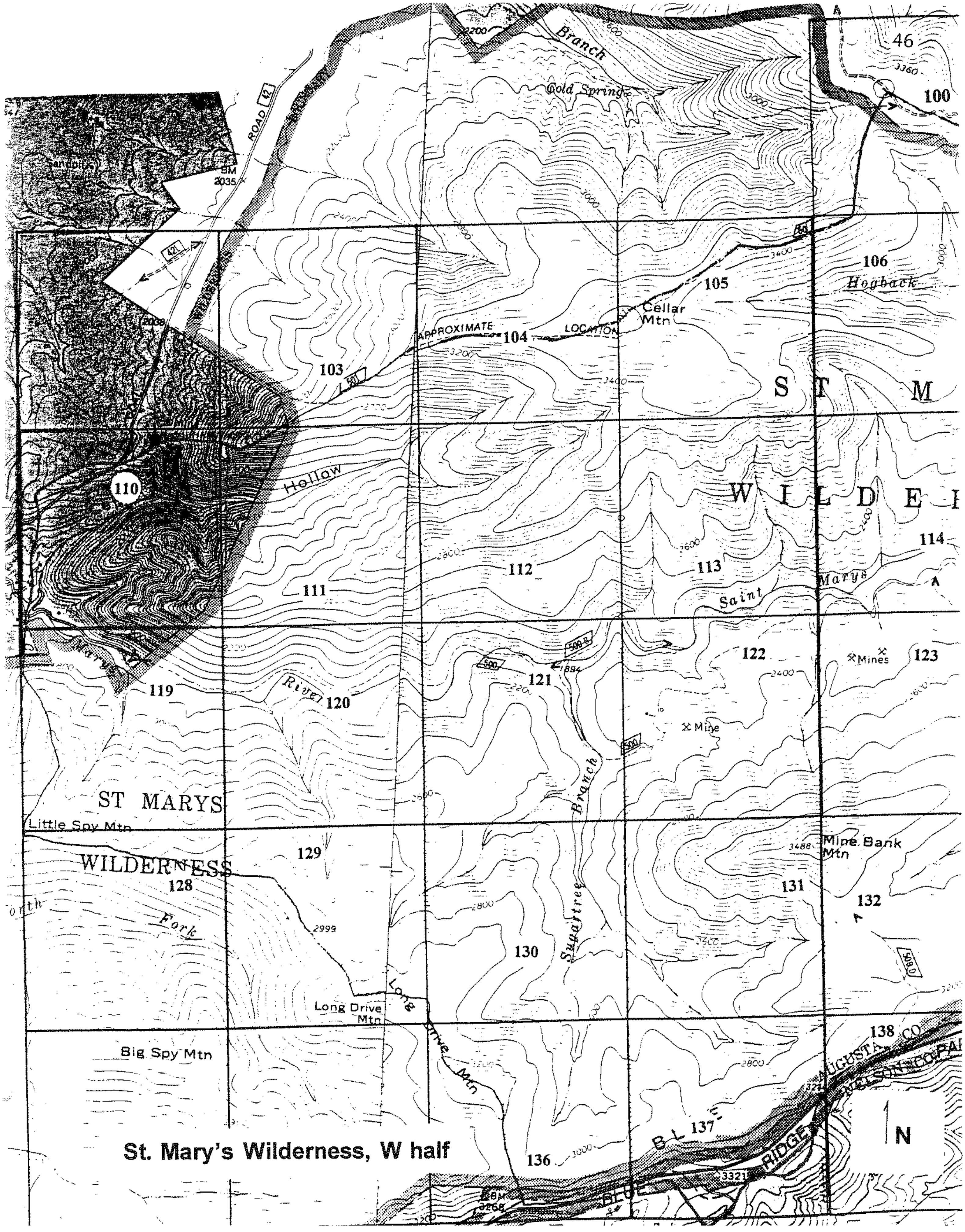
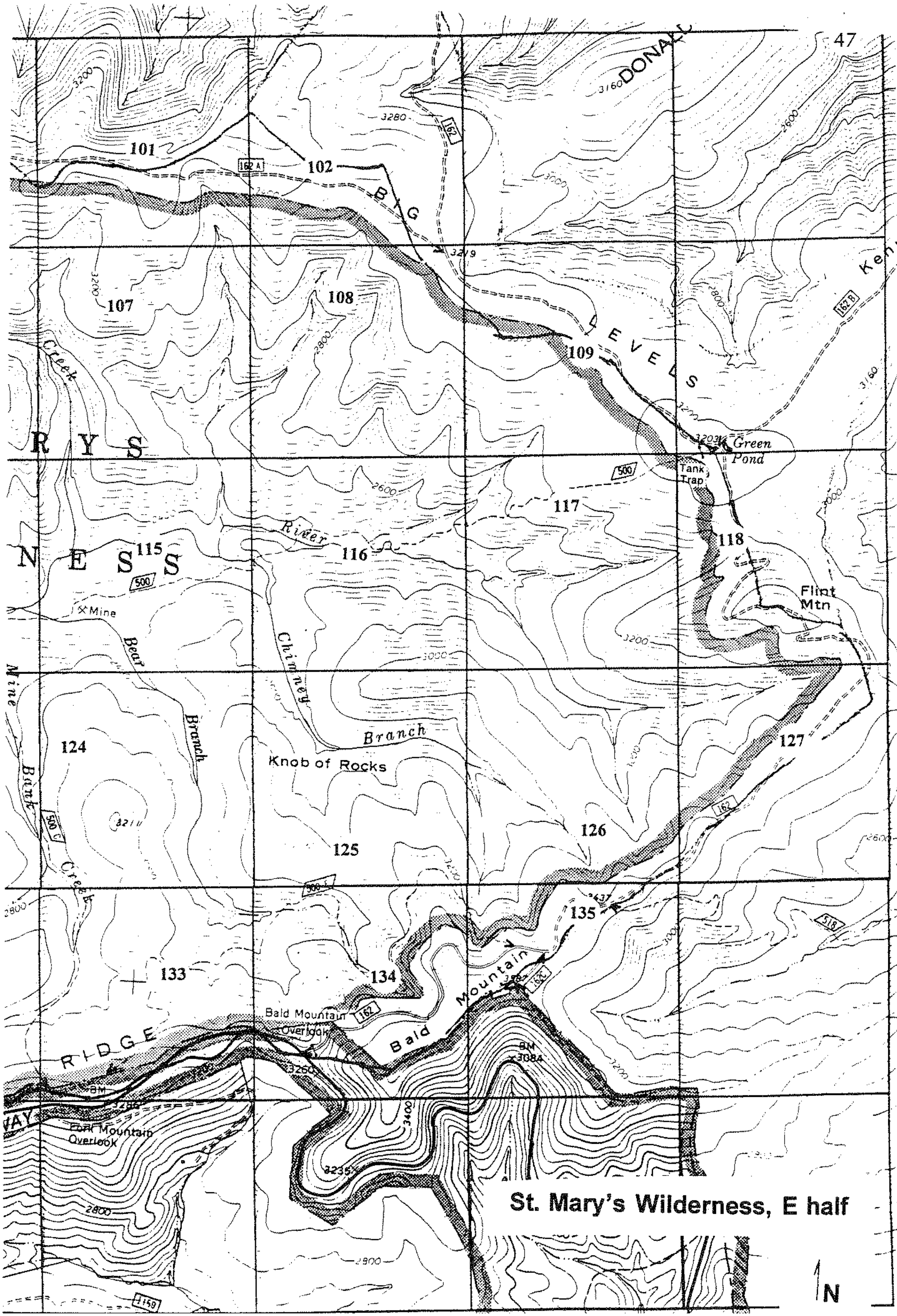
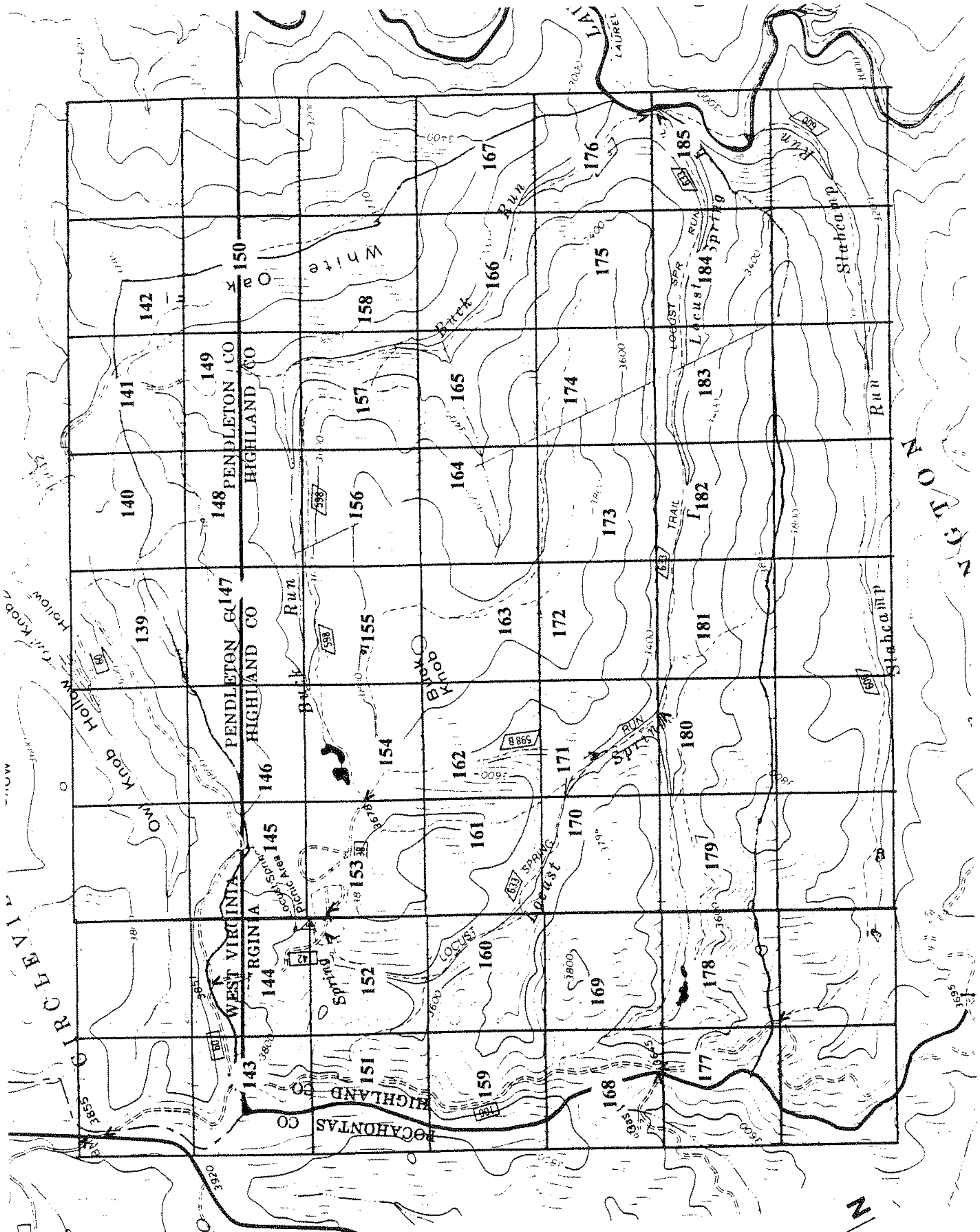


