# LICHENS AND AIR QUALITY

# IN

# LYE BROOK WILDERNESS

# OF THE

# GREEN MOUNTAIN NATIONAL FOREST

Excerpts from the Final Report

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## PREFACE

Under a contract from the USDA National Forest Service a lichen study was performed in the Lye Brook Wilderness Area (LBW) of the Green Mountain National Forest. The objectives were to survey the lichens of the wilderness area, produce an inventory of the lichen flora, collect and analyze lichens for chemical contents, and evaluate the lichen flora with reference to the air quality. This establishes baseline data to determine the future change in air quality. All work was done at the University of Minnesota with consultation with Mr. Manfred Mielke, and with personnel on the Forest.

The Forest Service personnel have been very helpful during the field work which has contributed significantly to the success of the project. The study was made possible by funds from the U. S. Forest Service, Green Mountain National Forest and NAS & PF Forest Health Protection. Dave Rugg, statistician with the NCFES did the statistical analysis. I would especially like to acknowledge the able assistance of Zhenfan Wang in the field and the laboratory. The assistance of all of these is gratefully acknowledged.

## ABSTRACT

This study of the lichens of the Lye Brook Wilderness was designed 1) to collect lichens for a lichen species list, 2) to collect lichens for elemental analysis, 3) to study the health and distributions of species most sensitive to air pollution, and 4) to assess the effects of air quality on lichens. Eighteen localities were studied throughout the wilderness. Samples of three species were collected at four localities for elemental analysis.

The lichen flora is quite diverse. There were 126 species present including six species very sensitive to sulfur dioxide. The distributions of these sensitive species do not show patterns that would suggest directional air quality problems. All of the lichens found were in good health and with normal fertility. The lichens studied by elemental analysis show levels of all elements comparable to other clean areas. ANOVA analysis showed higher levels of thallus accumulation in LBW than in White Mt. Wilderness areas for the 1993 data. There seem to be no indications of threatening air quality problems (mainly sulfur dioxide) in the wilderness.

Recommendations are for periodic (5 year) restudy of the lichens by elemental analysis A complete lichen restudy of the lichen flora should be done every 10-15 years. If construction or maintenance activities are planned within the wilderness, a lichenologist should be consulted to prevent loss of species.

## INTRODUCTION

Lichens are composite plants composed of two different types of organisms. The lichen plant body (thallus) is made of fungi and algae living together in a symbiotic arrangement in which both partners are benefited and the composite plant body can grow in places where neither component could live alone. The thallus has no protective layer on the outside, such as the epidermis of a leaf, so the air in the thallus has free exchange with the atmosphere. Lichens are slow growing (a few millimeters per year) and remain alive for many years and so they must have a habitat that is relatively undisturbed in order to survive. Lichens vary greatly in their ecological requirements but almost all of them can grow in places that only receive periodic moisture. When moisture is lacking they go dormant until the next rain or dew-fall. Some species can grow in habitats with very infrequent occurrences of moisture while others need high humidity and frequent wetting in order to survive. This difference in moisture requirements is very important in the distribution of lichens.

Lichens are known to be very sensitive to low levels of many atmospheric pollutants Many are damaged or killed by levels of sulfur dioxide, nitrogen oxides, fluorides or ozone alone or in various combinations. Levels of sulfur dioxide as low as 13 $\mu$g/cubic meter (annual average) will cause the death of some lichens (LeBlanc et al., 1972). Other lichens are less sensitive and a few can tolerate levels of sulfur dioxide over 300 $\mu$g/cubic meter (Laundon, 1967, Trass, 1973). The algae of the thallus are the first to be damaged in areas with air pollution and the first indication of damage is discoloring and death of the algae causing bleached lobes, which quickly leads to the death of the lichen. After the lichen dies it disappears from the substrate within a few months to a year as it disintegrates and decomposes (Wetmore, 1982).

Lichens are more sensitive to air pollution when they are wet and physiologically active and are least sensitive when dry (Nash, 1973, Marsh & Nash, 1979) and are more sensitive when growing on acid substrates.

Contrary to some published reports (Medlin, 1985) there is little evidence that most lichens are good indicators of acid precipitation. However, Sigal & Johnston (1986) have reported that one species of Umbilicaria shows visible damage due to artificial acid rain. They also report that similar symptoms were found in collections from various localities in North America. Lechowicz (1987) reported that acid rain only slightly reduced growth of Cladina stellaris but Hutchinson et al. (1986) reported that extremely acid precipitation (less than pH 3.5) killed or damaged some mosses and lichens. Scott & Hutchinson (1987) showed temporary reduction of photosynthesis in Cladina stellaris and C. rangiferina after artificial acid rain.

Lichens are able to accumulate chemical elements in excess of their metabolic needs depending on the levels in the substrate and the air, and, since lichens are slow growing and long lived, they serve as good summarizers of the environmental conditions in which they are growing. Chemical analysis of the thallus of lichens growing in areas of high fallout of certain elements will show elevated levels in the thallus. Toxic substances (such as sulfur) are also accumulated and determination of the levels of these toxic elements can provide indications of the sub-lethal but elevated levels in the air.

The Lye Brook Wilderness (LBW) is about 15,680 acres and is located in southern Vermont, about 20 miles north of Bennington. The wilderness is fairly steep and mountainous with some small lakes and streams. The elevations range from 900 to 2880 ft. The ridgetops have red spruce (Picea rubens) mixed with sugar maple (Acer saccharum), birch (Betula). Some of the hillsides have hemlock (Tsuga canadensis), beech (Fagus grandifolia) and sugar maple. In the low and wet areas there are some balsam for (Abies balsamea) and white ash (Fraxinus americana) and red maple (Acer rubrum). Rock outcrops are frequent on the ridges and hillsides and some of low areas have bogs. The Burning is an area that is quite different. It is a large area on the ridge that was burned around 1900 and is now heath with scattered red spruce with some white pines (Pinus strobus).

Most of the forest had been extensively logged prior to 1960 with only limited logging since. The last area to be logged was around Kelly Stand.

There probably has been no lichen collecting in the wilderness prior to this study and no literature references to lichen collections from the wilderness have been found.

## METHODS

Field work was done during late July and August, 1993 when 565 collections were made at 18 localities. A complete list of collection localities is given in Appendix I and these are indicated on Fig. . Collection localities, about 2 acres in size, were selected first to give a general coverage of the wilderness, second, to sample all vegetational types, and third, to be in localities that should be rich in lichens. Undisturbed as well as disturbed habitats (such as old logging roadsides and trails) were studied. At each locality voucher specimens of all species found were collected to record the total flora for each locality and to avoid missing different species that might appear similar in the field. At some localities additional material of selected species was collected for chemical analysis (see below). While collecting at each locality observations were made about the general health of the lichens. Lichen health was evaluated by looking for damaged or dying lichens on all of the trees where collections were made (at least 100 trees). The presence of many dead, dying, or abnormal thalli of particular species at a locality would indicate poor health, but an occasional damaged thallus is not significant.

Identifications were carried out at the University of Minnesota with the aid of comparison material in the herbarium and using thin layer chromatography for identification of the lichen substances where necessary. The original packet of each collection has been deposited in the University of Minnesota Herbarium. All specimens deposited at the University of Minnesota have been entered into the herbarium computerized data base maintained there.

## LICHEN FLORA

The following list of lichens is based on my collections. Species found only once are indicated by "Rare". In the first columns the letters indicate the sensitivity to sulfur dioxide, if known, according to the categories proposed by Wetmore (1983): S=Sensitive, I Intermediate, T=Tolerant. S-I is intermediate between Sensitive and Intermediate and I-T is intermediate between Intermediate and Tolerant. Species in the Sensitive category are absent when annual average levels of sulfur dioxide are above 50 $\mu g$ per cubic meter. The Intermediate category includes those species present between 50 and 100 $\mu g$ and those in the Tolerant category are present at over 100 $\mu g$ per cubic meter. Those species without sensitivity designations have unknown sensitivity.

## SPECIES LIST

I Alectoria sarmentosa (Ach.) Ach. :RARE
Anaptychia palmulata (Michx.) Vain.
1 unidendified species of Arthopyrenia
Bacidia chlorantha (Tuck.) Fink
Bacidia schweinitzii (Tuck.) Schneid.
Baeomyces rufus (Huds.) Rebent. :RARE
S Bryoria furcellata (Fr.) Brodo & Hawksw.
Bryoria nadvornikiana (Gyeln.) Brodo & Hawksw.
Buellia arnoldii Serv. & Nadv. :RARE
I Buellia stillingiana Steiner
Calicium trabinellum Ach. :RARE
S-I Candelaria concolor (Dicks.) B. Stein
Candelariella efflorescens R. Harris & Buck
Cetraria oakesiana Tuck.
I Cetraria orbata (Nyl.) Fink
I Cetraria pinastri (Scop.) Gray
I Cetraria sepincola (Ehrh.) Ach.
Cetrelia olivetorum (Nyl.) W. & C. Culb.
Chaenotheca chrysocephala (Turn. ex Ach.) Th. Fr. RARE
Chaenotheca laevigata Nadv. :RARE
Chaenotheca xyloxena Nadv. :RARE
Chaenothecopsis lignicola (Nadv.) Schmidt :RARE
Cladina arbuscula (Wallr.) Hale & W. Culb. :RARE
Cladina mitis (Sandst.) Hustich
Cladina rangiferina (L.) Nyl.
Cladina stellaris (Opiz) Brodo :RARE
Cladonia bacillaris Nyl. :RARE
Cladonia caespiticia (Pers.) Flörke
Cladonia chlorophaea (Flörke ex Somm.) Spreng. :RARE
Cladonia coccifera (L.) Willd.
I Cladonia coniocraea (Flörke) Spreng.
Cladonia cornuta (L.) Hoffm.
Cladonia crispata (Ach.) Flot.
I Cladonia cristatella Tuck. :RARE
Cladonia deformis (L.) Hoffm. :RARE
Cladonia digitata (L.) Hoffm.
Cladonia floerkeana (Fr.) Flörke
Cladonia furcata (Huds.) Schrad.
Cladonia grayi G. K. Merr. ex Sandst.
Cladonia merochlorophaea Asah.

