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# LICHENS AND AIR QUALITY IN

# GRAND PORTAGE NATIONAL MONUMENT

## FINAL REPORT

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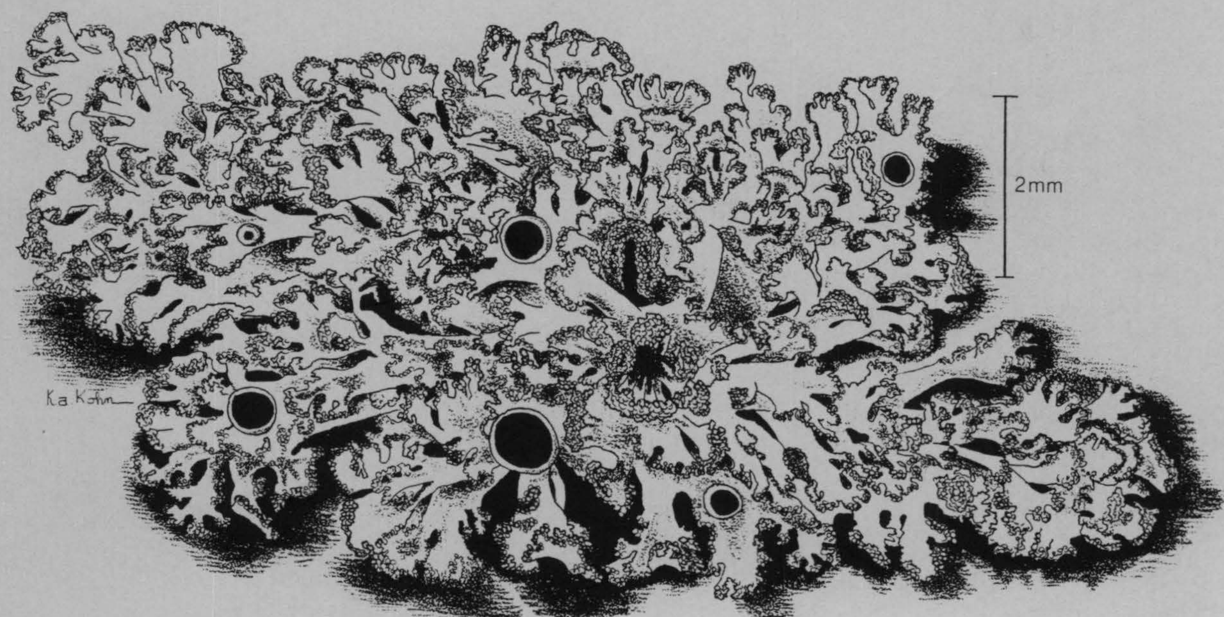


*Physcia millegrania*

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# LICHENS AND AIR QUALITY
# IN
# GRAND PORTAGE NATIONAL MONUMENT

Final Report

Prepared for

National Park Service

Midwest Region

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by

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# LICHENS OF GRAND PORTAGE NATIONAL MONUMENT

## ABSTRACT

This study of the lichens of Grand Portage National Monument was designed to collect lichens for a lichen flora and for elemental analysis, to study the health and distributions of species most sensitive to air pollution, and to assess the air quality on the lichens. Six localities were studied, both near the shore of Lake Superior and on the Pigeon River. Samples of four species were collected and analyzed for element accumulations.

The lichen flora was quite diverse for so small an area. There were 183 taxa of lichens present and numerous species very sensitive to sulfur dioxide. The distributions of the most sensitive species did not show patterns that would suggest air quality problems. The lichens studied by elemental analysis showed, in most cases, normal accumulations. The reason for the higher magnesium in three species at Fort Charlotte is unknown but the slightly elevated lead levels at Mt. Rose may be due to automobile traffic. Therefore, there seem to be no indications of air quality problems in the park now.

Recommendations are for annual elemental analysis of lichens to detect any changes due to the reactivation of the power plant at Schroeder. A complete restudy of the lichen flora should be done every 3-5 years.

# PREFACE

Under a contract with the National Park Service through the U. S. Forest Service (USDA/42-649) a lichen study was to be performed in Grand Portage National Monument. This study was to survey the lichens of the park, produce a lichen flora, collect and analyze lichens for chemical contents and evaluate the lichen flora with reference to the air quality. This study was to establish baseline data for future restudy and determine the presence of any air quality problems that might be shown by the lichens at the time of the study. All work was done at the University of Minnesota with frequent consultation with Dr. James Bennett, Great Lakes CPSU, Madison, Wisc. and with personnel in the park.

The park personnel have been very helpful during the field work in providing local transportation and information which has contributed significantly to the success of the project. The study was made possible by funds from the National Park Service. The assistance of all of these is gratefully acknowledged.

# 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 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 ug/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 ug/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 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.

Grand Portage NM is located in the northeastern tip of Minnesota and was established in 1951. It is comprised of a small area of 710 acres around the historic fort on the shore of Lake Superior, a narrow band along the nine mile historic portage trail to Fort Charlotte on the Pigeon River, and the area around Fort Charlotte. The fort on Lake Superior has been restored but no restoration has been done at Fort Charlotte and no buildings remain near the Pigeon River.

Most of the area within the park boundaries has been logged and is now in second growth pines, balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), quaking aspen (*Populus tremuloides*), white birch (*Betula papyrifera*) and other hardwoods. In some of the wetter areas there are white cedar (*Thuja occidentalis*) and black ash (*Fraxinus nigra*). Some rock outcrops occur at various places but the Lake Superior shore has no rock outcrops within the park boundaries. Mt. Rose rises to 906 ft (2760 m) above the reconstructed Northwest Company fir trade depot at Grand Portage and has extensive rock outcrops on the south side.

There have been no previous lichen collections from within the park boundaries but Bruce Fink collected at several locations near Grand Portage at the beginning of this century (Fink, 1899). Clifford Wetmore and his students have also collected at many places near Grand Portage since 1970 so the lichen flora of the area (but not the park) is well known.

## METHODS

Field work was done during August, 1991 when 373 collections were made at six localities. A complete list of collection localities is given in Appendix I and are indicated on Fig. 1. Localities for collecting were selected first to give a general coverage of the park, second, to sample all vegetational types, and third, to be in localities that should be rich in lichens. Undisturbed as well as disturbed habitats 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.

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 and a representative set of duplicates has been sent to the park and to the Smithsonian Institution. 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. 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 50ug per cubic meter. The Intermediate category includes those species present between 50 and 100ug and those in the Tolerant category are present at over 100ug per cubic meter.

## SPECIES LIST

| | |
|---|---|
| | *Acarospora americana* Magn. |
| | *Acarospora fuscata* (Nyl.) Arn. |
| I | *Anisomeridium biforme* (Borr.) R. Harris |
| | *Arthonia caesia* (Flot.) Körb. |
| | *Arthonia patellulata* Nyl. |
| I | *Arthonia radiata* (Pers.) Ach. |
| | 1 unidentified species of *Arthonia* |
| | *Aspicilia caesiocinerea* (Nyl. ex Malbr.) Arn. |
| | *Aspicilia cinerea* (L.) Körb. |
| | *Bacidia epixanthoides* (Nyl.) Lett. |
| | *Bacidia laurocerasi* (Delise ex Duby) Vain. in Zahlbr. |
| | *Bacidia polychroa* (Th. Fr.) Körb. |
| | *Bacidia sphaeroides* (Dicks.) Zahlbr. |
| I | *Bryoria furcellata* (Fr.) Brodo & Hawksw. |
| | *Bryoria nadvornikiana* (Gyeln.) Brodo & Hawksw. |
| S | *Bryoria trichodes* (Michx.) Brodo & Hawksw. |
| I | *Buellia disciformis* (Fr.) Mudd |
| | *Buellia stillingiana* Steiner |
| | *Calicium parvum* Tibell |
| | *Calicium trabinellum* Ach. |

S-I *Caloplaca cerina* (Ehrh.) Th. Fr.