St. Mary's Wilderness, W half

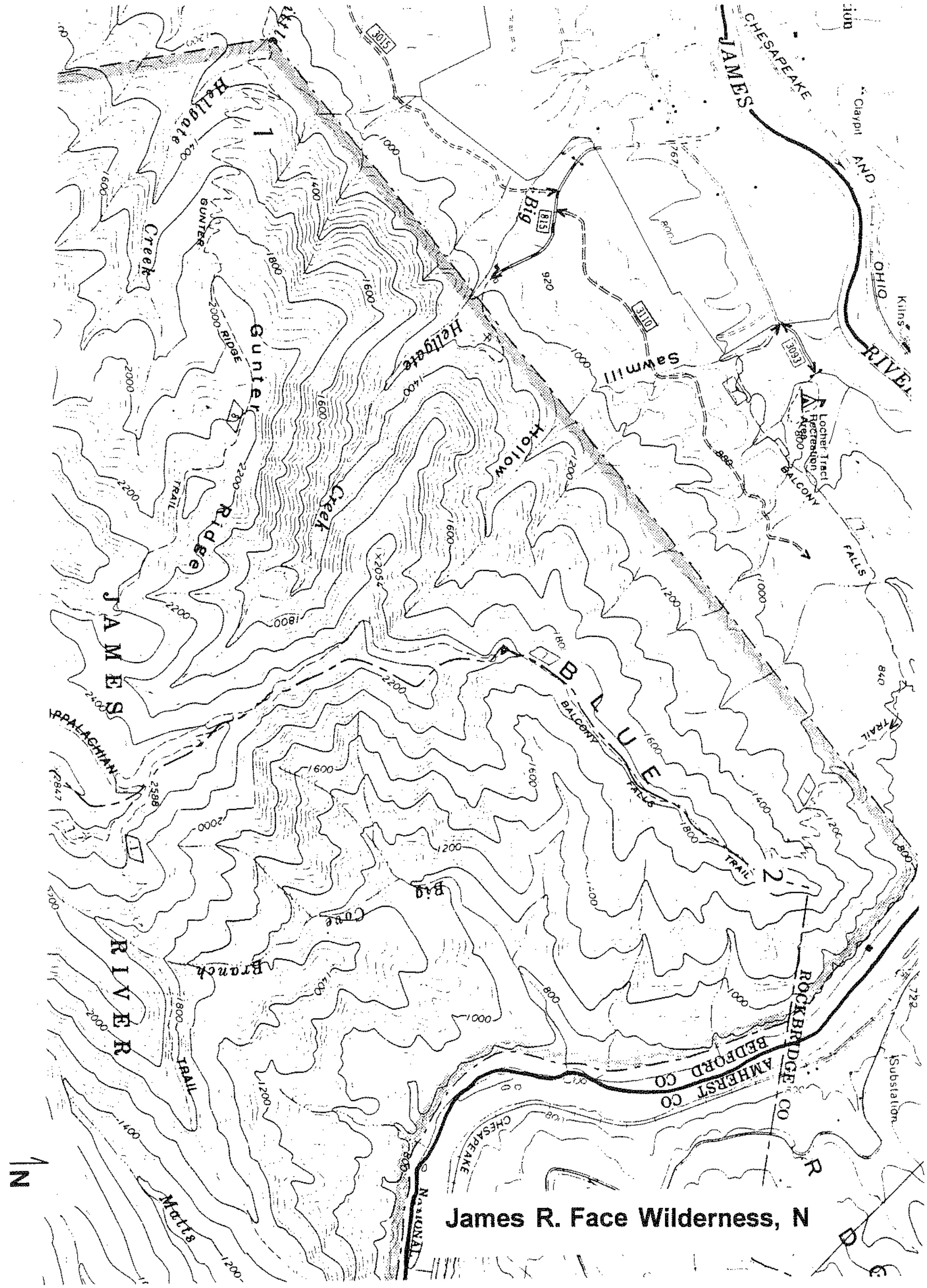


St. Mary's Wilderness, E half

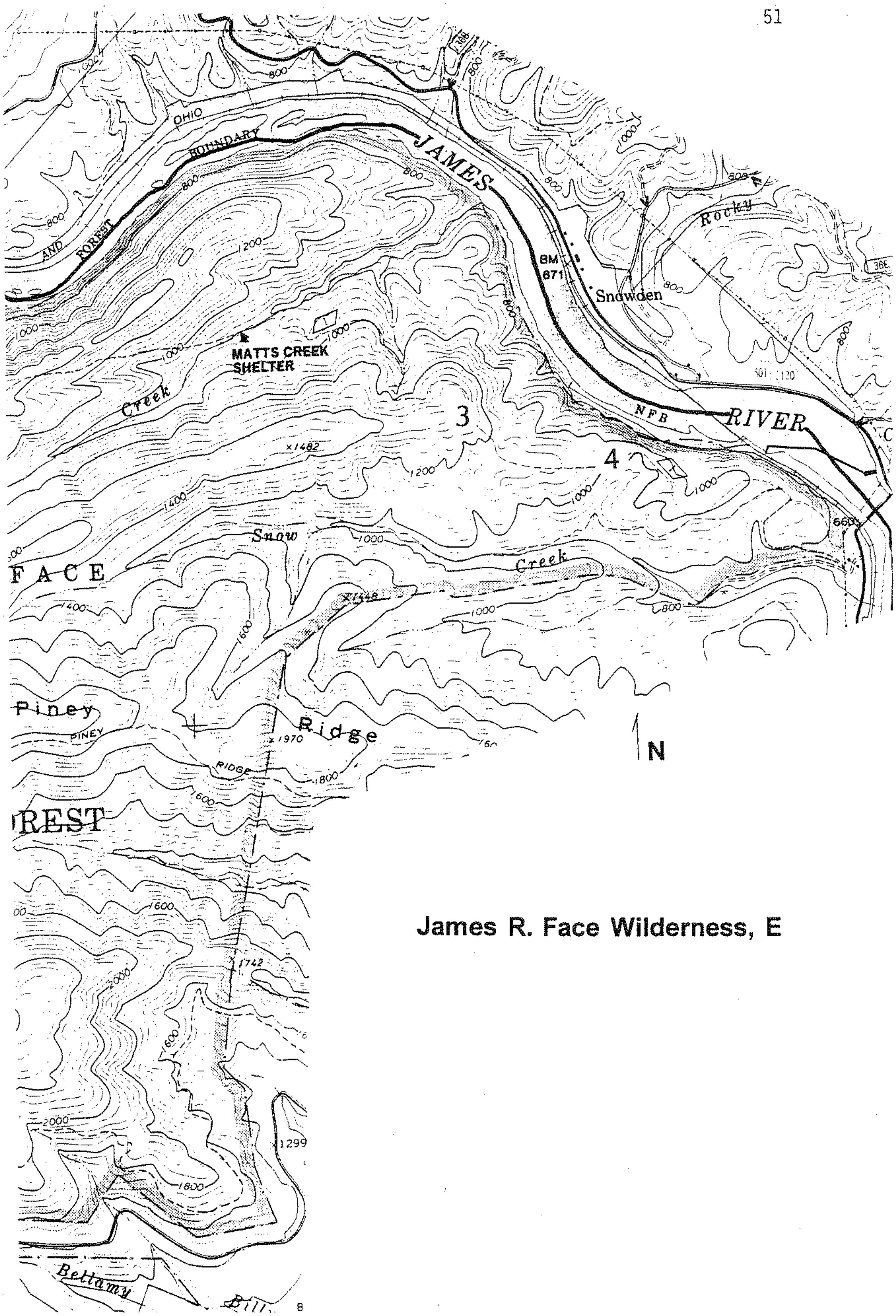


Locust Spring

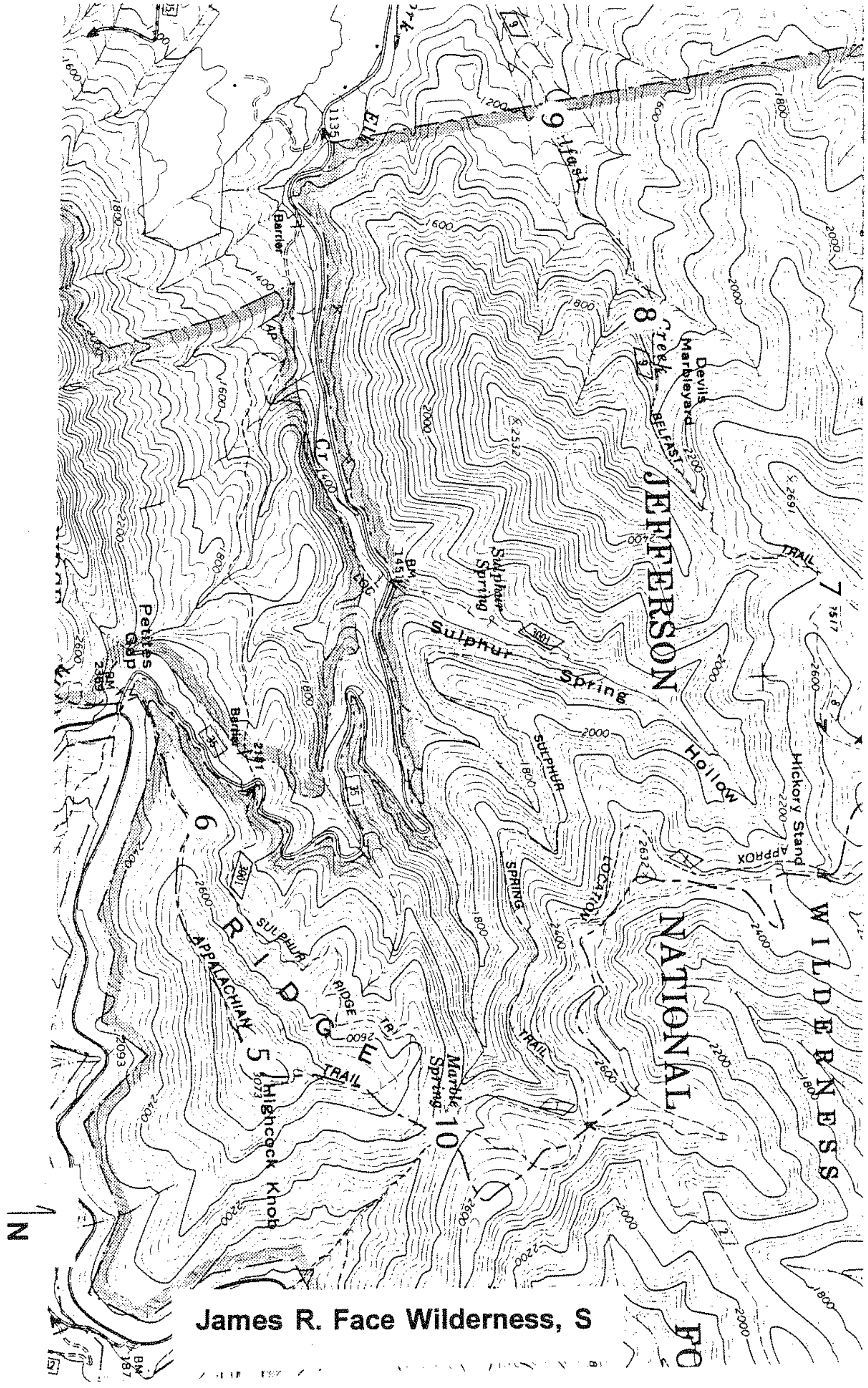
APPENDIX 2. Locations of sites in the James River Face Wilderness of the Jefferson National Forest from which lichens were collected for elemental analysis. These are the same areas collected by St. Clair (1987) in an earlier lichen survey. Numbers indicate the sample number and the locations of numbers on the base map indicte the sites from which lichen samples were collected for elemental analysis. Base map is USGS 7.5 minute series map (Snowden Quad). Scale 1:24,000.