Cladonia squamosa (Scop.) Hoffm.
Conotrema urceolatum (Ach.) Tuck.
Diploschistes scruposus (Schreb.) Norm. :RARE
I Evernia mesomorpha Nyl.
I Graphis scripta (L.) Ach.
Haematomma cismonicum Beltr.
Haematomma elatinum (Ach.) Mass.
Haematomma pustulatum Brodo & W. Culb.
Hypocenomyce friesii (Ach. in Lilj.) P. James & G. Schneid. :RARE
I Hypogymnia physodes (L.) Nyl.
S Hypogymnia tubulosa (Schaer.) Hav.
I Imshaugia aleurites (Ach.) S. F. Meyer
Julella fallaciosa (Stizenb. ex Arn.) R. Harris :RARE
I Lecanora chlarotera Nyl.
I Lecanora pulicaris (Pers.) Ach.
Lecanora thysanophora Harris ined.
Lecanora wisconsinensis Magn.
Lecidea helvola (Körb. ex Hellb.) Oliv.
2 unidendified species of Lecidea
Lecidella euphorea (Flörke) Hert.
Lepraria finkii (B. de Lesd. in Hue) R. Harris
Lepraria neglecta (Nyl.) Lett.
2 unidendified species of Lepraria
Leptogium cyanescens (Rabenh.) Körb. :RARE
Leptorhaphis epidermidis (Ach.) Th. Fr. :RARE
S Lobaria pulmonaria (L.) Hoffm.
Lobaria quercizans Michx.
I Lopadium pezizoideum (Ach.) Körb.
Micarea bauschiana (Körb.) V. Wirth & Vezda :RARE
2 unidendified species of Micarea
I Mycoblastus sanguinarius (L.) Norm.
Mycocalicium subtile (Pers.) Szat. :RARE
Ochrolechia pseudopallescens Brodo.
Ochrolechia trochophora (Vain) Oshio :RARE
Parmelia appalachensis W. Culb. :RARE
Parmelia aurulenta Tuck.
Parmelia caperata (L.) Ach.
Parmelia cumberlandia (Gyeln.) Hale :RARE
Parmelia galbina Ach. :RARE
I Parmelia olivacea (L.) Ach. :RARE
I Parmelia rudecta Ach.
I Parmelia saxatilis (L.) Ach.
I Parmelia septentrionalis (Lynge) Ahti
S Parmelia squarrosa Hale
S-I Parmelia subaurifera Nyl.
I Parmelia subrudecta Nyl.
I-T Parmelia sulcata Tayl.
1 unidendified species of Parmelia
I Parmeliopsis ambigua (Wulf. in Jacq.) Nyl.
I Parmeliopsis hyperopta (Ach.) Arn.
Peltigera canina (L.) Willd. :RARE
I Pertusaria amara (Ach.) Nyl.
Pertusaria consocians Dibb. :RARE
Pertusaria macounii (Lamb) Dibb.

I Pertusaria multipunctoides Dibb. :RARE
Pertusaria ophthalmiza (Nyl.) Nyl.
Pertusaria propinqua Müll. Arg. :RARE
Pertusaria trachythallina Erichs.
Pertusaria velata (Turn.) Nyl. :RARE
2 unidendified species of Pertusaria
Phaeocalicium polyporaeum (Nyl.) Tibell
Phaeophyscia chloantha (Ach.) Moberg :RARE
Phaeophyscia pusilloides (Zahlbr.) Essl.
Phaeophyscia rubropulchra (Degel.) Moberg
I Physcia aipolia (Ehrh. ex Humb.) Fürnr. :RARE
I Physcia millegrana Degel.
I Physcia stellaris (L.) Nyl. :RARE
I Physconia detersa (Nyl.) Poelt :RARE
Placynthiella icmalea (Ach.) Coppins & James
I Platismatia glauca (L.) W. & C. Culb.
Platismatia tuckermanii (Oakes) W. & C. Culb.
Porpidia albocaerulescens (Wulf.) Hert. & Knoph
Porpidia crustulata (Ach.) Hert. & Knoph
Porpidia macrocarpa (DC. in Lam. & DC.) Hert. & Schwab :RARE
Pseudevernia cladonia (Tuck.) Hale & W. Culb.
Pseudevernia consocians (Vain.) Hale & W. Culb.
Pyrenula pseudobufonia (Rehm.) R. Harris
Pyxine sorediata (Ach.) Mont. :RARE
Ramalina intermedia (Del. ex Nyl.) Nyl.
S Ramalina obtusata (Arn.) Bitt. :RARE
Rhizocarpon concentricum (Dav.) Beltram. :RARE
Rhizocarpon hochstetteri (Körb.) Vain.
Rinodina ascociscana Tuck.
Sarea resinae (Fr. ex Fr.) Kuntze :RARE
I Scoliciosporum chlorococcum (Graewe ex Stenh.) Vezda
Trapeliopsis flexuosa (Fr.) Coppins & James :RARE
Trapeliopsis granulosa (Hoffm.) Lumbsch. :RARE
Trapeliopsis viridescens (Schrad.) Coppins & James
Umbilicaria vellea (L.) Ach. :RARE
S Usnea filipendula Stirt. :RARE
S-I Usnea hirta (L.) Weber ex Wigg.
S-I Usnea subfloridana Stirt.
1 unidendified species of Verrucaria

## DISCUSSION OF FLORA

This list of species presents the first listing of lichens from the Lye Brook Wilderness and includes 126 species found during this study. There are also 11 additional unidentified species, some of which are undescribed. The lichen flora is typical of the eastern deciduous forest. These hardwood forests have fewer lichens than conifer and mixed forests because the dense shade is not favorable to the growth of many species. Some of the most common species are Cetraria oakesiana, Hypogymnia physodes, Parmelia rudecta, P. subaurifera, Phaeophyscia rubropulchra and Graphis scripta.

The lichens of The Burning and in the swamp near Kelly Stand include several species rare in the LBW. Some of these rare species that are now present may be lost in the future due to natural causes as succession progresses in these areas.

None of the lichen distributions show unexpected patterns. Many of the species prefer wetter areas, such as bogs, and were only found in these bogs. Some of the species found only once are rare wherever they are found throughout their distributional range and might be found at other localities with further searching; and, others may require special substrates that are rare in the wilderness. The cases of rarity do not necessarily reflect sensitivity damage due from sulfur dioxide.

There were no cases where lichens sensitive to sulfur dioxide were observed to be damaged or killed. All species normally found fertile were also fertile in the wilderness. There are numerous species with blue-green algae, which are very sensitive to sulfur dioxide. One of the most sensitive lichens, Lobaria pulmonaria, was found twice in the LBW. These observations indicate that there is no air quality degradation in the wilderness due to sulfur dioxide that causes visible damage to the lichen flora.

This study found the following number of species in the different sensitivity categories.

| Category | # of Species |
|---|---|
| Sensitive | 6 |
| S/I | 4 |
| Intermediate | 30 |
| I/T | 1 |
| Tolerant | 0 |

Most lichen species are unknown as to sensitivity category. The absence of species in the more tolerant categories in LBW indirectly indicates the lack of sulfur dioxide problems. In areas of high sulfur dioxide these categories would have more species and the most sensitive categories would have fewer species. The RARE species in LBW are not related to air quality (see above). The only way to determine past air quality impacts on the present lichen species inventory is by comparison with historical data (from before the presumed impacts occurred). Since there are no historical species lists from this area it cannot be determined whether the present lichen flora has changed prior to this study.

Another way of analyzing the lichen flora of an area is to study the distributions of the sensitive species within the wilderness to look for voids in the distributions that might be caused by air pollution. Showman (1975) has described and used this technique in assessing sulfur dioxide levels around a power plant in Ohio. Only the very common species have meaning with such a technique since the rare species may be absent due to other factors. This method of assessing air quality is weak but occasionally is useful in detecting directional effects in an area.

Many of the lichens in the wilderness have known sensitivity to sulfur dioxide according to the list presented in Wetmore (1983). There were six species in the most sensitive category. These species are usually absent when sulfur dioxide levels are above 50 $\mu g$ per cubic meter average annual concentrations. The species that occur in the LBW in the most sensitive category are as follows.

Bryoria furcellata
Hypogymnia tubulosa
Lobaria pulmonaria
Parmelia squarrosa
Ramalina obtusata
Usnea filipendula

The distributions of these species are shown in Fig. 2-7. Although these species are not found at all localities and most are not common or rare, there is no indication that the voids in the distributions are due to high levels of sulfur dioxide. Some of the localities where collections were made do not have suitable habitats or substrates for some of these species. This is especially true for Lobaria pulmonaria that requires moist habitats.