*Caloplaca chrysophthalma* Degel.

*Caloplaca cinnabarina* (Ach.) Zahlbr.

*Caloplaca flavovirescens* (Wulf.) Dalla Torre & Sarnth.

I *Caloplaca holocarpa* (Hoffm.) Wade

*Candelaria fibrosa* (Fr.) Müll. Arg.

*Candelariella efflorescens* R. Harris & Buck

I *Candelariella vitellina* (Hoffm.) Müll. Arg.

*Catillaria nigroclavata* (Nyl.) Schuler

*Cetraria halei* W. & C. Culb.

I *Cetraria pinastri* (Scop.) Gray

*Cetrelia olivetorum* (Nyl.) W. & C. Culb.

*Chaenotheca brunneola* (Ach.) Müll. Arg.

*Chaenotheca trichialis* (Ach.) Th. Fr.

*Cladina mitis* (Sandst.) Hustich

*Cladina rangiferina* (L.) Nyl.

*Cladina stellaris* (Opiz) Brodo

*Cladonia amaurocraea* (Flörke) Schaer.

*Cladonia bacillaris* Nyl.

*Cladonia caespiticia* (Pers.) Flörke

*Cladonia cenotea* (Ach.) Schaer.

*Cladonia chlorophaea* (Flörke ex Somm.) Spreng.

I *Cladonia coniocraea* (Flörke) Spreng.

I *Cladonia cristatella* Tuck.

*Cladonia cryptochlorophaea* Asah.

I *Cladonia fimbriata* (L.) Fr.

*Cladonia furcata* (Huds.) Schrad.

*Cladonia gracilis* (L.) Willd.

*Cladonia phyllophora* Ehrh. ex Hoffm.

*Cladonia pyxidata* (L.) Hoffm.

*Cladonia scabriuscula* (Delise in Duby) Nyl.

*Cladonia turgida* Ehrh. ex Hoffm.

*Cladonia uncialis* (L.) Web. ex Wigg.

*Collema subflaccidum* Degel.

*Dermatocarpon luridum* (With.) Laundon

S *Dimerella lutea* (Dicks.) Trev.

*Ephebe ocellata* Henss.

I *Evernia mesomorpha* Nyl.

*Haematomma elatinum* (Ach.) Mass.

*Haematomma pustulatum* Brodo & W. Culb.

*Heterodermia speciosa* (Wulf.) Trev.

*Hypocenomyce scalaris* (Ach. in Lilj.) Choisy

I *Hypogymnia physodes* (L.) Nyl.

S *Hypogymnia tubulosa* (Schaer.) Hav.

*Imshaugia aleurites* (Ach.) S. F. Meyer

*Imshaugia placorodia* (Ach.) S. F. Meyer

*Julella fallaciosa* (Stizenb. ex Arn.) R. Harris

*Lecanactis chloroconia* Tuck.

*Lecania dubitans* (Nyl.) A. L. Sm.

I *Lecanora allophana* Nyl.

*Lecanora caesiorubella* Ach.

*Lecanora cenisia* Ach.

I *Lecanora circumborealis* Brodo & Vitik.

T *Lecanora dispersa* (Pers.) Somm.

*Lecanora impudens* Degel.
T *Lecanora muralis* (Schreb.) Rabenh.
*Lecanora polytropa* (Hoffm.) Rabenh.
*Lecanora pulicaris* (Pers.) Ach.
*Lecanora rupicola* (L.) Zahlbr.
I *Lecanora symmicta* (Ach.) Ach.
*Lecanora thysanophora* Harris ined.
*Lecanora wisconsinensis* Magn.
*Lecidea albohyalina* (Nyl.) Th. Fr.
*Lecidella euphorea* (Flörke) Hert.
*Lecidella stigmatea* (Ach.) Hert. & Leuck.
*Lecidea berengeriana* (Mass.) Nyl.
*Lecidea helvola* (Körb. ex Hellb.) Oliv.
*Lecidella euphorea* (Flörke) Hert.
*Lepraria finkii* (B. de Lesd. in Hue) R. Harris
*Leptogium cyanescens* (Rabenh.) Körb.
*Leptogium saturninum* (Dicks.) Nyl.
S *Lobaria pulmonaria* (L.) Hoffm.
*Megaspora verrucosa* (Ach.) Hafeln. & Wirth
*Micarea melaena* (Nyl.) Hedl.
I *Mycoblastus sanguinarius* (L.) Norm.
*Mycocalicium subtile* (Pers.) Szat.
*Nephroma bellum* (Spreng.) Tuck.
*Nephroma helveticum* Ach.
*Nephroma parile* (Ach.) Ach.
*Nephroma resupinatum* (L.) Ach.
S *Ochrolechia rosella* (Müll. Arg.) Vers.
*Pannaria leucophaea* (Vahl) P. Jörg.
*Parmelia aurulenta* Tuck.
I *Parmelia caperata* (L.) Ach.
*Parmelia conspersa* (Ach.) Ach.
*Parmelia cumberlandia* (Gyeln.) Hale
*Parmelia disjuncta* Erichs.
*Parmelia exasperata* De Not.
I *Parmelia exasperatula* Nyl.
*Parmelia flaventior* Stirt.
*Parmelia galbina* Ach.
*Parmelia glabratula* (Lamy) Nyl.
I *Parmelia olivacea* (L.) Ach.
*Parmelia omphalodes* (L.) Ach.
I *Parmelia rudecta* Ach.
I *Parmelia saxatilis* (L.) Ach.
I *Parmelia septentrionalis* (Lynge) Ahti
*Parmelia sorediata* (Ach.) Th. Fr.
S *Parmelia squarrosa* Hale
*Parmelia stictica* (Duby) Nyl.
I-T *Parmelia subargentifera* Nyl.
I *Parmelia subaurifera* Nyl.
I *Parmelia subrudecta* Nyl.
I-T *Parmelia sulcata* Tayl.
I *Parmelia trabeculata* Ahti
I *Parmeliopsis ambigua* (Wulf. in Jacq.) Nyl.
I *Parmeliopsis hyperopta* (Ach.) Arn.
*Peltigera aphthosa* (L.) Willd.