James R. Face Wilderness, N

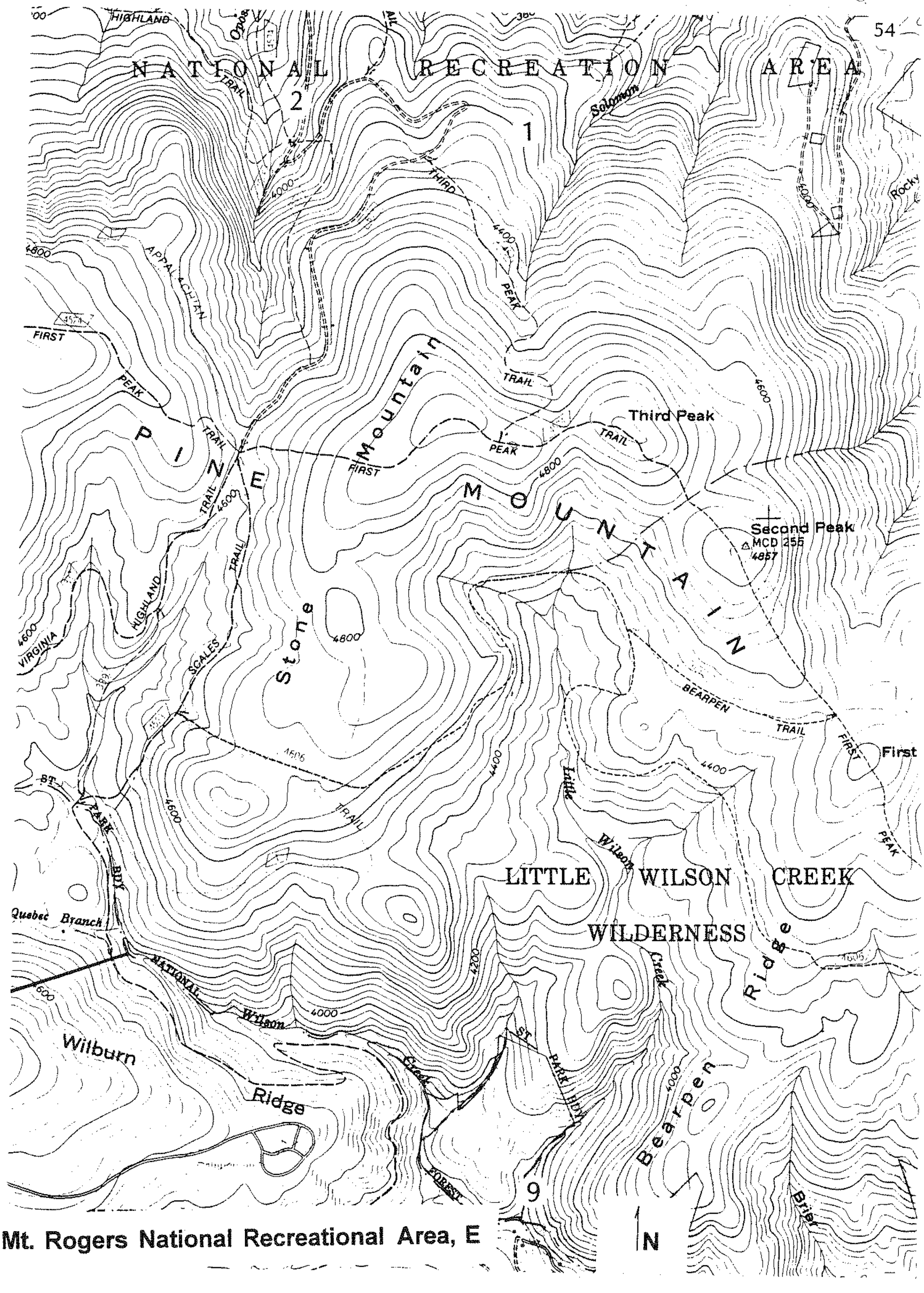


James R. Face Wilderness, E

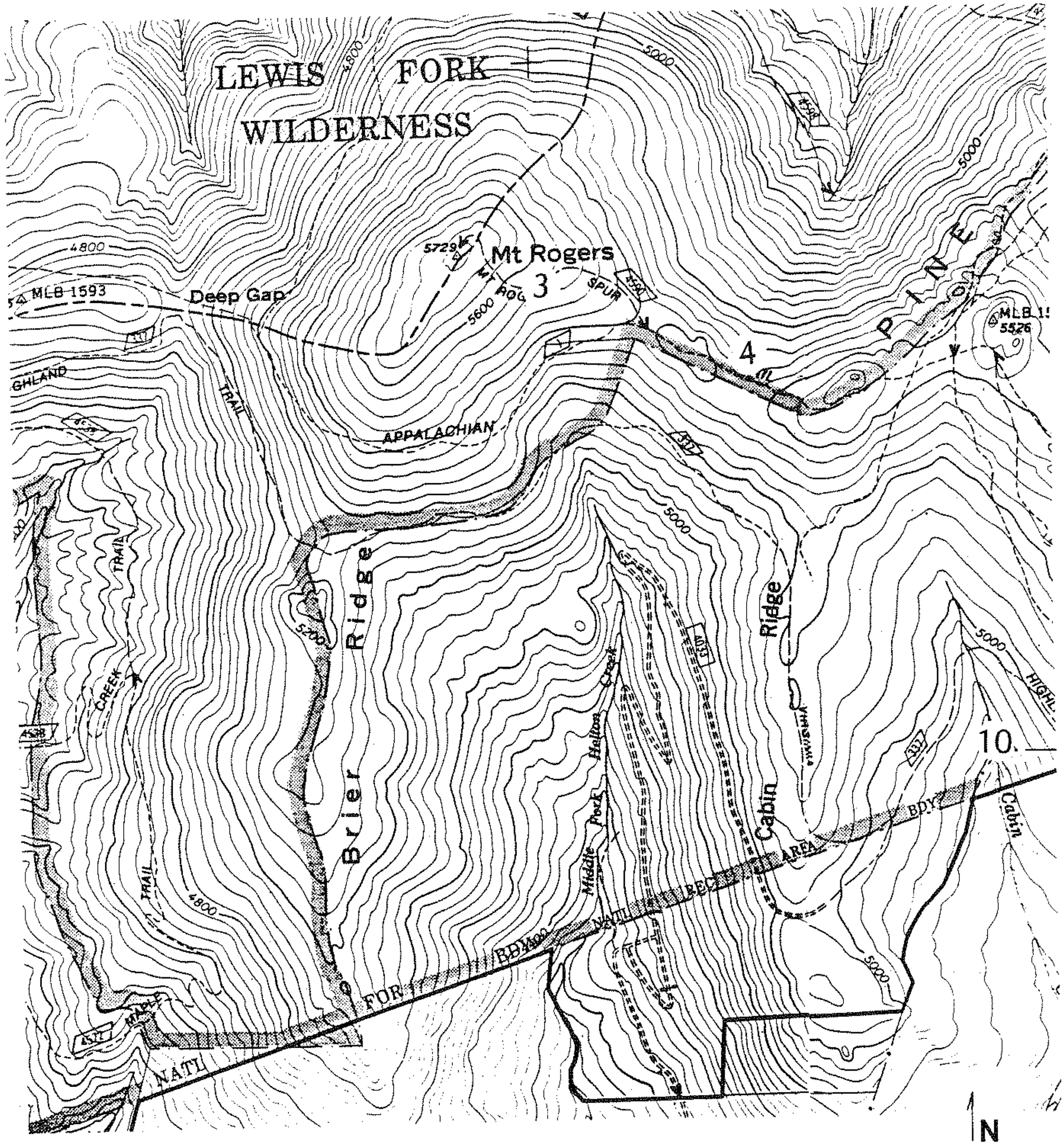


James R. Face Wilderness, S

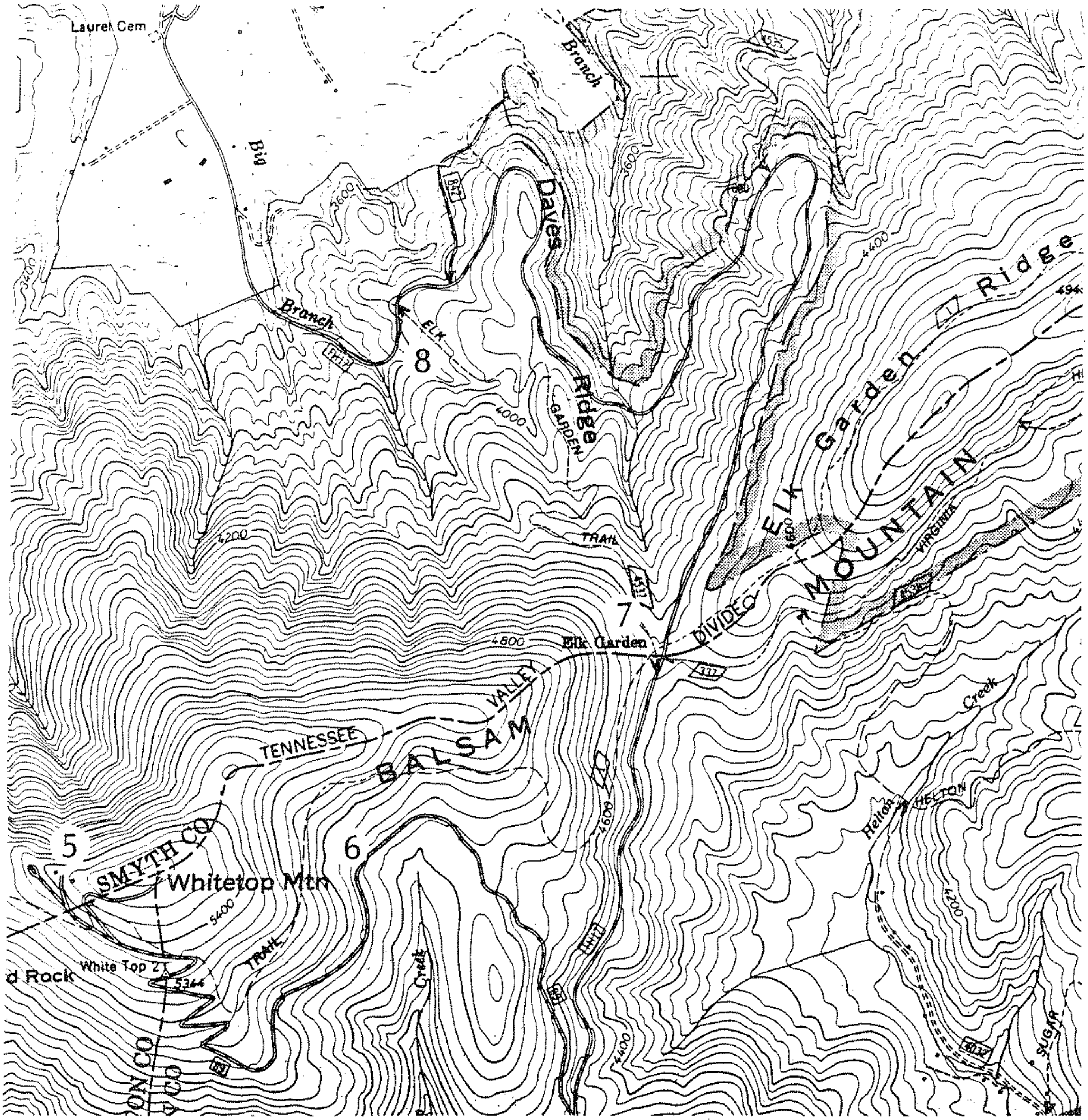
APPENDIX 3. Locations of sites at the Mount Rogers National Recreational Area of the Jefferson National Forest from which lichens were collected for elemental analysis. Numbers indicate the sample number and the locations of numbers on the base map indicte the sites from which lichen samples were collected for elemental analysis. Base maps are USGS 7.5 minute series maps (Whitetop Mt. and Trout Dale Quads). Scale 1:24,000.



Mt. Rogers National Recreational Area, E



Mt. Rogers National Recreational Area, Central



Mt. Rogers National Recreational Area, W

N

APPENDIX 4. Element data for lichen (Flavoparmelia caperata) samples collected from each locality in the George Washington and Jefferson National Forests in the 1995 survey. The last digit of each site number is a sample number (1-3); the first part of the site number is the grid number. (For example, site no. 112 from this table is sample #2 from grid number 11). Samples from the Jefferson National Forest were given arbitrary numbers (site locations are given in last column). All element data are in percent; means and standard deviations are calculated for each site and for each location. Elevations of each site are given in meters.

Site No.	Elevation (m)	N (%)	S (%)	Mean N	SD N	Mean S	SD S
Brown's Run							
11		2.14	0.21				
12	798.5	2.19	0.22	2.123333	0.076376	0.213333	0.005774
13		2.04	0.21				
21		2.23	0.23				
22	536.4	2.11	0.23	2.193333	0.072342	0.233333	0.005774
23		2.24	0.24				
31		1.65	0.17				
32	469.4	1.62	0.18	1.623333	0.025166	0.176667	0.005774
33		1.6	0.18				
41		2	0.18				
42	365.8	1.99	0.2	1.983333	0.020817	0.19	0.01
43		1.96	0.19				
51		1.73	0.19				
52	822.9	1.63	0.17	1.666667	0.055076	0.18	0.01
53		1.64	0.18				
61		1.9	0.19				
62	609.6	2.05	0.2	1.943333	0.092916	0.193333	0.005774
63		1.88	0.19				
71		1.55	0.16				
72	426.7	1.47	0.17	1.53	0.052915	0.166667	0.005774
73		1.57	0.17				
81		1.87	0.2				
82	548.6	1.74	0.18	1.986667	0.321299	0.2	0.02
83		2.35	0.22				
91		2.16	0.23				
92	829.1	2.12	0.23	2.09	0.088882	0.223333	0.011547
93		1.99	0.21				
101		1.89	0.21				
102	640.1	1.78	0.21	1.79	0.095394	0.206667	0.005774
103		1.7	0.2				
111		1.72	0.21				
112	518.2	1.84	0.21	1.82	0.091652	0.22	0.017321
113		1.9	0.24				
121		1.78	0.19				
122	609.6	1.83	0.18	1.793333	0.032146	0.19	0.01