## ELEMENTAL ANALYSIS

An important method of assessing the effects of air quality is by examining the elemental content of the lichens (Nieboer et al, 1972, 1977, 1978; Erdman & Gough, 1977; Puckett & Finegan, 1980; Nash & Sommerfeld, 1981). Elevated but sublethal levels of sulfur or other elements might indicate incipient damaging conditions.

Four species of lichens were collected for elemental analysis in the LBW. At some localities not all species were present in quantities needed for the analysis.

## METHODS

Lichens were collected in spunbound olefin bags at four localities in different parts of the wilderness for laboratory analysis (Fig. 1). Species collected were Cladina rangiferina, Evernia mesomorpha, Hypogymnia physodes, and Parmelia sulcata. These species were selected because they are locally present in abundance and relatively easy to clean. Cladina rangiferina was present at only two elemental analysis localities and was collected from the ground. Evernia mesomorpha was not present at one locality and was collected from conifer branches. Hypogymnia physodes and Parmelia sulcata were present at all four localities and were collected from conifer bark.

Four localities were selected for elemental analysis and are indicated on the map of collection localities (Fig. 1). These localities are: North of Little Mud Pond (9 Aug. 1993), Hill west of Lye Brook (8 Aug. 1993), West side of Bourn Pond (4 Aug. 1993), and North of Kelly Stand (30 July 1993). Full locality citations are given in Appendix I. Ten to 20 grams of each species were collected at each locality.

Lichens were air dried and cleaned of all bark and detritis under a dissecting microscope but thalli were not washed. Three samples (replicates) of each collection were submitted for analysis. Because of the scarcity of Cladina rangiferina in LBW, these samples were submitted along with lichens from another study, where adequate material was available for parallel analytical splits. Analysis was done for sulfur and multi-element analysis by the Research Analytical Laboratory at the University of Minnesota. In the sulfur analysis, a ground and pelleted 100-150 mg sample was prepared for total sulfur by dry combustion and measurement of evolved sulfur dioxide on a LECO Sulfur Determinator, model no. SC-132, by infra red absorption. Multi-element determination for Ca, Mg, Na, K, P, Fe, Mn, Al, Cu, Zn, Cd, Cr, Ni, Pb, and B were determined simultaneously by Inductively Coupled

Plasma (ICP) Atomic Emission Spectrometry. For the ICP one gram of dried plant material was dry ashed in a 20 ml high form silica crucible at 485 degrees Celsius for 10-12 hrs. Crucibles were covered during the ashing as a precaution against contamination. The dry ash was boiled in 2N HCl to improve the recovery of Fe, Al and Cr and followed by transfer of the supernatant to 7 ml plastic disposable tubes for direct determination by ICP.

## RESULTS AND DISCUSSION

Table gives the results of the analyses for all three replicates arranged by species. Table 2 gives the means and standard deviations for each set of replicates. Values for National Bureau Of Standards Peach Leaves (NBS Peach) and a locally used lichen standard (Cladina stellaris) are also given. Lichens collected from hardwood bark sometimes have different accumulations than those collected from conifer bark. To reduce this substrate variable, all tree lichens were collected from conifer bark whenever possible. Different species may accumulate different amounts of elements and this is evident when comparing sulfur levels of the different species. Cladina rangiferina has lower levels of sulfur than the other species. None of the reported values were below the lower detection limits of the instruments.

All of the levels found in the LBW lichens are within typical limits for similar lichens in clean areas and the levels within each species are fairly uniform across all localities. At Kelly Stand two species showed higher accumulations but that may be due to historical effects rather than air quality. This shows that there is no point-source of pollution effecting one part of LBW.

The sulfur levels in lichens tested range from 535 to 1780 ppm for all samples and these values are near background levels as cited by Solberg (1967) Erdman & Gough (1977), Nieboer et al (1977) and Puckett & Finegan (1980) for other species of lichens. Levels may be as low as 200-300 in the arctic (Tomassini et al, 1976) while levels in polluted areas are 4300-5200 ppm (Seaward, 1973) or higher. The sulfur levels in LBW are well within typical levels for clean areas as reported in the literature.