*Peltigera canina* (L.) Willd.
*Peltigera elisabethae* Gyeln.
*Peltigera evansiana* Gyeln.
I *Peltigera horizontalis* (Huds.) Baumg.
*Peltigera lepidophora* (Nyl. ex Vain.) Bitter
*Peltigera malacea* (Ach.) Funck
*Peltigera membranacea* (Ach.) Nyl.
*Peltigera neckeri* Hepp ex Müll. Arg.
*Peltigera polydactyla* (Neck.) Hoffm.
*Peltigera praetextata* (Flörke ex Somm.) Zopf
*Peltigera rufescens* (Weis) Humb.
*Pertusaria alpina* Hepp ex Ahles
I *Pertusaria amara* (Ach.) Nyl.
*Pertusaria ophthalmiza* (Nyl.) Nyl.
*Pertusaria trachythallina* Erichs.
*Phaeocalicium populneum* (Brond. ex Duby) Schmidt
*Phaeophyscia adiastola* (Essl.) Essl.
*Phaeophyscia chloantha* (Ach.) Moberg
*Phaeophyscia pusilloides* (Zahlbr.) Essl.
1 unidentified species of *Phaeophyscia*
I *Phlyctis argena* (Spreng.) Flot.
I *Physcia adscendens* (Th. Fr.) Oliv.
I *Physcia aipolia* (Ehrh. ex Humb.) Fürnr.
*Physcia caesia* (Hoffm.) Fürnr.
I *Physconia detersa* (Nyl.) Poelt
*Placynthiella icmalea* (Ach.) Coppins & James
*Platismatia tuckermanii* (Oakes) W. & C. Culb.
*Pseudevernia consocians* (Vain.) Hale & W. Culb.
*Psilolechia lucida* (Ach.) Choisy
S *Ramalina americana* Hale
I *Ramalina dilacerata* (Hoffm.) Hoffm.
*Ramalina intermedia* (Del. ex Nyl.) Nyl.
*Rhizocarpon disporum* (Naeg. ex Hepp) Müll. Arg.
*Rhizocarpon grande* (Flörke ex Flot.) Arn.
*Rhizocarpon obscuratum* (Ach.) Mass.
*Rhizoplaca subdiscrepans* (Nyl.) R. Sant.
*Rinodina archaea* (Ach.) Arn.
*Sarea resinae* (Fr. ex Fr.) Kuntze
I *Scoliciosporum chlorococcum* (Graewe ex Stenh.) Vezda
I *Stenocybe major* (Nyl.) Körb.
*Stenocybe pullatula* (Ach.) B. Stein.
*Stereocaulon saxatile* Magn.
*Strigula stigmatella* (Ach.) R. Harris
*Trapeliopsis granulosa* (Hoffm.) Lumbsch.
*Umbilicaria mammulata* (Ach.) Tuck.
*Umbilicaria muehlenbergii* (Ach.) Tuck.
*Umbilicaria vellea* (L.) Ach.
*Usnea cavernosa* Tuck.
S *Usnea filipendula* Stirt.
S-I *Usnea hirta* (L.) Weber ex Wigg.
*Usnea lapponica* Vain.
*Usnea longissima* Ach.
S-I *Usnea subfloridana* Stirt.
1 unidentified species of *Usnea*

*Verrucaria aethiobola* Wahlenb. in Ach.
1 unidentified species of *Verrucaria*
*Xanthoria elegans* (Link) Th. Fr.
S-I *Xanthoria fallax* (Hepp in Arn.) Arn.
I *Xanthoria polycarpa* (Hoffm.) Rieber

## DISCUSSION OF FLORA

This list includes 183 taxa collected for this study. There are also an additional 4 unidentified species, some of which are undescribed. The most common species are *Cladina rangiferina*, *Hypogymnia physodes*, *Parmelia sulcata*, and *Evernia mesomorpha*.

This list of species presents the first listing of lichens for the park itself, although the surrounding area is well known lichenologically with over 350 species known from Cook County according to the comupter data base for Minnesota lichens at the University of Minnesota Herbarium. The reduced number of species in the park is due to the small size of the park and the limited kinds of habitats present within the park boundaries.

Distribution within the park have little meaning in such a small area. Many species were found only on the occasional rock outcrops or other special habitats, and other species are not found in every suitable habitat. There is no indication that the distribution of any species is not due to normal ecological conditions.

The lichen flora is quite diverse for such a small area because of its location in the lichenologically rich boreal forest above Lake Superior. Most areas further south in the temperate forest region would have fewer lichens. 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 park. These observations indicate that there is no air quality degradation in the park due to sulfur dioxide that causes observable damage to the lichen flora.

Another way of analyzing the lichen flora of an area is to study the distributions of the sensitive species within the park 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.

Many of the lichens in the park have known sensitivity to sulfur dioxide according to the list presented in Wetmore (1983). Species in the most sensitive category are usually absent when sulfur dioxide levels are above 50ug per cubic meter average annual concentrations. The S-I category is between Sensitive and Intermediate. The species that occur in the park in the most sensitive category are as follows.

Fig. 2. *Bryoria trichodes* (Michx.) Brodo & Hawksw.
Fig. 3. *Dimerella lutea* (Dicks.) Trev.
Fig. 4. *Hypogymnia tubulosa* (Schaer.) Hav.
Fig. 5. *Lobaria pulmonaria* (L.) Hoffm.
Fig. 6. *Ochrolechia rosella* (Müll. Arg.) Vers.
Fig. 7. *Parmelia squarrosa* Hale
Fig. 8. *Ramalina americana* Hale
Fig. 9. *Usnea filipendula* Stirt.

The distributions of these species are mapped Fig. 2-9. Although these species are not found at all localities and many are not common, there is no indication that the voids in the distributions are due to poor air quality. 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 at two localities in the park. All species were present at both localities in quantities needed for the analysis.

## METHODS

Lichen samples of four species were collected in spunbound olefin bags at two localities in different parts of the park for laboratory analysis. Species collected and the substrates were *Cladina rangiferina* on the ground, *Evernia mesomorpha* on conifer branches, *Hypogymnia physodes* on conifer branches, and *Parmelia sulcata* on conifer branches. These species were selected because they are locally present in abundance and relatively easy to clean.

The two localities selected for elemental analysis are indicated on the map of collection localities. These localities are: Mt. Rose above Lake Superior, and Fort Charlotte on the Pigeon River. 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 of each collection were submitted for analysis. 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 1 gives the results of the analyses for all three