123		1.77	0.2				

131		1.83	0.2				
132	859.5	1.81	0.2	1.823333	0.011547	0.196667	0.005774
133		1.83	0.19				
141		1.87	0.21				
142	640.1	1.71	0.19	1.793333	0.080208	0.2	0.01
143		1.8	0.2				
151		1.63	0.17				
152	487.7	1.64	0.18	1.64	0.01	0.176667	0.005774
153		1.65	0.18				
161		1.94	0.2				
162	737.6	1.8	0.21	1.896667	0.083865	0.206667	0.005774
163		1.95	0.21				
171		2.25	0.23				
172	853.4	2.1	0.21	2.163333	0.077675	0.213333	0.015275
173		2.14	0.2				
181		1.73	0.17				
182	560.8	1.73	0.17	1.7	0.051962	0.166667	0.005774
183		1.64	0.16				
191		1.6	0.16				
192	542.5	1.63	0.15	1.666667	0.090738	0.16	0.01
193		1.77	0.17				
201		1.58	0.18				
202	829.1	1.48	0.19	1.523333	0.051316	0.183333	0.005774
203		1.51	0.18				
211		1.63	0.16				
212	652.3	1.5	0.16	1.533333	0.085049	0.156667	0.005774
213		1.47	0.15				
221		1.62	0.19				
222	725.4	1.47	0.16	1.53	0.079373	0.166667	0.020817
223		1.5	0.15				
231		1.23	0.15				
232	640.1	1.3	0.16	1.246667	0.047258	0.153333	0.005774
233		1.21	0.15				
241		1.14	0.14				
242	646.2	1.28	0.17	1.28	0.14	0.166667	0.025166
243		1.42	0.19				
251		1.92	0.19				
252	762	1.69	0.17	1.786667	0.119304	0.176667	0.011547
253		1.75	0.17				
261		1.64	0.16				
262	762	1.67	0.17	1.706667	0.090738	0.166667	0.005774
263		1.81	0.17				

Means	1.762821	0.187821
Standard Dev	0.256231	0.023831
	2.35	0.24
	1.14	0.14

Fridley Gap				Mean N	SD N	Mean S	SD S
271		1.96	0.22				
272	762	1.86	0.19	1.91	0.05	0.2	0.017321
273		1.91	0.19				
281		1.88	0.18				
282	774.2	1.7	0.17	1.796667	0.090738	0.176667	0.005774
283		1.81	0.18				
291		1.6	0.18				
292	896.1	1.7	0.19	1.693333	0.090185	0.186667	0.005774
293		1.78	0.19				
301		2.09	0.21				
302	762	2.06	0.2	2.07	0.017321	0.2	0.01
303		2.06	0.19				
311		2.08	0.2				
312	755	2.1	0.2	2.09	0.01	0.203333	0.005774
313		2.09	0.21				
321		1.7	0.19				
322	871.7	1.75	0.17	1.763333	0.070946	0.19	0.02
323		1.84	0.21				
331		1.83	0.17				
332	670.6	1.82	0.17	1.84	0.026458	0.17	5.82E-11
333		1.87	0.17				
341		1.57	0.17				
342	701	1.57	0.19	1.586667	0.028868	0.183333	0.011547
343		1.62	0.19				
351		1.88	0.17				
352	798.6	1.94	0.18	1.92	0.034641	0.183333	0.015275
353		1.94	0.2				
361		1.85	0.19				
362	664.5	1.87	0.19	1.873333	0.025166	0.19	0
363		1.9	0.19				
371		1.43	0.16				
372	664.5	1.2	0.15	1.33	0.117898	0.163333	0.015275
373		1.36	0.18				
381		1.69	0.16				
382	822.9	1.71	0.16	1.723333	0.041633	0.16	0
383		1.77	0.16				
391		1.62	0.15				
392	502.9	1.44	0.14	1.513333	0.094516	0.146667	0.005774
393		1.48	0.15				