Table 1. Analysis of Lye Brook Lichens
Values in ppm of thallus dry weight

| Species | | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. rangiferina | 302 | 1083 | 207 | 170 | 157 | 173 | 47.8 | 54.6 | 17.1 | 1.6 | 0.4 | 2.9 | 0.7 | 0.3 | 0.1 | 535 | Lye Brook |
| C. rangiferina | 266 | 976 | 190 | 161 | 166 | 183 | 47.2 | 47.7 | 16.4 | 1.5 | 0.4 | 3.3 | 0.6 | 0.3 | 0.1 | 555 | Lye Brook |
| C. rangiferina | 269 | 1001 | 186 | 163 | 159 | 175 | 47.9 | 48.3 | 16.0 | 1.7 | 0.4 | 3.0 | 0.9 | 0.4 | 0.1 | 650 | Lye Brook |
| C. rangiferina | 312 | 1446 | 283 | 170 | 206 | 259 | 20.8 | 17.2 | 24.5 | 1.8 | 0.8 | 3.2 | 0.6 | 0.3 | 0.1 | 750 | Bourn Pond |
| C. rangiferina | 342 | 1637 | 235 | 175 | 183 | 229 | 19.3 | 15.0 | 24.6 | 2.0 | 0.8 | 3.1 | 0.5 | 0.3 | 0.1 | 750 | Bourn Pond |
| C. rangiferina | 332 | 1573 | 215 | 174 | 188 | 232 | 20.8 | 15.5 | 24.5 | 1.9 | 0.8 | 3.5 | 0.5 | 0.3 | 0.1 | 530 | Bourn Pond |
| E. mesomorpha | 653 | 2964 | 668 | 265 | 151 | 186 | 32.7 | 43.9 | 41.5 | 2.8 | 2.1 | 6.0 | 0.8 | 0.4 | 0.2 | 1330 | Little Mud P |
| E. mesomorpha | 646 | 2985 | 411 | 273 | 164 | 209 | 33.5 | 41.3 | 41.6 | 3.0 | 2.2 | 6.4 | 0.9 | 0.5 | 0.3 | 1330 | Little Mud P |
| E. mesomorpha | 738 | 2978 | 495 | 292 | 172 | 215 | 47.7 | 50.4 | 43.7 | 3.0 | 2.3 | 6.9 | 0.9 | 0.5 | 0.2 | 1430 | Little Mud P |
| E. mesomorpha | 456 | 1989 | 417 | 190 | 114 | 138 | 37.5 | 79.0 | 31.9 | 2.1 | 1.7 | 6.6 | 0.6 | 0.4 | 0.2 | 1070 | Lye Brook |
| E. mesomorpha | 449 | 1936 | 399 | 184 | 107 | 124 | 42.2 | 70.6 | 29.8 | 2.0 | 1.6 | 6.6 | 0.7 | 0.3 | 0.1 | 1035 | Lye Brook |
| E. mesomorpha | 439 | 1831 | 378 | 184 | 116 | 133 | 45.1 | 69.9 | 30.7 | 2.0 | 1.4 | 8.1 | 0.7 | 0.4 | 0.1 | 1070 | Lye Brook |
| E. mesomorpha | 422 | 1754 | 623 | 202 | 128 | 135 | 26.9 | 27.5 | 30.3 | 1.7 | 1.6 | 4.7 | 0.5 | 0.4 | 0.2 | 830 | Bourn Pond |
| E. mesomorpha | 463 | 1750 | 816 | 211 | 110 | 119 | 27.8 | 31.5 | 30.6 | 1.6 | 1.6 | 3.8 | 0.5 | 0.3 | 0.2 | 790 | Bourn Pond |
| E. mesomorpha | 464 | 1856 | 705 | 231 | 120 | 126 | 29.8 | 30.8 | 29.9 | 1.7 | 1.5 | 3.9 | 0.6 | 0.4 | 0.2 | 790 | Bourn Pond |
| H. physodes | 738 | 3862 | 8619 | 576 | 267 | 379 | 22.8 | 136.2 | 124.8 | 4.4 | 2.1 | 18.1 | 1.4 | 0.7 | 1.4 | 1380 | Little Mud P |
| H. physodes | 805 | 4416 | 5493 | 512 | 213 | 295 | 24.0 | 104.5 | 97.6 | 4.7 | 2.0 | 25.6 | 1.8 | 0.7 | 1.1 | 1380 | Little Mud P |
| H. physodes | 637 | 3807 | 8847 | 495 | 217 | 307 | 23.8 | 111.0 | 87.1 | 4.6 | 2.0 | 29.9 | 1.8 | 0.6 | 1.2 | 1420 | Little Mud P |
| H. physodes | 565 | 2743 | 7013 | 489 | 266 | 363 | 33.2 | 452.3 | 116.3 | 3.9 | 1.2 | 29.5 | 1.6 | 0.8 | 1.1 | 950 | Lye Brook |
| H. physodes | 694 | 3070 | 10832 | 507 | 252 | 322 | 51.0 | 506.4 | 116.7 | 3.5 | 1.3 | 33.7 | 1.2 | 0.7 | 1.4 | 1000 | Lye Brook |
| H. physodes | 619 | 2790 | 7764 | 492 | 243 | 322 | 70.5 | 508.1 | 121.4 | 3.4 | 1.3 | 25.8 | 1.1 | 0.7 | 1.2 | 1025 | Lye Brook |
| H. physodes | 813 | 3165 | 19606 | 653 | 191 | 229 | 30.0 | 281.7 | 88.1 | 3.6 | 2.8 | 17.5 | 1.0 | 0.6 | 0.9 | 1080 | Bourn Pond |
| H. physodes | 839 | 3127 | 21785 | 670 | 202 | 250 | 29.1 | 279.6 | 86.2 | 3.6 | 2.8 | 18.1 | 1.1 | 0.6 | 0.9 | 990 | Bourn Pond |
| H. physodes | 943 | 3414 | 17798 | 726 | 199 | 235 | 30.6 | 266.4 | 86.7 | 3.6 | 2.8 | 17.2 | 1.1 | 0.5 | 0.8 | 1020 | Bourn Pond |
| H. physodes | 2405 | 6348 | 6706 | 1008 | 521 | 794 | 57.1 | 139.8 | 102.3 | 6.0 | 3.1 | 25.7 | 2.4 | 1.1 | 0.7 | 1490 | Kelly Stand |
| H. physodes | 2037 | 5771 | 5686 | 901 | 544 | 814 | 58.2 | 110.6 | 96.4 | 5.5 | 2.8 | 26.1 | 2.4 | 1.1 | 0.5 | 1440 | Kelly Stand |
| H. physodes | 2336 | 6162 | 5900 | 932 | 542 | 807 | 55.5 | 120.7 | 100.4 | 6.4 | 2.8 | 43.5 | 2.3 | 1.1 | 0.6 | 1350 | Kelly Stand |
| P. sulcata | 1359 | 4517 | 1074 | 382 | 309 | 385 | 26.9 | 60.8 | 93.0 | 6.6 | 3.4 | 22.2 | 2.0 | 0.8 | 0.7 | 1550 | Little Mud P |
| P. sulcata | 1221 | 4222 | 1164 | 368 | 333 | 415 | 26.2 | 64.3 | 93.7 | 6.7 | 3.6 | 26.5 | 2.1 | 0.8 | 0.6 | 1530 | Little Mud P |
| P. sulcata | 1298 | 4442 | 1096 | 376 | 299 | 378 | 27.0 | 63.9 | 91.0 | 6.6 | 3.6 | 23.9 | 2.0 | 0.7 | 0.7 | 1780 | Little Mud P |
| P. sulcata | 1092 | 3547 | 1541 | 317 | 271 | 317 | 42.3 | 344.1 | 115.9 | 5.1 | 2.7 | 21.4 | 1.4 | 0.6 | 0.4 | 1080 | Lye Brook |
| P. sulcata | 664 | 2024 | 3587 | 405 | 301 | 326 | 16.9 | 181.7 | 94.5 | 5.1 | 2.8 | 24.1 | 1.7 | 0.7 | 0.4 | 1020 | Bourn Pond |
| P. sulcata | 663 | 2144 | 3357 | 384 | 326 | 356 | 29.2 | 183.5 | 96.8 | 5.0 | 2.8 | 23.1 | 1.8 | 0.8 | 0.4 | 1010 | Bourn Pond |
| P. sulcata | 689 | 2355 | 3036 | 357 | 318 | 352 | 18.1 | 162.2 | 85.0 | 4.6 | 2.6 | 22.7 | 1.8 | 0.8 | 0.4 | 1010 | Bourn Pond |
| P. sulcata | 1727 | 4364 | 2048 | 606 | 450 | 638 | 48.9 | 95.2 | 84.3 | 5.2 | 3.2 | 17.6 | 1.8 | 0.9 | 0.4 | 1360 | Kelly Stand |
| P. sulcata | 1724 | 4402 | 2064 | 599 | 443 | 634 | 40.7 | 98.9 | 87.6 | 5.5 | 3.4 | 17.5 | 1.8 | 0.9 | 0.4 | 1410 | Kelly Stand |
| P. sulcata | 1765 | 4516 | 2021 | 636 | 465 | 681 | 44.4 | 99.7 | 85.9 | 5.3 | 3.3 | 17.2 | 1.8 | 0.9 | 0.4 | 1480 | Kelly Stand |
| Standards | | | | | | | | | | | | | | | | | |
| C. stellaris | 195 | 664 | 234 | 264 | 421 | 566 | 74.6 | 20.4 | 17.1 | 2.1 | 0.9 | 12.7 | 1.0 | 0.8 | 0.2 | 410 | |
| C. stellaris | 198 | 664 | 242 | 274 | 435 | 587 | 78.9 | 20.6 | 18.0 | 3.0 | 1.0 | 13.9 | 1.1 | 0.9 | 0.2 | 423 | |
| C. stellaris | 194 | 658 | 234 | 271 | 416 | 551 | 80.6 | 20.2 | 17.1 | 2.2 | 1.0 | 14.1 | 1.2 | 1.0 | 0.2 | 460 | |
| NBS-Peach | 1182 | 3695 | 4433 | 1164 | 459 | 177 | 17.3 | 686.6 | 71.3 | 2.8 | 17.1 | 10.8 | 1.5 | 1.9 | 0.2 | NA | |
| NBS-Peach | 1210 | 3718 | 4523 | 1199 | 467 | 178 | 24.1 | 702.1 | 64.6 | 3.3 | 17.5 | 12.0 | 1.7 | 2.1 | 0.3 | NA | |
| NBS-Peach | 1202 | 3675 | 4557 | 1208 | 459 | | 20.0 | 696.8 | 66.1 | 3.2 | 17.4 | 12.6 | 1.9 | 2.2 | 0.3 | NA | |

Table 2. Summary of Analysis of Lye Brook Lichens
Values in ppm of thallus dry weight