Peat Group 14

Table 1. Analysis of Grand Portage Lichens

Values in ppm of thallus dry weight

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | S | Locality | Num |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. rangiferina | 879 | 2096 | 862 | 479 | 572 | 605 | 31.0 | 48.3 | 33.1 | 3.1 | 2.6 | 2.3 | 0.6 | 1.2 | 1.3 | 560 | Mt. Rose | 100 |
| C. rangiferina | 943 | 2252 | 739 | 462 | 427 | 430 | 27.1 | 46.3 | 30.7 | 2.7 | 2.4 | 6.8 | 0.5 | 0.8 | 0.6 | 500 | Mt. Rose | 101 |
| C. rangiferina | 940 | 2281 | 881 | 501 | 503 | 538 | 27.6 | 54.7 | 33.2 | 3.2 | 2.7 | 5.8 | 1.2 | 1.0 | 0.4 | 660 | Mt. Rose | 102 |
| C. rangiferina | 622 | 2048 | 723 | 359 | 287 | 257 | 27.2 | 148.2 | 20.4 | 2.2 | 1.7 | 4.6 | # | 0.8 | # | 490 | Ft. Charlotte | 103 |
| C. rangiferina | 655 | 2015 | 748 | 385 | 313 | 281 | 25.1 | 170.8 | 21.8 | 2.3 | 1.7 | 1.4 | # | 1.0 | # | 490 | Ft. Charlotte | 104 |
| C. rangiferina | 689 | 2060 | 774 | 379 | 279 | 248 | 25.3 | 163.8 | 21.6 | 2.4 | 1.6 | 2.6 | # | 0.8 | # | 525 | Ft. Charlotte | 105 |
| E. mesomorpha | 610 | 2645 | 985 | 351 | 621 | 695 | 40.6 | 25.7 | 35.4 | 4.0 | 3.0 | 10.3 | 0.5 | 1.3 | 0.2 | 930 | Mt. Rose | 106 |
| E. mesomorpha | 577 | 2467 | 1001 | 331 | 636 | 706 | 46.9 | 26.7 | 33.2 | 4.0 | 2.9 | 10.1 | *0.3 | 1.4 | 0.2 | 930 | Mt. Rose | 107 |
| E. mesomorpha | 711 | 2841 | 1758 | 357 | 678 | 731 | 45.6 | 25.2 | 31.9 | 3.6 | 3.2 | 10.9 | 0.7 | 1.3 | 0.5 | 1000 | Mt. Rose | 108 |
| E. mesomorpha | 1090 | 3252 | 2045 | 370 | 557 | 531 | 34.0 | 39.9 | 43.6 | 3.1 | 3.2 | 8.8 | # | 0.9 | # | 910 | Ft. Charlotte | 109 |
| E. mesomorpha | 991 | 3003 | 1732 | 366 | 446 | 417 | 30.8 | 38.8 | 39.2 | 2.8 | 3.3 | 6.2 | # | 0.7 | # | 920 | Ft. Charlotte | 110 |
| E. mesomorpha | 1036 | 3057 | 1961 | 369 | 572 | 548 | 30.5 | 37.5 | 40.1 | 3.0 | 3.7 | 6.4 | # | 0.9 | # | 1020 | Ft. Charlotte | 111 |
| H. physodes | 591 | 2822 | 30102 | 607 | 625 | 660 | 27.8 | 134.6 | 66.8 | 4.8 | 2.1 | 23.9 | *0.3 | 1.2 | 0.7 | 930 | Mt. Rose | 112 |
| H. physodes | 705 | 3488 | 18895 | 641 | 743 | 885 | 35.7 | 99.3 | 61.6 | 5.2 | 2.2 | 21.1 | 2.5 | 1.5 | 1.0 | 1020 | Mt. Rose | 113 |
| H. physodes | 796 | 3306 | 22498 | 648 | 611 | 723 | 31.8 | 116.5 | 69.1 | 4.8 | 2.1 | 17.3 | 1.9 | 1.3 | 1.2 | 990 | Mt. Rose | 114 |
| H. physodes | 832 | 3216 | 18202 | 724 | 546 | 516 | 31.5 | 214.4 | 82.6 | 4.5 | 2.0 | 14.1 | 1.3 | 1.2 | 1.0 | 890 | Ft. Charlotte | 115 |
| H. physodes | 909 | 3629 | 16472 | 694 | 612 | 612 | 33.0 | 231.1 | 86.0 | 5.0 | 2.5 | 17.0 | 1.9 | 1.2 | 1.0 | 870 | Ft. Charlotte | 116 |
| H. physodes | 1083 | 3868 | 16339 | 751 | 598 | 582 | 32.1 | 240.3 | 78.8 | 4.8 | 2.7 | 12.8 | 2.2 | 1.3 | 0.9 | 980 | Ft. Charlotte | 117 |
| P. sulcata | 816 | 2596 | 4658 | 476 | 994 | 1041 | 32.7 | 80.4 | 77.3 | 6.7 | 3.4 | 14.2 | 2.4 | 1.8 | 0.8 | 980 | Mt. Rose | 118 |
| P. sulcata | 895 | 2757 | 4520 | 494 | 971 | 1010 | 31.4 | 80.9 | 74.9 | 6.9 | 3.6 | 15.3 | 2.1 | 1.6 | 0.8 | 1080 | Mt. Rose | 119 |
| P. sulcata | 723 | 2417 | 4028 | 487 | 959 | 992 | 29.6 | 96.8 | 68.3 | 6.5 | 3.3 | 20.0 | 1.8 | 1.6 | 0.3 | 1080 | Mt. Rose | 120 |
| P. sulcata | 1522 | 3730 | 4193 | 542 | 799 | 700 | 22.4 | 212.8 | 101.5 | 6.1 | 4.7 | 17.6 | 2.0 | 1.3 | 0.9 | 1180 | Ft. Charlotte | 121 |
| P. sulcata | 1396 | 3544 | 4213 | 514 | 717 | 625 | 21.9 | 154.3 | 102.3 | 5.9 | 4.3 | 17.2 | 2.0 | 1.2 | 0.6 | 1140 | Ft. Charlotte | 122 |
| P. sulcata | 1655 | 3957 | 4114 | 630 | 881 | 749 | 24.4 | 245.5 | 101.7 | 6.4 | 5.8 | 16.3 | 1.4 | 1.3 | 1.2 | 1130 | Ft. Charlotte | 123 |
| C. stellaris | 200 | 742 | 225 | 276 | 482 | 598 | 90.3 | 20.5 | 20.4 | 2.7 | 2.1 | 15.7 | 1.7 | 1.3 | 0.1 | 450 | Lichen standard | |
| C. stellaris | 188 | 730 | 228 | 268 | 463 | 574 | 80.3 | 20.5 | 20.2 | 2.5 | 1.8 | 12.7 | 1.0 | 1.0 | 0.1 | 423 | Lichen standard | |
| C. stellaris | | | | | | | | | | | | | | | | 437 | Lichen standard | |
| NBS-Peach | 1183 | 3701 | 4170 | 1135 | 490 | 178 | 13.3 | 676.2 | 67.2 | 3.2 | 17.1 | 11.3 | 2.7 | 2.9 | 0.2 | | NBS-P standard | |
| NBS-Peach | 1224 | 3736 | 4175 | 1161 | 501 | 192 | 20.8 | 683.6 | 69.1 | 3.4 | 17.6 | 12.9 | 2.9 | 3.7 | 0.1 | | NBS-P standard | |

* = one value at or below detection limit; included as 0.7 of detection limit
# = two or more values at or below detection limit; not included in calculations

Table 2. Summary of Analysis of Grand Portage Lichens

Values in ppm of thallus dry weight

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | S | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. rangiferina | | | | | | | | | | | | | | | | | |
| Mean | 921 | 2210 | 827 | 480 | 501 | 524 | 28.6 | 49.8 | 32.3 | 3.0 | 2.6 | 5.0 | 0.8 | 1.0 | 0.8 | 573 | Mt. Rose |
| Std. Dev. | 37 | 100 | 77 | 20 | 73 | 88 | 2.1 | 4.4 | 1.4 | 0.2 | 0.1 | 2.4 | 0.4 | 0.2 | 0.5 | 81 | Mt. Rose |
| Mean | 655 | 2041 | 749 | 374 | 293 | 262 | 25.8 | 160.9 | 21.3 | 2.3 | 1.6 | 2.9 | # | 0.8 | # | 502 | Ft. Charlotte |
| Std. Dev. | 33 | 23 | 25 | 13 | 18 | 17 | 1.2 | 11.6 | 0.7 | 0.1 | 0.1 | 1.6 | # | 0.1 | # | 20 | Ft. Charlotte |