393		1.48	0.15				
401		1.57	0.18				
402	627.8	1.53	0.2	1.526667	0.045092	0.186667	0.011547
403		1.48	0.18				
411		1.85	0.17				
412	701	1.92	0.18	1.853333	0.065064	0.173333	0.005774
413		1.79	0.17				
421		1.61	0.14				
422	792.5	1.4	0.1	1.553333	0.134288	0.126667	0.023094
423		1.65	0.14				
431		1.84	0.17				
432	670.5	1.77	0.16	1.816667	0.040415	0.17	0.01
433		1.84	0.18				
441		1.62	0.15				
442	670.5	1.6	0.15	1.596667	0.025166	0.146667	0.005774
443		1.57	0.14				
451		1.73	0.17				
452	755.9	1.61	0.16	1.666667	0.060277	0.163333	0.005774
453		1.66	0.16				
461		1.87	0.18				
462	737.6	1.74	0.16	1.803333	0.065064	0.17	0.01
463		1.8	0.17				
471		1.87	0.2				
472	676.6	1.81	0.2	1.86	0.045826	0.196667	0.005774
473		1.9	0.19				
481		1.88	0.18				
482	780.3	1.71	0.16	1.786667	0.086217	0.163333	0.015275
483		1.77	0.15				
491		1.69	0.17				
492	798.6	1.7	0.16	1.706667	0.020817	0.163333	0.005774
493		1.73	0.16				
501		1.77	0.22				
502	725.4	1.55	0.2	1.676667	0.113725	0.213333	0.011547
503		1.71	0.22				
511		1.37	0.18				
512	853.4	1.37	0.16	1.376667	0.011547	0.163333	0.015275
513		1.39	0.15				
521		1.66	0.15				
522	859.5	1.67	0.15	1.636667	0.049329	0.156667	0.011547
523		1.58	0.17				
531		1.77	0.17				
532	780.3	1.79	0.16	1.8	0.036056	0.17	0.01
533		1.84	0.18				

541		1.49	0.19				
542	865.6	1.6	0.23	1.533333	0.058595	0.196667	0.030551
543		1.51	0.17				
551		1.64	0.16				
552	1066.8	1.68	0.17	1.706667	0.083267	0.16	0.01
553		1.8	0.15				
561		1.53	0.15				
562	792.5	1.73	0.16	1.633333	0.100167	0.153333	0.005774
563		1.64	0.15				
571		1.62	0.15				
572	853.4	1.64	0.15	1.596667	0.058595	0.15	0
573		1.53	0.15				
581		1.57	0.15				
582	877.8	1.45	0.14	1.523333	0.064291	0.146667	0.005774
583		1.55	0.15				
591		1.54	0.15				
592	829.1	1.59	0.16	1.58	0.036056	0.153333	0.005774
593		1.61	0.15				
601		1.62	0.16				
602	868.7	1.51	0.16	1.54	0.07	0.16	0
603		1.49	0.16				
611		1.6	0.14				
612	883.9	1.42	0.14	1.526667	0.094516	0.14	0
613		1.56	0.14				
621		1.54	0.15				
622	914.4	1.64	0.14	1.6	0.052915	0.146667	0.005774
623		1.62	0.15				
	Means	1.694722	0.170093				
	Standard Dev.	0.179758	0.022235				
		1.2	0.1				
		2.1	0.23				

Skidmore Fork Sites				Mean N	SD N	Mean S	SD S
631		1.2	0.21				
632	1109.4	1.5	0.16	1.366667	0.152753	0.176667	0.028868
633		1.4	0.16				
641		1.5	0.19				
642	1036.3	1.4	0.16	1.466667	0.057735	0.19	0.03
643		1.5	0.22				
651		1.4	0.18				
652	743.7	1.6	0.15	1.533333	0.11547	0.163333	0.015275
653		1.6	0.16				

661		1.6	0.12				
662	745.2	1.7	0.18	1.733333	0.152753	0.16	0.034641
663		1.9	0.18				
671		1.1	0.16				
672	1109.4	1.1	0.1	1.166667	0.11547	0.14	0.034641
673		1.3	0.16				
681		1.5	0.16				
682	853.4	1.3	0.16	1.366667	0.11547	0.16	0
683		1.3	0.16				
691		1.1	0.13				
692	792.5	1.2	0.13	1.333333	0.321455	0.14	0.017321
693		1.7	0.16				
701		1.5	0.14				
702	768.1	1.4	0.14	1.5	0.1	0.143333	0.005774
703		1.6	0.15				
711		1.2	0.13				
712	932.7	1.3	0.14	1.233333	0.057735	0.133333	0.005774
713		1.2	0.13				
721		1.5	0.17				
722	1109.5	1.4	0.14	1.433333	0.057735	0.153333	0.015275
723		1.4	0.15				
731		1.3	0.14				
732	829	1.5	0.14	1.366667	0.11547	0.143333	0.005774
733		1.3	0.15				
741		1.6	0.16				
742	780.3	1.6	0.17	1.6	4.66E-10	0.166667	0.005774
743		1.6	0.17				
751		1.4	0.19				
752	929.6	1.6	0.18	1.533333	0.11547	0.183333	0.005774
753		1.6	0.18				
761		1.4	0.16				
762	975.4	1.5	0.14	1.4	0.1	0.153333	0.011547
763		1.3	0.16				
771		1.5	0.14				
772	1188.7	1.5	0.14	1.5	0	0.14	0
773		1.5	0.14				
781		1.2	0.1				
782	1091.1	1.1	0.12	1.166667	0.057735	0.12	0.02
783		1.2	0.14				
791		1.5	0.18				
792	731.5	1.7	0.18	1.666667	0.152753	0.173333	0.011547
793		1.8	0.16				

801		1.2	0.14				
802	816.8	1.1	0.09	1.2333333	0.1527525	0.1333333	0.0404145
803		1.4	0.17				
811		1.4	0.17				
812	847.3	1.5	0.17	1.4666667	0.057735	0.1733333	0.0057735
813		1.5	0.18				
821		1.5	0.12				
822	987.5	1.5	0.15	1.5	0	0.1466667	0.0251661
823		1.5	0.17				
831		1.5	0.15				
832	1207	1.4	0.14	1.4333333	0.057735	0.14	0.01
833		1.4	0.13				
841		1.3	0.12				
842	1048.5	1.5	0.13	1.4	0.1	0.13	0.01
843		1.4	0.14				
851		1.5	0.13				
852	853.4	1.3	0.12	1.3666667	0.1154701	0.1233333	0.0057735
853		1.3	0.12				
861		1.4	0.12				
862	890	1.5	0.11	1.5	0.1	0.1233333	0.0152753
863		1.6	0.14				
871		1.4	0.19				
872	975.4	1.4	0.17	1.3333333	0.1154701	0.1733333	0.0152753
873		1.2	0.16				
881		1.4	0.12				
882	938.8	1.4	0.1	1.4	4.657E-10	0.1166667	0.0152753
883		1.4	0.13				
891		1	0.1				
892	926.7	1	0.12	1.0666667	0.1154701	0.1133333	0.011547
893		1.2	0.12				
901		1.5	0.16				
902	1097.3	1.4	0.15	1.5	0.1	0.1566667	0.0057735
903		1.6	0.16				
911		1.5	0.14				
912	902.2	1.5	0.14	1.5666667	0.1154701	0.1466667	0.011547
913		1.7	0.16				
921		1.3	0.13				
922	1085	1.2	0.12	1.2666667	0.057735	0.1366667	0.0208167
923		1.3	0.16				
931		1.6	0.18				
932	1170.4	1.7	0.19	1.6333333	0.057735	0.2033333	0.0321455
933		1.6	0.24				
941		2	0.19				
942	1011.9	1.9	0.17	1.9666667	0.057735	0.1866667	0.0152753
943		2	0.2				