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <u>Cladina</u> <u>rangiferina</u> | | | | | | | | | | | | | | | | | |
| Mean | 279 | 1020 | 194 | 165 | 161 | 177 | 47.6 | 50.2 | 16.5 | 1.6 | 0.4 | 3.1 | 0.7 | 0.3 | 0.1 | 580 | Lye Brook |
| Std. dev. | 20 | 56 | 11 | 4 | 4 | 5 | 0.4 | 3.8 | 0.5 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | <.1 | 61 | Lye Brook |
| Mean | 329 | 1552 | 244 | 173 | 192 | 240 | 20.3 | 15.9 | 24.5 | 1.9 | 0.8 | 3.2 | 0.5 | 0.3 | 0.1 | 677 | Bourn Pond |
| Std. dev. | 15 | 97 | 35 | 3 | 12 | 17 | 0.9 | 1.2 | 0.1 | 0.1 | <.1 | 0.2 | <.1 | <.1 | <.1 | 127 | Bourn Pond |
| <u>Evernia</u> <u>mesomorpha</u> | | | | | | | | | | | | | | | | | |
| Mean | 679 | 2976 | 525 | 277 | 162 | 203 | 38.0 | 45.2 | 42.3 | 2.9 | 2.2 | 6.4 | 0.9 | 0.5 | 0.2 | 1363 | Little Mud P |
| Std. dev. | 51 | 11 | 131 | 14 | 10 | 15 | 8.4 | 4.7 | 1.2 | 0.1 | 0.1 | 0.5 | 0.1 | <.1 | <.1 | 58 | Little Mud P |
| Mean | 448 | 1919 | 398 | 186 | 113 | 132 | 41.6 | 73.2 | 30.8 | 2.0 | 1.6 | 7.1 | 0.7 | 0.4 | 0.1 | 1058 | Lye Brook |
| Std. dev. | 9 | 81 | 20 | 3 | 5 | 7 | 3.8 | 5.1 | 1.1 | 0.1 | 0.2 | 0.9 | <.1 | <.1 | <.1 | 20 | Lye Brook |
| Mean | 450 | 1787 | 715 | 215 | 119 | 126 | 28.2 | 29.9 | 30.3 | 1.6 | 1.6 | 4.1 | 0.5 | 0.4 | 0.2 | 803 | Bourn Pond |
| Std. dev. | 24 | 60 | 97 | 15 | 9 | 8 | 1.5 | 2.1 | 0.4 | 0.1 | 0.1 | 0.5 | <.1 | <.1 | <.1 | 23 | Bourn Pond |
| <u>Hypogymnia</u> <u>physodes</u> | | | | | | | | | | | | | | | | | |
| Mean | 727 | 4028 | 7653 | 527 | 232 | 327 | 23.5 | 117.2 | 103.1 | 4.6 | 2.0 | 24.5 | 1.7 | 0.6 | 1.2 | 1393 | Little Mud P |
| Std. dev. | 85 | 337 | 1874 | 43 | 30 | 45 | 0.7 | 16.8 | 19.4 | 0.1 | 0.1 | 6.0 | 0.2 | 0.1 | 0.1 | 23 | Little Mud P |
| Mean | 626 | 2868 | 8536 | 496 | 254 | 336 | 51.6 | 489.0 | 118.1 | 3.6 | 1.2 | 29.7 | 1.3 | 0.7 | 1.2 | 992 | Lye Brook |
| Std. dev. | 65 | 177 | 2023 | 10 | 12 | 24 | 18.6 | 31.8 | 2.8 | 0.3 | <.1 | 3.9 | 0.3 | 0.1 | 0.2 | 38 | Lye Brook |
| Mean | 865 | 3235 | 19730 | 683 | 197 | 238 | 29.9 | 275.9 | 87.0 | 3.6 | 2.8 | 17.6 | 1.1 | 0.6 | 0.9 | 1030 | Bourn Pond |
| Std. dev. | 69 | 156 | 1996 | 38 | 5 | 11 | 0.8 | 8.3 | 1.0 | <.1 | <.1 | 0.5 | <.1 | <.1 | 0.1 | 46 | Bourn Pond |
| Mean | 2259 | 6094 | 6098 | 947 | 535 | 805 | 56.9 | 123.7 | 99.7 | 6.0 | 2.9 | 31.8 | 2.4 | 1.1 | 0.6 | 14: | Kelly Stand |
| Std. dev. | 196 | 295 | 538 | 55 | | 11 | 1.4 | 14.9 | 3.0 | 0.5 | 0.2 | 10.1 | <.1 | <.1 | 0.1 | | Kelly Stand |
| <u>Parmelia</u> <u>sulcata</u> | | | | | | | | | | | | | | | | | |
| Mean | 1293 | 4393 | 1111 | 375 | 314 | 393 | 26.7 | 63.0 | 92.6 | 6.6 | 3.5 | 24.2 | 2.1 | 0.7 | 0.7 | 1620 | Little Mud P |
| Std. dev. | 69 | 153 | 47 | 7 | 18 | 20 | 0.4 | 1.9 | 1.4 | 0.1 | 0.1 | 2.1 | <.1 | 0.1 | <.1 | 139 | Little Mud P |
| Mean | 672 | 2175 | 3326 | 382 | 315 | 345 | 21.4 | 175.8 | 92.1 | 4.9 | 2.7 | 23.3 | 1.7 | 0.7 | 0.4 | 1013 | Bourn Pond |
| Std. dev. | 15 | 168 | 277 | 25 | 12 | 16 | 6.7 | 11.8 | 6.3 | 0.3 | 0.1 | 0.7 | 0.1 | 0.1 | <.1 | 6 | Bourn Pond |
| Mean | 1739 | 4427 | 2044 | 613 | 453 | 651 | 44.7 | 97.9 | 86.0 | 5.3 | 3.3 | 17.5 | 1.8 | 0.9 | 0.4 | 1417 | Kelly Stand |
| Std. dev. | 23 | 79 | 22 | 20 | 11 | 26 | 4.1 | 2.4 | 1.7 | 0.1 | 0.1 | 0.2 | <.1 | <.1 | <.1 | 60 | Kelly Stand |
| Standards | | | | | | | | | | | | | | | | | |
| <u>Cladina</u> <u>stellaris</u> | | | | | | | | | | | | | | | | | |
| Mean | 196 | 662 | 237 | 270 | 424 | 568 | 78.0 | 20.4 | 17.4 | 2.4 | 1.0 | 13.5 | 1.1 | 0.9 | 0.2 | 431 | |
| Std. dev. | 2 | 3 | 5 | 5 | 10 | 18 | 3.1 | 0.2 | 0.5 | 0.5 | 0.1 | 0.7 | 0.1 | 0.1 | <.1 | 26 | |
| Peach | | | | | | | | | | | | | | | | | |
| | 1198 | 3696 | 4504 | 1190 | 462 | 177 | 20.5 | 695.2 | 67.3 | 3.1 | 17.3 | 1.8 | 1.7 | 1 | | NA | |
| dev. | 14 | 21 | 64 | 23 | 5 | 1 | 3.5 | 7.8 | 3.5 | 0.3 | 0.2 | 1.0 | 0.2 | 1 | | NA | |

All of the other elements show normal levels for areas with low pollution or relatively clean air. The elemental levels in the same species in the White Mt. Wilderness areas are very similar but slightly lower than those in the LBW. In two species some elements are somewhat higher at the Kelly Stand.

**Further statistical comparisons between Lye Brook Wilderness and White Mountains lichens have been omitted in this excerpt of the Final Report.**

### Statistical Analysis Conclusions

The levels of most elements are higher in the LBW than in the White Mt. wildernass areas. When comparing localities with the LBW, Kelly Stand was significantly higher in two species than the other localities. The levels at Bourn Pond were lowest in two species. The higer levels at Kelly stand may be due to historical activities in the area rather than air quality effects. LBW elemental levels are higher than clean areas in northen Minnesota some species.

## CONCLUSIONS

There is no indication that the lichens of LBW are being damaged by sulfur dioxide or the other elements studied. The lichen flora is diverse for such an area and there is no impoverishment of the lichen flora in any part of the the wilderness. There are six species in the most sensitive category to sulfur dioxide in the wilderness and most of these are rare. This rarity seems to be due more to ecological and climatic conditions than pollution since these species are quite healthy when present. The maps of the distributions of the more sensitive species do not show any significant voids that are not due to normal ecological conditions. There is no evidence of damaged or dead lichens in any area where healthy ones are not also present. The elemental analyses do not show abnormal accumulations of polluting elements at any locality. There is no geographical gradient of accumulations from north to south. Elemental levels are slightly higher than those in the White Mt. Wilderness areas.

## RECOMMENDATIONS

Although there seem to be no sulfur dioxide effects or impacts from other elements monitored in LBW now, periodic restudy is recommended. Elemental analysis should be done every 5 years and compared to the levels reported in this study. A complete floristic restudy should be done every 10-15 years

If plans are developed to do extensive trail construction or maintenance in the LBW, a lichenologist should be consulted to help design the work so that rare lichens are not lost.

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## APPENDIX I

Lye Brook Wilderness collection Localities

Collection numbers are those of Clifford Wetmore. All collections are listed in ascending order by number and date of collection. All localities are in the Green Mountain National Forest, located in Bennington County, Vermont.

Green Mountain National Forest, Lye Brook Wilderness, Bennington County, Vermont

72507-72532 Up the Lye Brook Falls Trail near talus slopes 3 miles southeast of Manchester Center. On west facing hillsides with maples, black spruce and some hemlock, elev. 1800 ft. 29 July 1993.

72533-72548 Along Lye Brook Falls Trail 2 miles south of Manchester Depot. On ridge with maple and hemlock, elev. 1300 ft. 29 July 1993

72549-72590 North of Kelly Stand at southern end of wilderness along Branch Pond Brook. Along stream with balsam fir, maples and yellow birch, elev. 2250 ft. 30 July 1993. CHEMICAL ANALYSIS.

72591-72611 Southeast of Branch Pond Brook in southern end of wilderness. On gentle hillside with beech, sugar maple and yellow birch, elev. 2520 ft. 30 July 1993.

72612-72648 Four miles south of Manchester Center. In deep gully on north facing slope and ridge with yellow birch and some hemlock and maple, elev. 1700 ft. 31 July 1993.

72649-72676 : Upper part of Lye Brook Hollow below Lye Brook Trail. On banks above stream with maple, birch, red spruce and some balsam fir, elev. 2350 ft. 1 Aug. 1993

72677-72708 : 1.5 miles east of Sunderland. On west facing hillside among overgrown talus with birch, maple, hemlock and some red spruce, elev. 1600 ft. 3 Aug. 1993.

72709-72746 : West side of Bourn Pond. Near lake with balsam fir, red spruce, birch and maple, elev. 2540 ft. 4 Aug. 1993. CHEMICAL ANALYSIS.

72747-72777 Half mile south of Bourn Pond. At edge of flooded red spruce swamp with some dead balsam fir, elev. 2580 ft. 4 Aug. 1993.

72778-72808 North of Branch Pond, west of trail to Bourn Pond. On small hill with white and yellow birch, red maple and some young red spruce and balsam fir, elev. 2660 ft 5 Aug. 1993

72809-72842 Northwest corner of Little Mud Pond (4 miles SE of Manchester). Along stream with beaver dams and red maple, red spruce, balsam fir and yellow birch, elev. 2250 ft. 6 Aug. 1993

72843-72871 North of Little Mud Pond above shelter. (3 miles of Manchester). In beech-maple woods on gentle slope with sugar maple, beech and some ash and young red spruce and balsam fir, elev. 2260 ft. 6 Aug. 1993

72872-72910 Hill west of Lye Brook (3 miles south of Manchester Center). On peak with red spruce, yellow birch and maples, elev. 2200 ft. 8 Aug. 1993. CHEMICAL ANALYSIS

72911-72941 North of Little Mud Pond. Near beaver swamps along old logging road with maples, red spruce and balsam fir, elev. 2330 ft. 9 Aug. 1993. CHEMICAL ANALYSIS

72942-72985 One mile east of Prospect Rock near trail junction. In beech-maple woods with some yellow birch and ash, elev. 2330 ft. 9 Aug. 1993

72986-73014 The Burning at southern end of wilderness (2 miles SE of Sunderland). On ridgetop southeast of pond in heath with red spruce and some white pine, elev. 2475 ft. 10 Aug. 1993

73015-73046 On hilltop east of main trail (3.5 miles E of Sunderland). In wet area with red spruce, balsam fir, some red maple and yellow birch, elev. 2600 ft. 13 Aug. 1993

73047-73071 Southwest corner of wilderness above Mill Creek. On gentle west slope with hemlock, maples and beech with few ash and oaks, elev. 1050 ft. 14 Aug. 1993

## APPENDIX II

Species Sensitive to Sulfur Dioxide

Based on the list of lichens with known sulfur dioxide sensitivity compiled from the literature, the following species in the Lye Brook Wilderness Area fall within the Sensitive category as listed by Wetmore, 1983. Sensitive species (S) are those present only under 50 $\mu$g sulfur dioxide per cubic meter (average annual). Open circles on the maps are localities where the species was not found and solid circles are where it was found. Only the species in the Sensitive category are mapped

Note: Refer to text for interpretation of these maps and precautions concerning absence in parts of the wilderness.