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | S | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E. mesomorpha | | | | | | | | | | | | | | | | | |
| Mean | 633 | 2651 | 1248 | 347 | 645 | 711 | 44.4 | 25.9 | 33.5 | 3.9 | 3.0 | 10.4 | *0.5 | 1.3 | 0.3 | 953 | Mt. Rose |
| Std. Dev. | 70 | 187 | 442 | 14 | 30 | 18 | 3.3 | 0.8 | 1.8 | 0.2 | 0.1 | 0.4 | *0.2 | 0.1 | 0.2 | 40 | Mt. Rose |
| Mean | 1039 | 3104 | 1913 | 368 | 525 | 499 | 31.8 | 38.7 | 41.0 | 3.0 | 3.4 | 7.1 | # | 0.8 | # | 950 | Ft. Charlotte |
| Std. Dev. | 50 | 131 | 162 | 2 | 69 | 71 | 1.9 | 1.2 | 2.3 | 0.2 | 0.3 | 1.4 | # | 0.1 | # | 61 | Ft. Charlotte |

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | S | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H. physodes | | | | | | | | | | | | | | | | | |
| Mean | 697 | 3205 | 23832 | 632 | 660 | 756 | 31.8 | 116.8 | 65.8 | 4.9 | 2.1 | 20.8 | *1.6 | 1.4 | 1.0 | 980 | Mt. Rose |
| Std. Dev. | 103 | 344 | 5721 | 22 | 72 | 116 | 4.0 | 17.6 | 3.9 | 0.3 | 0.1 | 3.3 | *1.1 | 0.2 | 0.2 | 46 | Mt. Rose |
| Mean | 941 | 3571 | 17004 | 723 | 585 | 570 | 32.2 | 228.6 | 82.5 | 4.7 | 2.4 | 14.6 | 1.8 | 1.2 | 0.9 | 913 | Ft. Charlotte |
| Std. Dev. | 128 | 330 | 1039 | 28 | 35 | 49 | 0.8 | 13.1 | 3.6 | 0.2 | 0.4 | 2.2 | 0.5 | <0.1 | 0.1 | 59 | Ft. Charlotte |

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | S | Locality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P. sulcata | | | | | | | | | | | | | | | | | |
| Mean | 812 | 2590 | 4402 | 486 | 975 | 1014 | 31.2 | 86.0 | 73.5 | 6.7 | 3.4 | 16.5 | 2.1 | 1.6 | 0.6 | 1047 | Mt. Rose |
| Std. Dev. | 86 | 170 | 331 | 9 | 17 | 25 | 1.5 | 9.3 | 4.7 | 0.2 | 0.1 | 3.1 | 0.3 | 0.1 | 0.3 | 58 | Mt. Rose |
| Mean | 1524 | 3744 | 4173 | 562 | 799 | 691 | 22.9 | 204.2 | 101.8 | 6.1 | 4.9 | 17.0 | 1.8 | 1.3 | 0.9 | 1150 | Ft. Charlotte |
| Std. Dev. | 130 | 207 | 52 | 60 | 82 | 62 | 1.3 | 46.2 | 0.4 | 0.3 | 0.8 | 0.6 | 0.3 | <0.1 | 0.3 | 26 | Ft. Charlotte |

| Species | P | K | Ca | Mg | Al | Fe | Na | Mn | Zn | Cu | B | Pb | Ni | Cr | Cd | S | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. stellaris | | | | | | | | | | | | | | | | | |
| Mean | 194 | 736 | 227 | 272 | 472 | 586 | 85.3 | 20.5 | 20.3 | 2.6 | 2.0 | 14.2 | 1.4 | 1.2 | 0.1 | 437 | Lichen standard |
| Std. Dev. | 9 | 8 | 2 | 6 | 13 | 17 | 7.1 | 0.1 | 0.2 | 0.2 | 0.2 | 2.1 | 0.5 | 0.2 | 0.1 | 13 | Lichen standard |
| NBS-Peach leaves | | | | | | | | | | | | | | | | | |
| Mean | 1204 | 3719 | 4173 | 1148 | 495 | 185 | 17.1 | 679.9 | 68.2 | 3.3 | 17.4 | 12.1 | 2.8 | 3.3 | 0.1 | NA | NBS-P standard |
| Std. Dev. | 29 | 25 | 4 | 18 | 7 | 10 | 5.3 | 5.3 | 1.3 | 0.1 | 0.3 | 1.1 | 0.1 | 0.6 | 0.1 | NA | NBS-P standard |

* = one value at or below detection limit; included as 0.7 of detection limit
# = two or more values at or below detection limit; not included in calculations

replicates arranged by species. Table 2 gives the means and standard deviations for each set of replicates. Some of the reported values are below the lower detection limits of the instruments. If one reading was below the detection limit (indicated by * in the tables) 0.7 of the detection limit was used for that reading in the calculations. If two or more readings were below the detection limits (indiated by # in the tables) no calculations were done on that species at that locality.

All of the levels found in the Grand Portage lichens are within typical limits for similar lichens. Manganese was unusually high at Fort Charlotte in three of the species and lead was somewhat higher for some species at Mt. Rose. The reasons for the manganese is unknown but the lead may be due to automobile traffic on the highway at the base of the hill. From these tables it can be seen that there is no consistent correlation between element levels and location in the park for most elements, including sulfur. Although one species may have somewhat higher levels of one replicate at one locality, the other species may have higher levels at another locality so there is no overall correlation between high element levels and any one locality. The sulfur levels in lichens tested range from 490 to 1180 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. Different species may accumulate different amounts of elements and this is evident when comparing sulfur levels of different species. *Cladina rangiferina* has lower levels of sulfur than the other species. Even when taking these differences into account there is no clear trend in accumulated levels of sulfur.

These tables indicate that there are no air pollution problems in the park that can be detected with these methods.

## CONCLUSIONS

There is no indication that the lichens of Grand Portage NM are being damaged by air quality. The lichen flora is quite diverse and there is no impoverishment of the lichen flora in any part of the the park. There are numerous species in the most sensitive category to sulfur dioxide in the park and, even though most of these are quite rare, this rarity does not indicate air quality problems. 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 except fro manganese at Fort Charlotte.

## RECOMMENDATIONS

Because of the reactivation of the power plant at Taconite Harbor near Schroeder this study provides an important base line for monitoring the effects of this power plant in the Grand Portage area. It is recommended that annual monitoring be done within the park. This should be by elemental analysis of the four lichens used in this study. These annual studies should be done for the next 3-5 years. Elemental analysis is the most sensitive of the techniques used in this study. It is also recommended that a complete restudy of the lichen flora be done every 5-10 years to detect long term changes due to any low level chronic air quality degradation.

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# APPENDIX I

## Collection Localities

Collection numbers are those of Clifford Wetmore. All collections are listed in ascending order by collection number and date of collection.