951		2	0.23				
952	1158.2	1.8	0.19	1.766667	0.251661	0.2	0.026458
953		1.5	0.18				
961		1.4	0.17				
962	1097.3	1.5	0.18	1.466667	0.057735	0.173333	0.005774
963		1.5	0.17				
971		1.1	0.16				
972	1292.4	1.2	0.22	1.166667	0.057735	0.17	0.045826
973		1.2	0.13				
981		1.3	0.19				
982	1286.3	1.2	0.13	1.3	0.1	0.16	0.03
983		1.4	0.16				
991		1.3	0.13				
992	1219.2	1.3	0.16	1.3	0	0.153333	0.020817
993		1.3	0.17				
	Means	1.432432	0.154054				
	Standard Dev.	0.203676	0.028329				
		1	0.09				
		2	0.24				

St. Mary's River Sites				Mean N	SD N	Mean S	SD S
1001		1.3	0.14				
1002	1024	1.2	0.15	1.266667	0.057735	0.153333	0.015275
1003		1.3	0.17				
1011		1.3	0.15				
1012	1036	1.2	0.15	1.3	0.1	0.15	0
1013		1.4	0.15				
1021		1.6	0.19				
1022	1036	1.3	0.16	1.433333	0.152753	0.166667	0.020817
1023		1.4	0.15				
1031		1.6	0.17				
1032	823	1.4	0.16	1.5	0.1	0.166667	0.005774
1033		1.5	0.17				
1041		1.4	0.17				
1042	1000	1.4	0.17	1.433333	0.057735	0.16	0.017321
1043		1.5	0.14				
1051		1.6	0.14				
1052	1030	1.6	0.14	1.633333	0.057735	0.163333	0.040415
1053		1.7	0.21				

1061		1.1	0.14				
1062	987	1	0.14	1.0333333	0.057735	0.1366667	0.0057735
1063		1	0.13				
1071		1.3	0.11				
1072	969	1.1	0.09	1.1666667	0.1154701	0.1033333	0.011547
1073		1.1	0.11				
1081		1.1	0.15				
1082	914	1.1	0.14	1.1	0	0.1366667	0.0152753
1083		1.1	0.12				
1091		1.4	0.15				
1092	981	1.4	0.15	1.4	4.657E-10	0.1533333	0.0057735
1093		1.4	0.16				
1101		1.4	0.14				
1102	579	1.4	0.13	1.4	4.657E-10	0.13	0.01
1103		1.4	0.12				
1111		1.4	0.13				
1112	792	1.4	0.14	1.4333333	0.057735	0.1366667	0.0057735
1113		1.5	0.14				
1121		1.5	0.13				
1122	804	1.4	0.14	1.5	0.1	0.1433333	0.0152753
1123		1.6	0.16				
1131		1.5	0.16				
1132	762	1.5	0.15	1.4666667	0.057735	0.15	0.01
1133		1.4	0.14				
1141		1.3	0.16				
1142	670	1.1	0.15	1.2	0.1	0.15	0.01
1143		1.2	0.14				
1151		1.3	0.16				
1152	716	1.1	0.11	1.2333333	0.1154701	0.1366667	0.0251661
1153		1.3	0.14				
1161		1.4	0.17				
1162	774	1.4	0.14	1.4333333	0.057735	0.1566667	0.0152753
1163		1.5	0.16				
1171		1.5	0.19				
1172	899	1.5	0.18	1.5	0	0.19	0.01
1173		1.5	0.2				
1181		1.4	0.15				
1182	975	1.3	0.11	1.3666667	0.057735	0.1433333	0.0305505
1183		1.4	0.17				
1191		1.5	0.12				
1192	564	1.5	0.11	1.5	0	0.1166667	0.0057735
1193		1.5	0.12				
1201		1.3	0.1				
1202	579	1.3	0.12	1.3	0	0.1133333	0.011547
1203		1.3	0.12				

1211		1.7	0.13				
1212	640	1.7	0.15	1.7	0	0.1433333	0.011547
1213		1.7	0.15				
1221		1.1	0.11				
1222	707	1.1	0.1	1.1	0	0.1033333	0.0057735
1223		1.1	0.1				
1231		1.1	0.14				
1232	750	1.1	0.13	1.1	0	0.14	0.01
1233		1.1	0.15				
1241		1.1	0.13				
1242	899	1	0.16	1.0333333	0.057735	0.15	0.0173205
1243		1	0.16				
1251		1	0.09				
1252	1000	1.1	0.13	1.1	0.1	0.11	0.02
1253		1.2	0.11				
1261		1.5	0.17				
1262	1005	1.5	0.17	1.4666667	0.057735	0.1633333	0.011547
1263		1.4	0.15				
1271		1.6	0.16				
1272	990	1.6	0.14	1.6333333	0.057735	0.15	0.01
1273		1.7	0.15				
1281		1.5	0.12				
1282	792	1.5	0.13	1.5	0	0.1266667	0.0057735
1283		1.5	0.13				
1291		1.6	0.13				
1292	822.9	1.7	0.13	1.6333333	0.057735	0.13	4.116E-11
1293		1.6	0.13				
1301		1.4	0.11				
1302	792.5	1.4	0.12	1.4333333	0.057735	0.1266667	0.0208167
1303		1.5	0.15				
1311		1.5	0.15				
1312	929.6	1.5	0.12	1.4666667	0.057735	0.1366667	0.0152753
1313		1.4	0.14				
1321		1.2	0.12				
1322	950.9	1.1	0.12	1.1333333	0.057735	0.1233333	0.0057735
1323		1.1	0.13				
1331		1.2	0.15				
1332	914.4	1.1	0.15	1.1333333	0.057735	0.1533333	0.0057735
1333		1.1	0.16				
1341		1	0.12				
1342	975.4	1	0.11	1.0333333	0.057735	0.1166667	0.0057735
1343		1.1	0.12				
1351		1.9	0.22				
1352	1047.6	1.9	0.22	1.8666667	0.057735	0.2166667	0.0057735
1353		1.8	0.21				

1361		2.1	0.23				
1362	944.9	2.1	0.24	2.1333333	0.057735	0.2333333	0.0057735
1363		2.2	0.23				
1371		2.1	0.24				
1372	899.2	2.2	0.23	2.1333333	0.057735	0.2366667	0.0057735
1373		2.1	0.24				
1381		1.3	0.19				
1382	987.5	1.3	0.17	1.3	0	0.1833333	0.011547
1383			0.19				
Means		1.3982759	0.1487179				
Standard Dev.		0.27026	0.0326301				
		1	0.09				
Laurel Fork sites		2.2	0.24				
				Mean N	SD N	Mean S	SD S
1391		1.3	0.18				
1392	1194.8	1.4	0.13	1.3666667	0.057735	0.1566667	0.0251661
1393		1.4	0.16				
1401		1.3	0.32				
1402	1167.4	1.3	0.18	1.2666667	0.057735	0.2266667	0.080829
1403		1.2	0.18				
1411		1.9	0.2				
1412	1121.7	1.9	0.2	1.9	0	0.2033333	0.0057735
1413		1.9	0.21				
1421		1.5	0.14				
1422	1127.8	1.5	0.14	1.5666667	0.1154701	0.1566667	0.0288675
1423		1.7	0.19				
1431		1.3	0.19				
1432	1158.2	1.2	0.16	1.2666667	0.057735	0.18	0.0173205
1433		1.3	0.19				
1441		1.1	0.15				
1442	1139.9	1.1	0.09	1.0666667	0.057735	0.1133333	0.0321455
1443		1	0.1				
1451		1.2	0.14				
1452	1127.8	1.2	0.14	1.2333333	0.057735	0.1466667	0.011547
1453		1.3	0.16				
1461		1.2	0.15				
1462	1158.2	1.1	0.13	1.2	0.1	0.1466667	0.0152753
1463		1.3	0.16				
1471		1	0.13				
1472	1158.2	0.8	0.07	0.9	0.1	0.11	0.034641
1473		0.9	0.13				
1481		1.3	0.16				
1482	1146	1.3	0.15	1.3666667	0.1154701	0.1633333	0.0152753
1483		1.5	0.18				