Fig. 2 Bryoria furcellata (Fr.) Brodo & Hawksw.
Fig. 3 Hypogymnia tubulosa (Schaer.) Hav.
Fig. 4. Lobaria pulmonaria (L.) Hoffm.
Fig. 5. Parmelia squarrosa Hale
Fig. 6. Ramalina obtusata (Arn.) Bitt.
Fig. 7. Usnea filipendula Stirt.

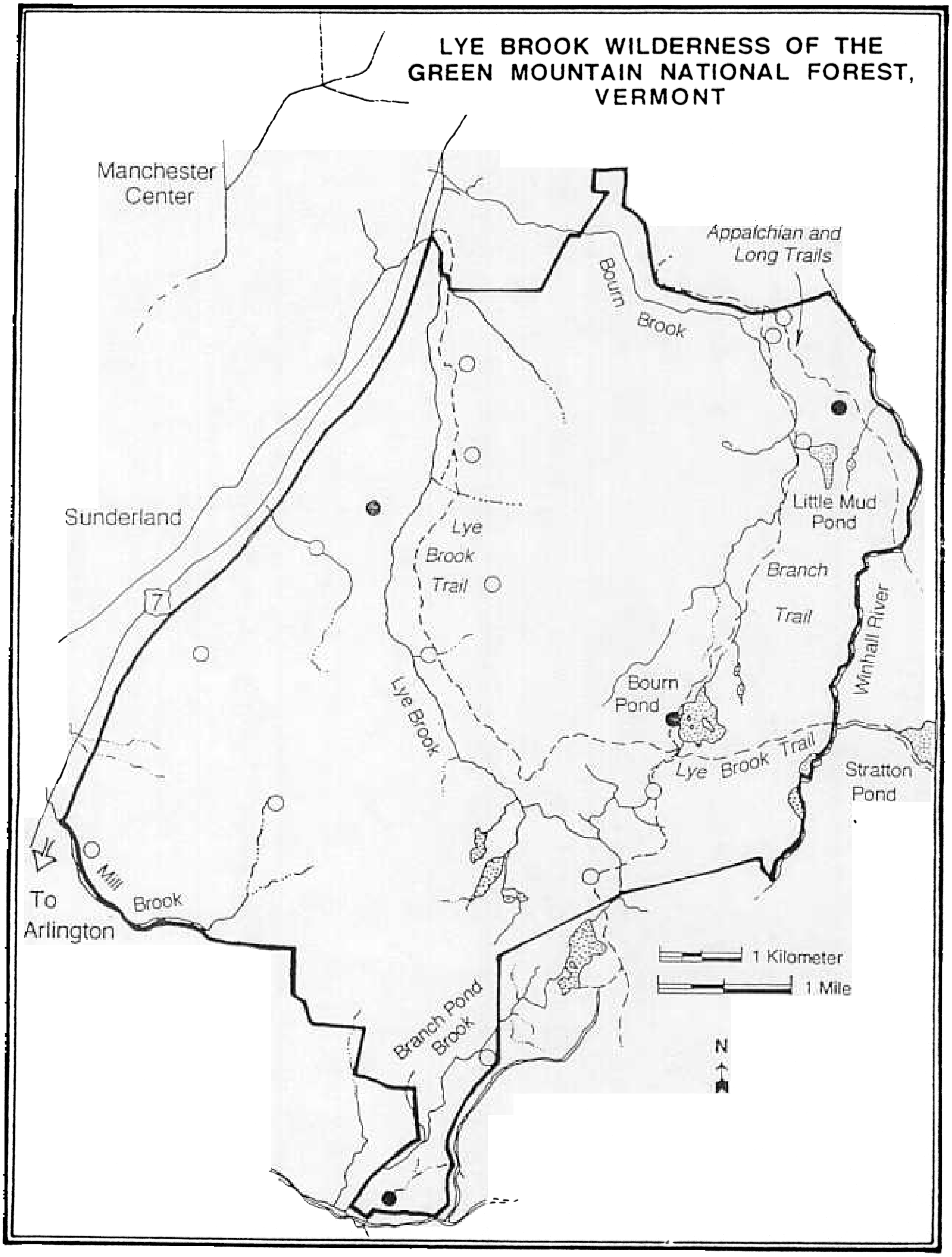


Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities and collection localities.

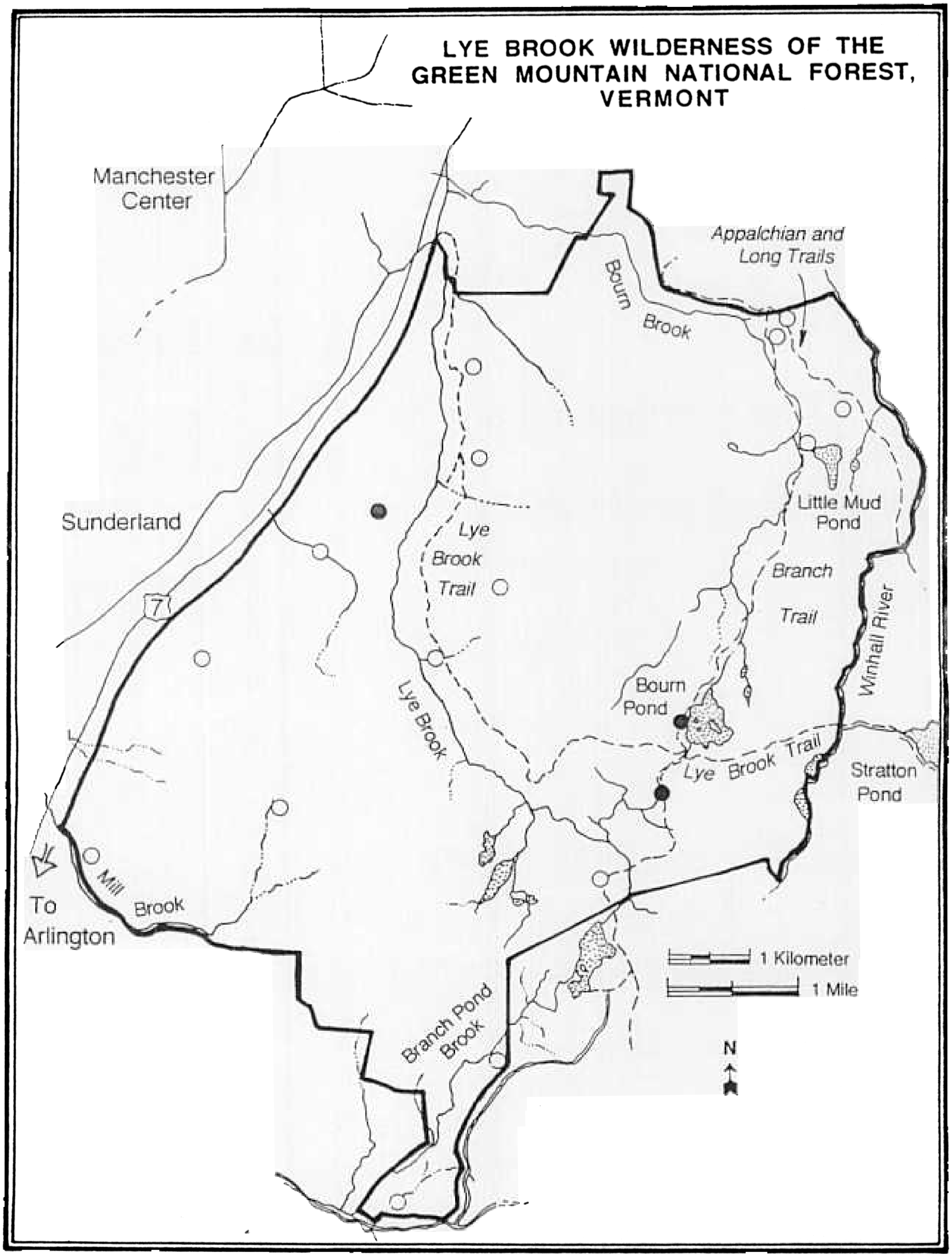


Fig. 2. Distribution of Bryoria furcellata.