Cook County, Minnesota

67885-67965 Mt. Rose above Grand Portage. Hill with quaking aspen, balsam fir and rocks and tallus slope facing the lake. Sec. 4, T63N, R6E. 12 Aug. 1991. CHEM. 47° 57' 45.7"N 81° 41' 17.4"W

67966-68021 1.5 miles up portage from Lake Superior at junction of two small streams. In alder, ash, balsam fir and big tooth aspen. Sec. 32, T64N, R6E. 12 Aug. 1991. 47° 58' 51.2"N 89° 41' 59.4"W

2012 68022-68116 At Fort Charlotte on Pigeon River. Along Pigeon river in balsam fir, aspen and some Thuja and white pine. Sec. 64N, R5E. 13 Aug. 1991. CHEM. 48° 00' 14.0"N 89° 49' 42.2"W

68117-68157 One mile East of Fort Charlotte and Pigeon River from north end of portage trail. In mixed forest of white pine, balsam fir, old quaking aspen and brush. Sec. 28, T64N, R5E. 13 Aug. 1991. 48° 00' 66.2"N 89° 48' 33.0"W

68158-68216 Near Grand Portage just on north side of highway 61. On rock outcrops near trail with jack pine and aspens. Sec. 4, T63N, R6E. 14 Aug. 1991. 47° 58' 24.0"N 89° 41' 15.1"W

68217-68257 3 miles north of Grand Portage along portage trail, 0.5 miles south of old highway. On low ridge with old quaking aspens, white birch and brush. Sec. 30, T64N, R6E. 14 Aug. 1991. 47° 59' 38.4"N 89° 43' 29.4"W

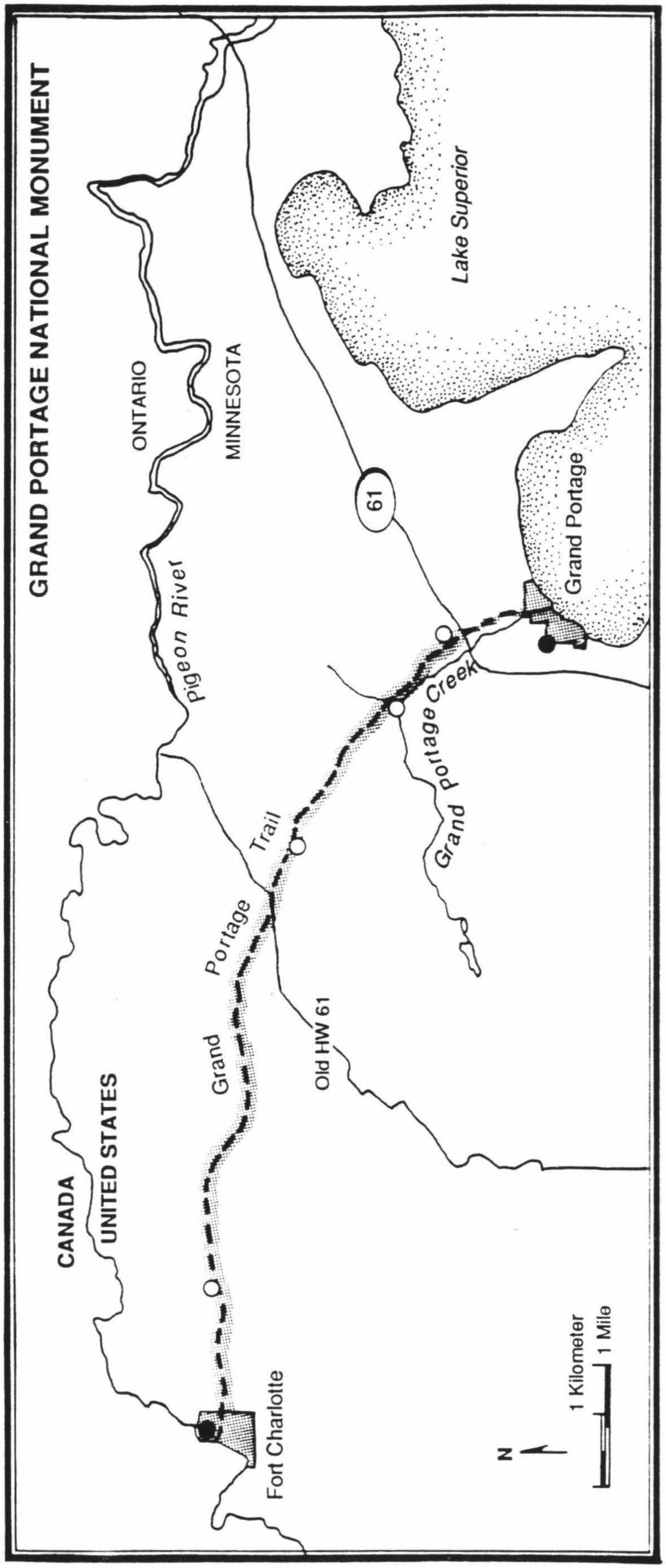


Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities and collection localities.

## 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 Grand Portage NM fall within the Sensitive category as listed by Wetmore, 1983. Sensitive species (S) are those present only under 50ug 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 park.

Fig. 2. *Bryoria trichodes* (Michx.) Brodo & Hawksw.
Fig. 3. *Dimerella lutea* (Dicks.) Trev.
Fig. 4. *Hypogymnia tubulosa* (Schaer.) Hav.
Fig. 5. *Lobaria pulmonaria* (L.) Hoffm.
Fig. 6. *Ochrolechia rosella* (Müll. Arg.) Vers.
Fig. 7. *Parmelia squarrosa* Hale
Fig. 8. *Ramalina americana* Hale
Fig. 9. *Usnea filipendula* Stirt.

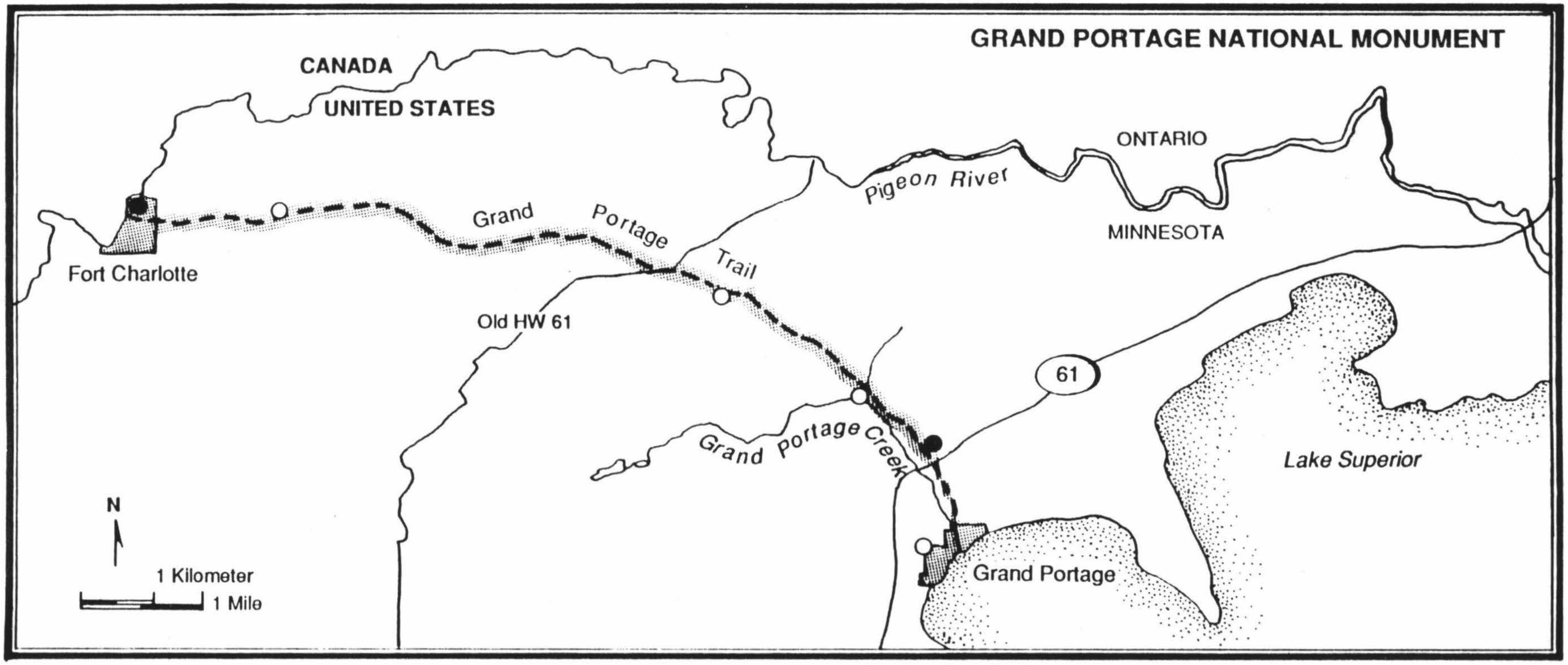


Fig. 2. Distribution of Bryoria trichodes.