1491		1.5	0.17				
1492	1066.8	1.4	0.15	1.4666667	0.057735	0.1666667	0.0152753
1493		1.5	0.18				
1501		1.6	0.15				
1502	1149.1	1.6	0.14	1.6	4.657E-10	0.1433333	0.0057735
1503		1.6	0.14				
1511		1.3	0.15				
1512	1133.8	1.1	0.13	1.2	0.1	0.1366667	0.011547
1513		1.2	0.13				
1521		1	0.12				
1522	1109.5	0.8	0.07	0.8666667	0.1154701	0.09	0.0264575
1523		0.8	0.08				
1531		1.2	0.12				
1532	1158.2	1.2	0.14	1.2	0	0.1266667	0.011547
1533		1.2	0.12				
1541		1.2	0.12				
1542	1146	1.4	0.18	1.2666667	0.1154701	0.1533333	0.0305505
1543		1.2	0.16				
1551		0.8	0.11				
1552	1170.4	0.9	0.09	0.9	0.1	0.11	0.02
1553		1	0.13				
1561		1.3	0.16				
1562	1161.3	1.3	0.14	1.3	0	0.15	0.01
1563		1.3	0.15				
1571		1.3	0.14				
1572	1082	1.4	0.15	1.3333333	0.057735	0.1666667	0.0378594
1573		1.3	0.21				
1581		1.3	0.11				
1582	1042.4	1.3	0.13	1.2666667	0.057735	0.12	0.01
1583		1.2	0.12				
1591		1.3	0.12				
1592	1143	1.3	0.13	1.3	0	0.1266667	0.0057735
1593		1.3	0.13				
1601		1.2	0.1				
1602	1094.2	1.1	0.09	1.1333333	0.057735	0.1	0.01
1603		1.1	0.11				
1611		1.4	0.15				
1612	1146	1.3	0.15	1.4	0.1	0.1533333	0.0057735
1613		1.5	0.16				
1621		1.1	0.14				
1622	1089.7	1	0.13	1.1333333	0.1527525	0.1566667	0.0378594
1623		1.3	0.2				
1631		1.2	0.14				
1632	1188.7	1.1	0.13	1.1666667	0.057735	0.1333333	0.0057735
1633		1.2	0.13				

1641		1.4	0.17				
1642	1063.7	1.4	0.17	1.4	4.66E-10	0.176667	0.011547
1643		1.4	0.19				
1651		1.6	0.17				
1652	1005.8	1.4	0.15	1.466667	0.11547	0.156667	0.011547
1653		1.4	0.15				
1661		1.2	0.15				
1662	960.1	1.1	0.14	1.133333	0.057735	0.146667	0.005774
1663		1.1	0.15				
1671		1.4	0.17				
1672	1030.2	1.2	0.15	1.3	0.1	0.14	0.036056
1673		1.3	0.1				
1681		1.1	0.12				
1682	1127.8	1	0.13	1.1	0.1	0.13	0.01
1683		1.2	0.14				
1691		0.9	0.14				
1692	1121.7	0.9	0.13	0.966667	0.11547	0.136667	0.005774
1693		1.1	0.14				
1701		1.2	0.12				
1702	1085.1	1.3	0.15	1.266667	0.057735	0.14	0.017321
1703		1.3	0.15				
1711		1	0.12				
1712	1036.3	0.9	0.08	0.966667	0.057735	0.096667	0.020817
1713		1	0.09				
1721		1.1	0.12				
1722	1182.6	1.1	0.11	1.1	0	0.113333	0.005774
1723		1.1	0.11				
1731		1.1	0.12				
1732	1109.5	1	0.09	1.033333	0.057735	0.1	0.017321
1733		1	0.09				
1741		1.2	0.13				
1742	1158.2	1.2	0.1	1.233333	0.057735	0.12	0.017321
1743		1.3	0.13				
1751		1.4	0.14				
1752	1094.2	1.3	0.11	1.366667	0.057735	0.12	0.017321
1753		1.4	0.11				
1761		1.2	0.14				
1762	975.4	1.2	0.12	1.166667	0.057735	0.13	0.01
1763		1.1	0.13				
1771		1.2	0.1				
1772	1121.7	1.2	0.13	1.166667	0.057735	0.11	0.017321
1773		1.1	0.1				

1781		1.2	0.12				
1782	1097.3	1.2	0.12	1.2	0	0.12	0
1783		1.2	0.12				
1791		1.3	0.13				
1792	1091.2	1.3	0.13	1.266667	0.057735	0.143333	0.023094
1793		1.2	0.17				
1801		0.9	0.14				
1802	1048.5	0.8	0.12	0.833333	0.057735	0.136667	0.015275
1803		0.8	0.15				
1811		1	0.14				
1812	1072.9	1.2	0.14	1.1	0.1	0.136667	0.005774
1813		1.1	0.13				
1821		1.2	0.12				
1822	1021.1	1.1	0.1	1.133333	0.057735	0.113333	0.011547
1823		1.1	0.12				
1831		1.3	0.12				
1832	1021.1	1.3	0.12	1.3	0	0.126667	0.011547
1833		1.3	0.14				
1841		1.3	0.13				
1842	999.7	1.2	0.14	1.233333	0.057735	0.136667	0.005774
1843		1.2	0.14				
1851		1.1	0.13				
1852	902.2	1.2	0.14	1.133333	0.057735	0.136667	0.005774
1853		1.1	0.14				
	Means	1.224113	0.138369				
	Standard Dev.	0.204904	0.031907				
		0.8	0.07				
		1.9	0.32				

Jefferson NF sites

	Elevation (m)	N (%)	S (%)	Mean N	SD N	Mean S	SD S	
3001		1.1	0.11					
3002	1170	1.3	0.17	1.16667	0.11547	0.14333	0.03055	Mt Rogers #2
3003		1.1	0.15					
3011		1.1	0.15					
3012	1274	1.1	0.1	1.1	0	0.12667	0.02517	Mt Rogers #1
3013		1.1	0.13					
3021		1	0.1					
3022	1688	1	0.12	1	0	0.11333	0.01155	Mt Rogers #3
3023		1	0.12					
3031		1.6	0.18					
3032	1477	1.4	0.15	1.46667	0.11547	0.15333	0.02517	Mt Rogers #10
3033		1.4	0.13					
3041		1.2	0.13					
3042	1628	0.9	0.1	1.1	0.17321	0.11667	0.01528	Mt Rogers #4
3043		1.2	0.12					
3051		1.1	0.14					
3052	1628	1.1	0.14	1.1	0	0.13667	0.00577	Mt Rogers #5
3053		1.1	0.13					
3061		0.8	0.11					
3062	1085	1	0.14	0.86667	0.11547	0.12333	0.01528	Mt Rogers #9
3063		0.8	0.12					
3071		1.5	0.16					
3072	1499	1.5	0.19	1.6	0.17321	0.15667	0.03512	Mt Rogers #6
3073		1.8	0.12					
3081		1.7	0.16					
3082	487.7	1.3	0.19	1.4	0.26458	0.17	0.01732	James R Face #8
3083		1.2	0.16					
3091		1.5	0.13					
3092	1158	1.4	0.16	1.46667	0.05774	0.15333	0.02082	Mt Rogers #8
3093		1.5	0.17					
3101		1.2	0.17					
3102	377.9	1.3	0.15	1.3	0.1	0.16333	0.01155	James R Face #9
3103		1.4	0.17					
3111		1.3	0.14					
3112	1347	1.4	0.13	1.36667	0.05774	0.13	0.01	Mt Rogers #7
3113		1.4	0.12					
3121		1.3	0.16					
3122	719.3	1.4	0.17	1.4	0.1	0.16667	0.00577	James R Face #10
3123		1.5	0.17					
3131		1.4	0.17					
3132	936.6	1.1	0.17	1.43333	0.35119	0.18	0.01732	James R Face #5
3133		1.8	0.2					
3141		1.4	0.18					
3142	767.2	1.5	0.19	1.46667	0.05774	0.19333	0.01528	James R Face #7
3143		1.5	0.21					
3151		2	0.24					
3152	780.3	1.7	0.18	1.76667	0.20817	0.20333	0.03215	James R Face #6
3153		1.6	0.19					
3161		1.2	0.17					
3162	402.3	1.6	0.15	1.26667	0.30551	0.13667	0.04163	James R Face #3
3163		1	0.09					

3171		1.4	0.2					
3172	310.9	1.6	0.19	1.46667	0.11547	0.19667	0.00577	James R Face #4
3173		1.4	0.2					
3181		1.5	0.21					
3182	499.9	1.5	0.18	1.5	0	0.19667	0.01528	James R Face #2
3183		1.5	0.2					
3191		1.4	0.18					
3192	438.9	1.5	0.14	1.46667	0.05774	0.16	0.02	James R Face #1
3193		1.5	0.16					
	Means	1.335	0.156					
	Standard Dev.	0.25098	0.03253					