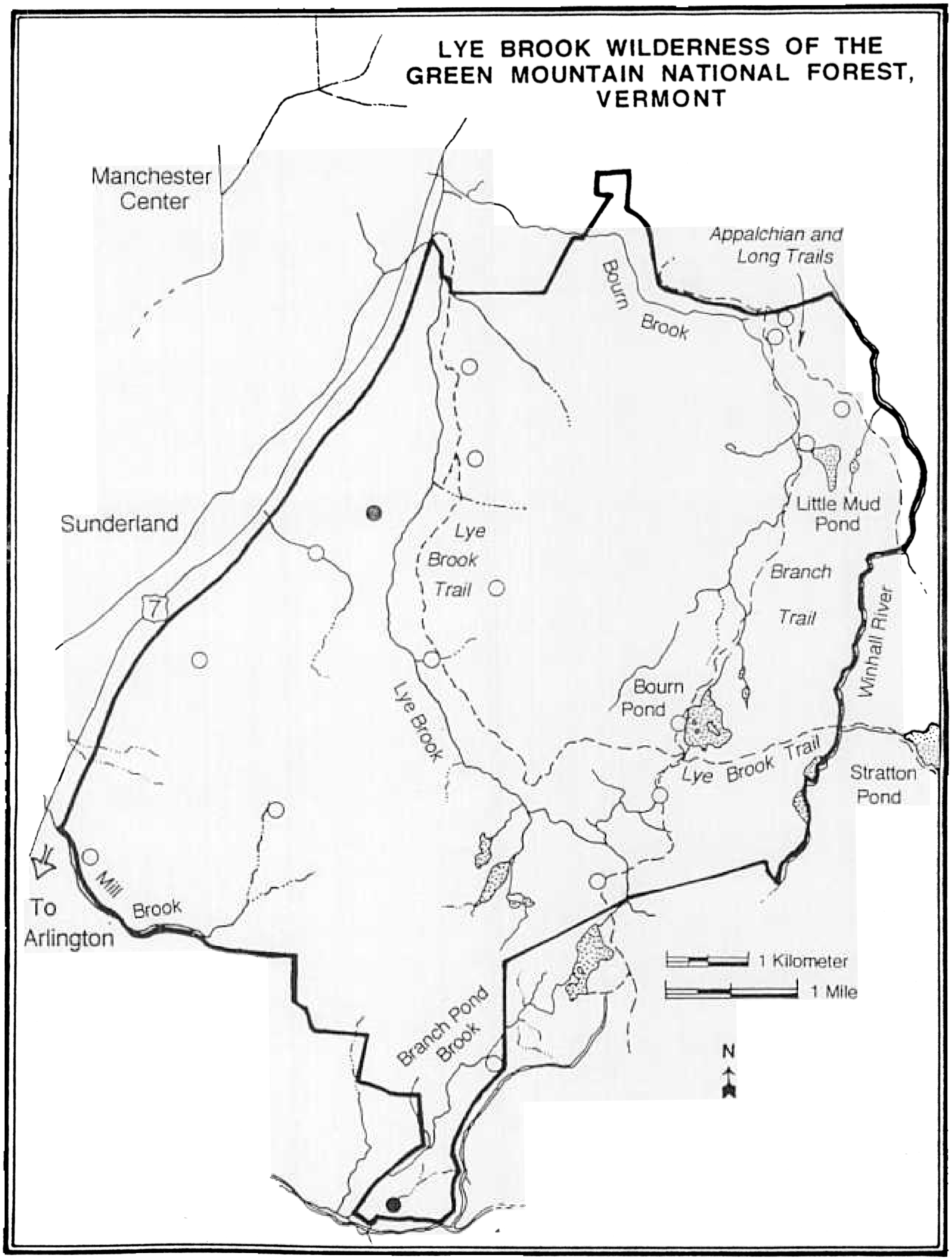


Fig. 3. Distribution of Hypogymnia tubulosa.

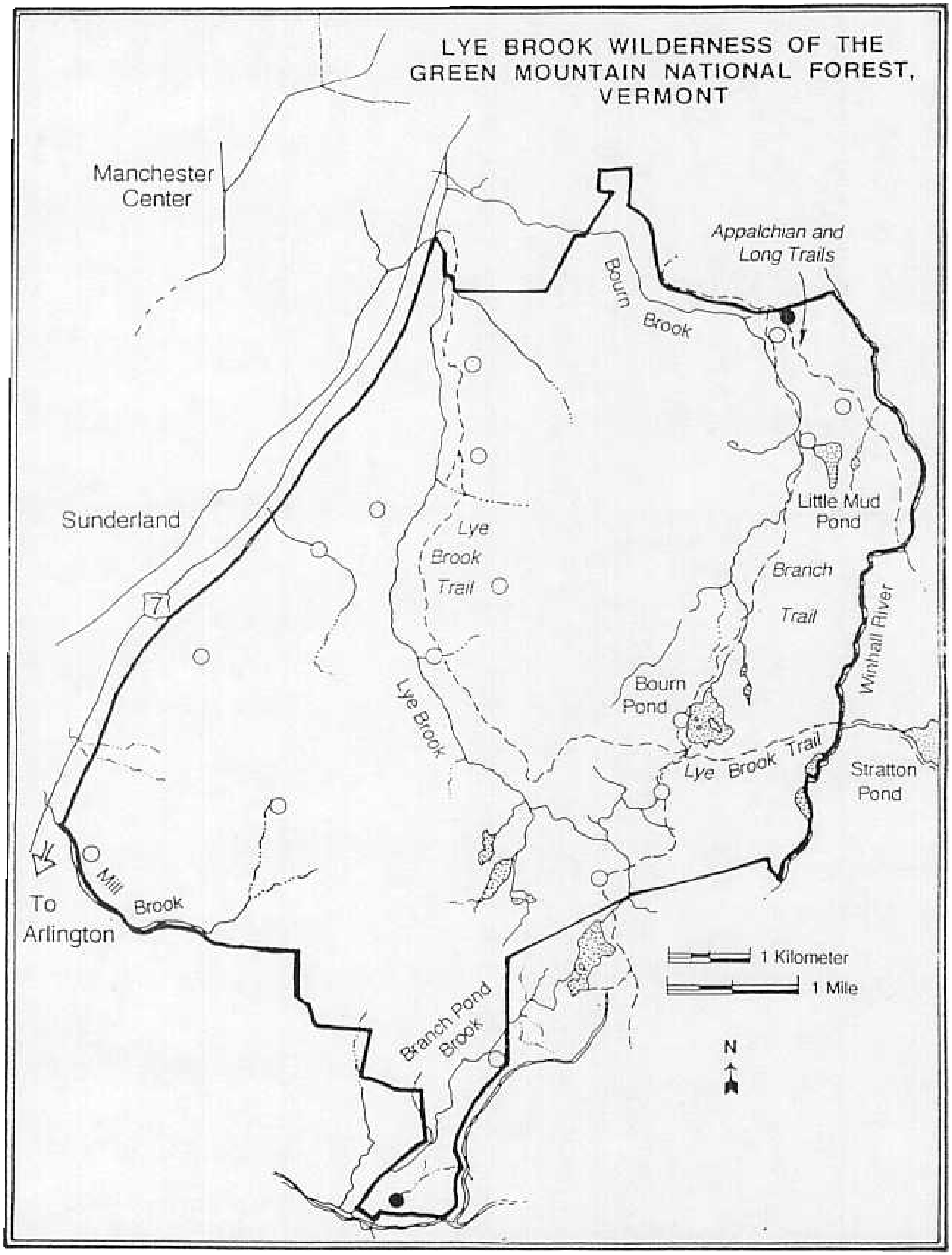


Fig. 4. Distribution of Lobaria pulmonaria.