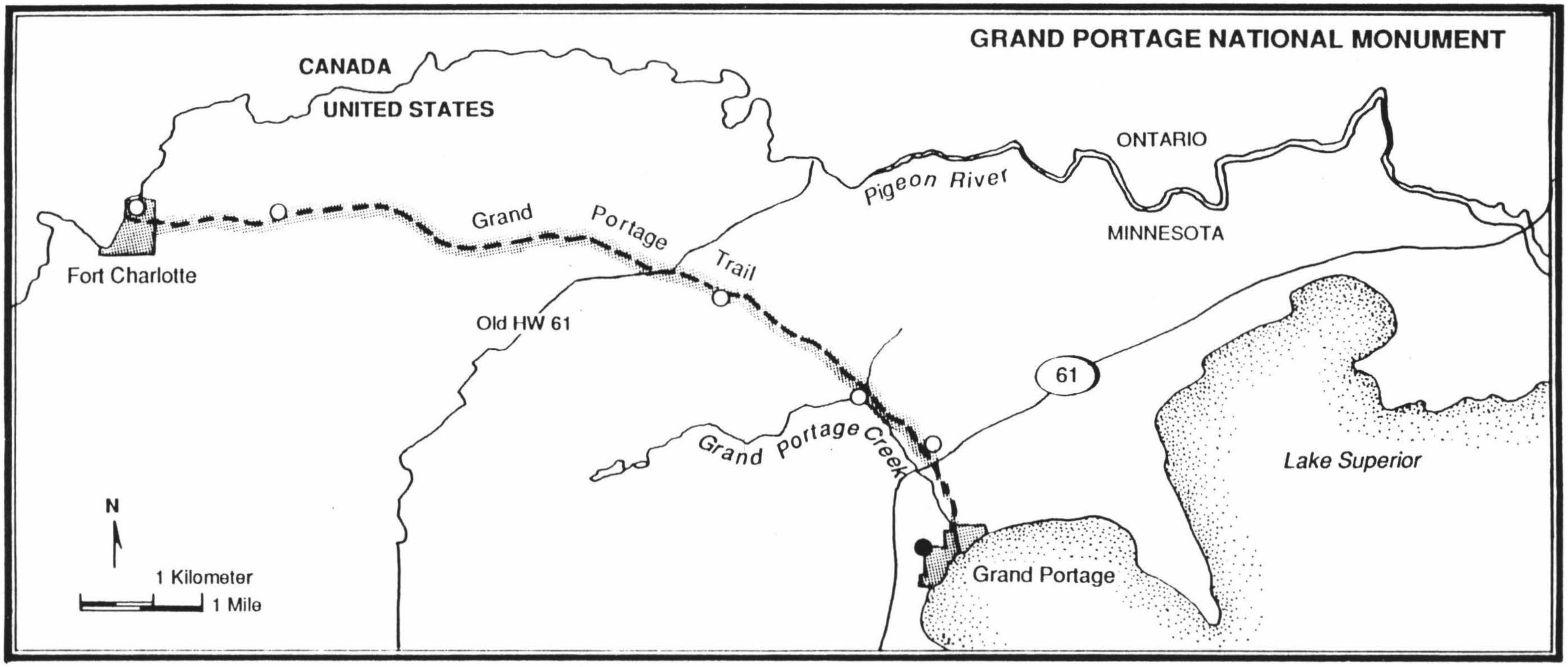


Fig. 3. Distribution of Dimerella lutea.

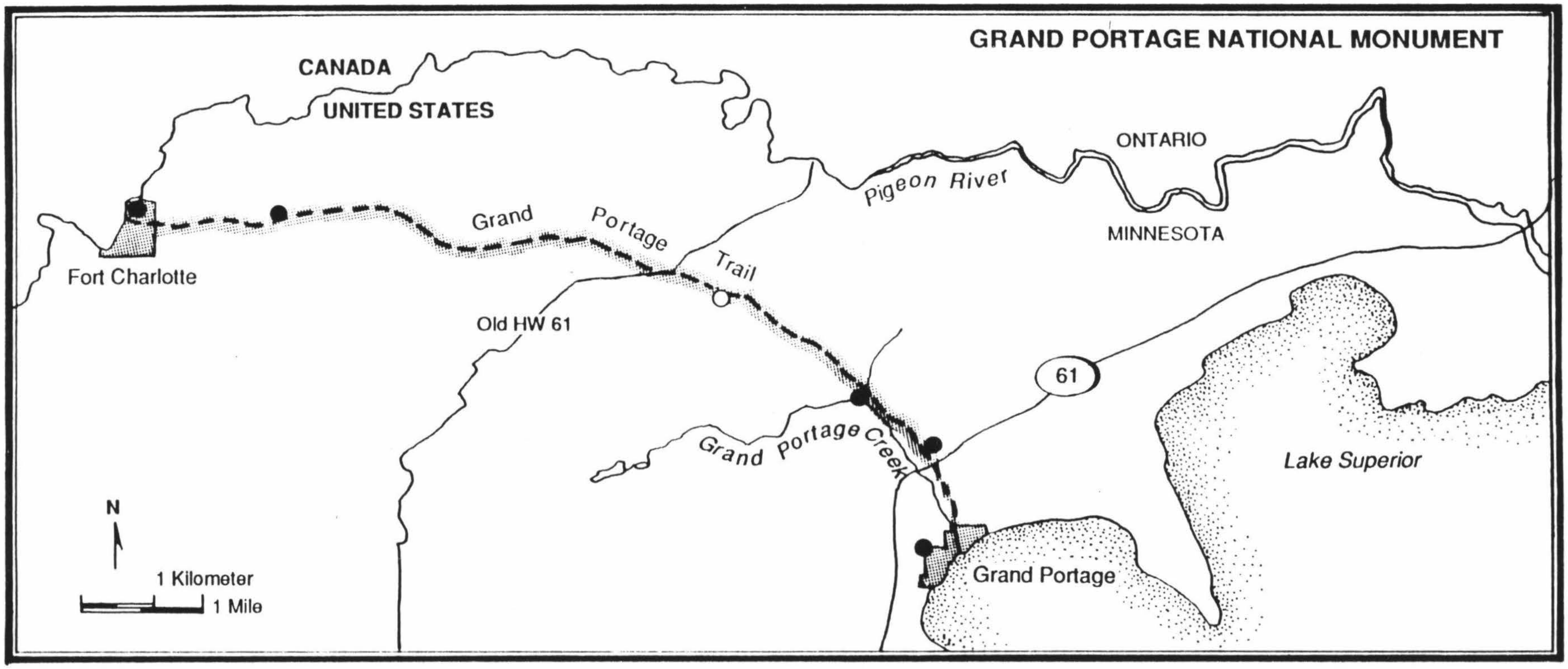


Fig. 4. Distribution of <u>Hypogymnia tubulosa</u>.