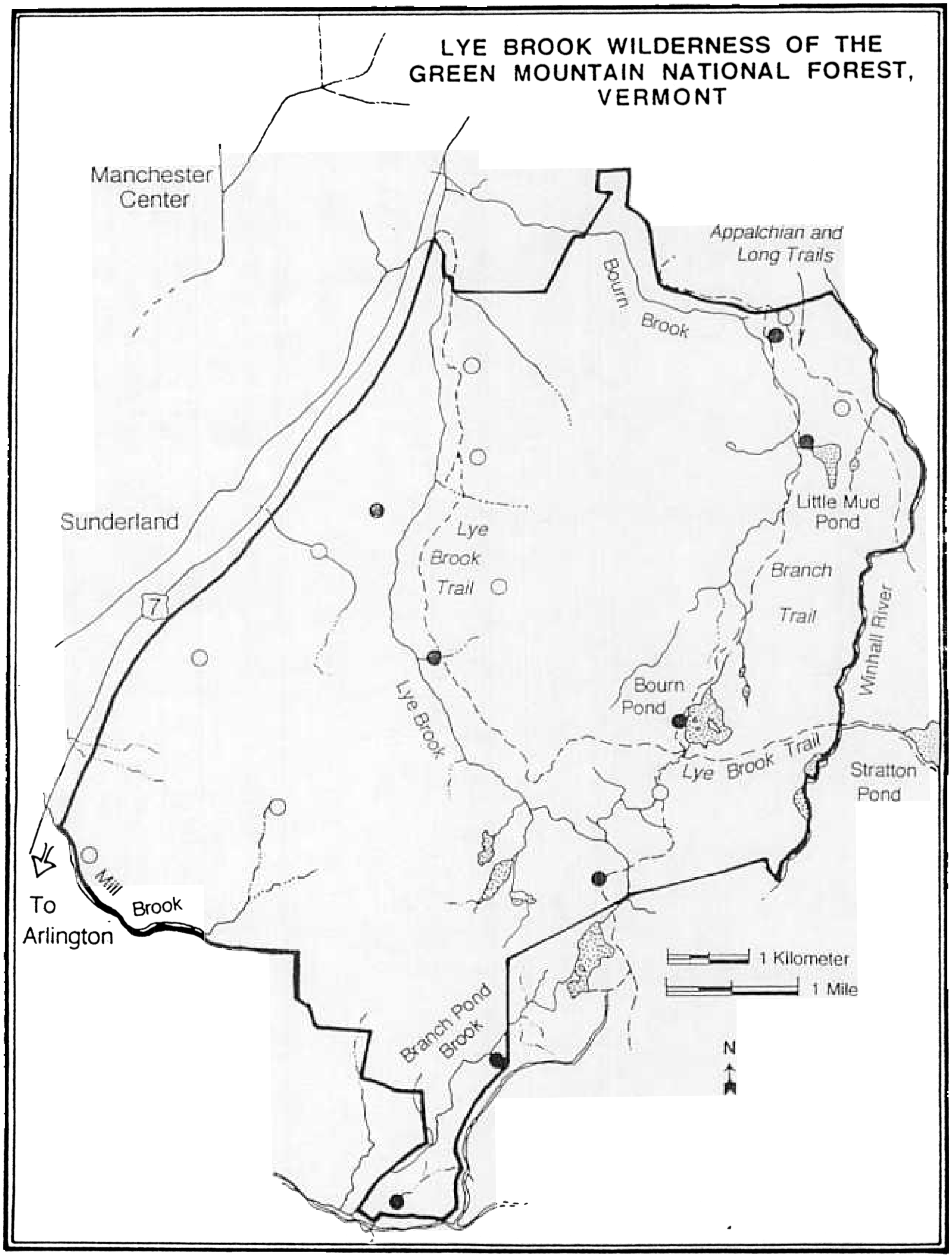


Fig. 5. Distribution of Parmelia squarrosa.

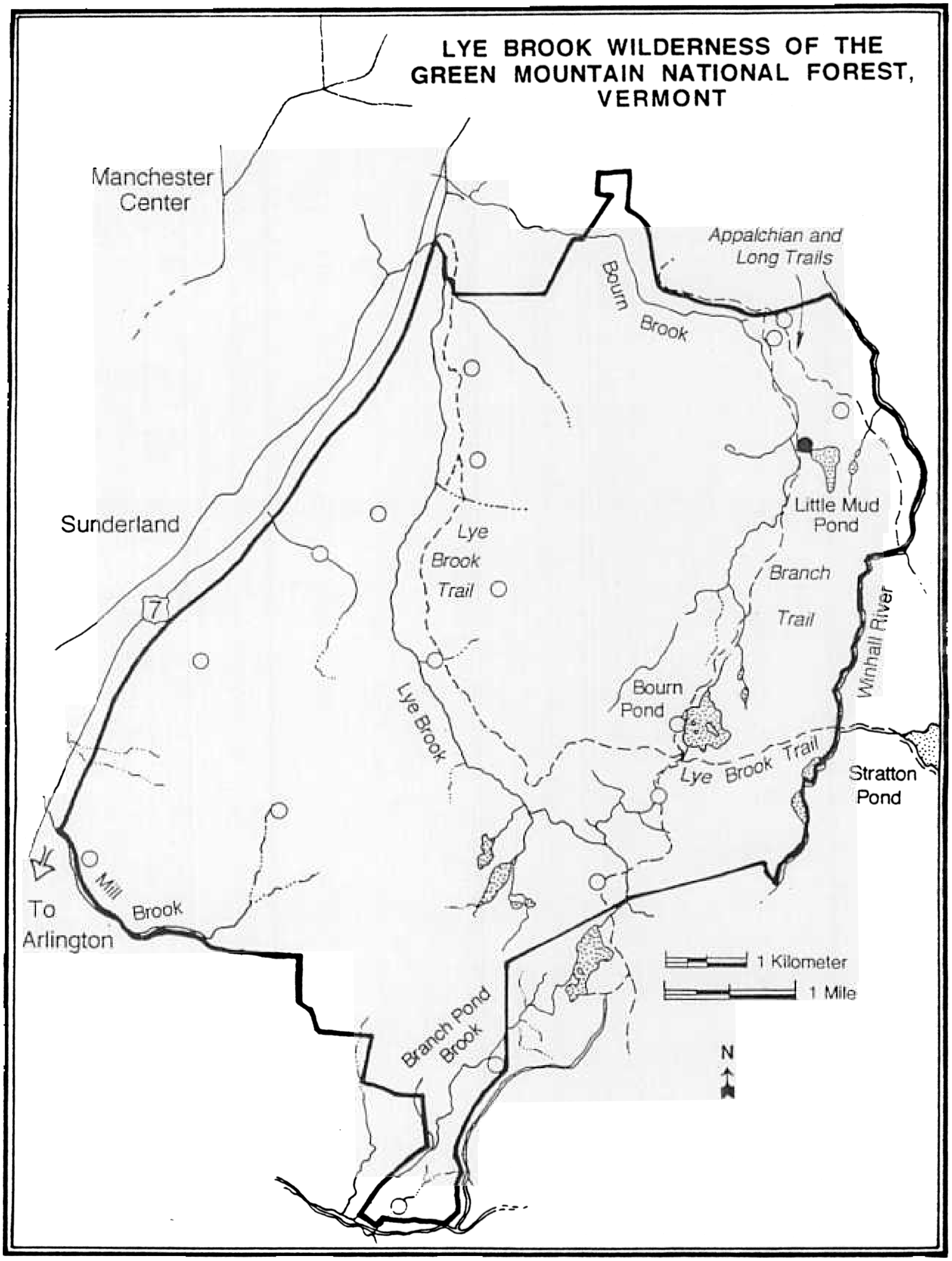


Fig. 6. Distribution of Ramalina obtusata.

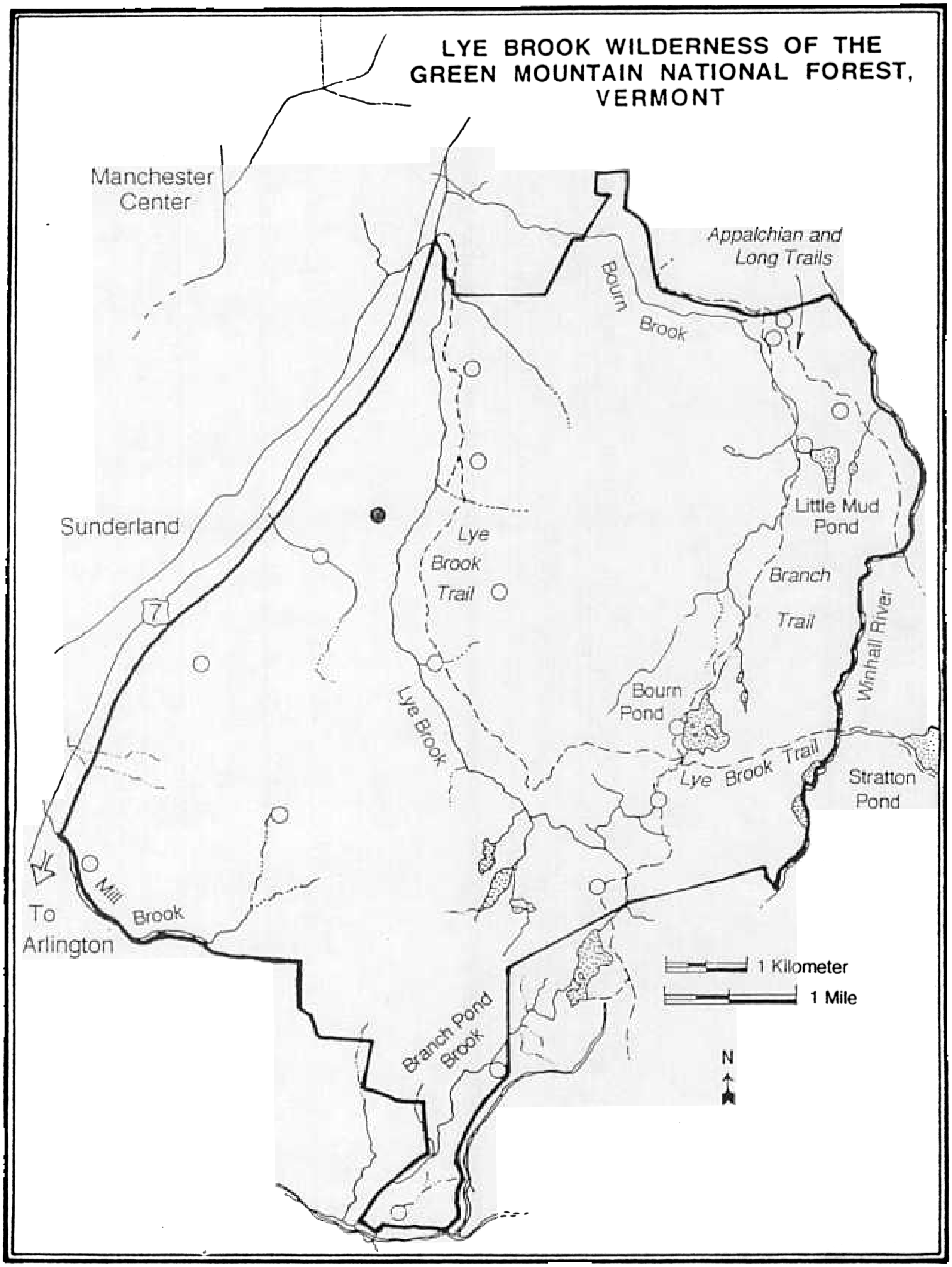


Fig. 7. Distribution of Usnea filipendula.