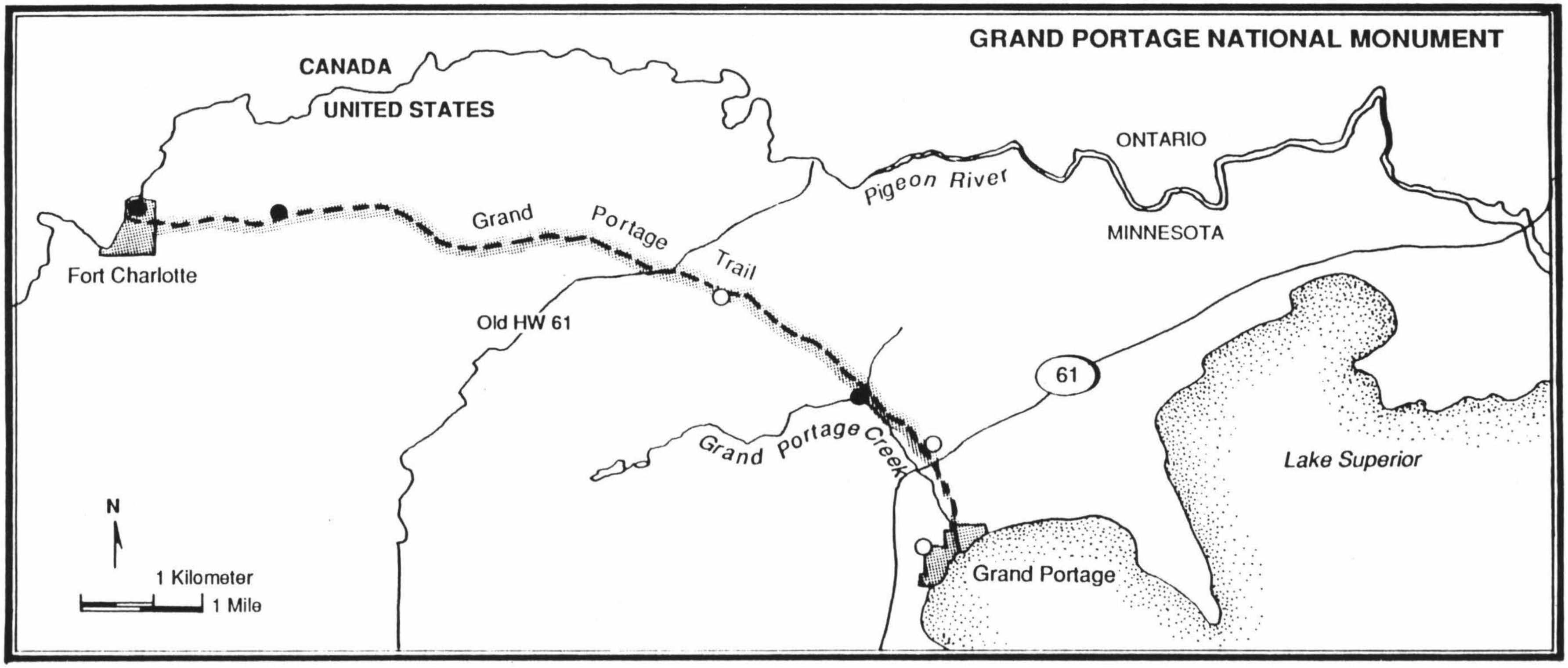


Fig. 5. Distribution of Lobaria pulmonaria.

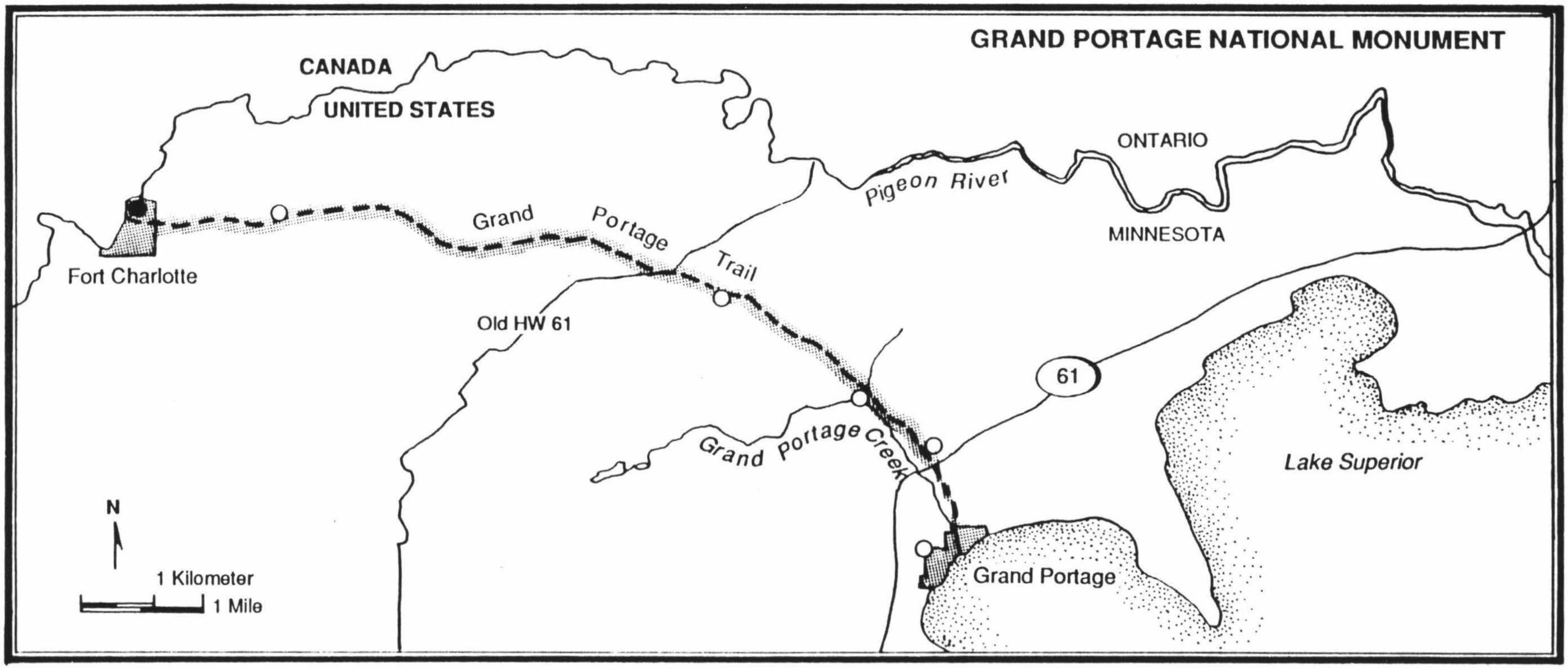


Fig. 6. Distribution of Ochrolechia rosella.

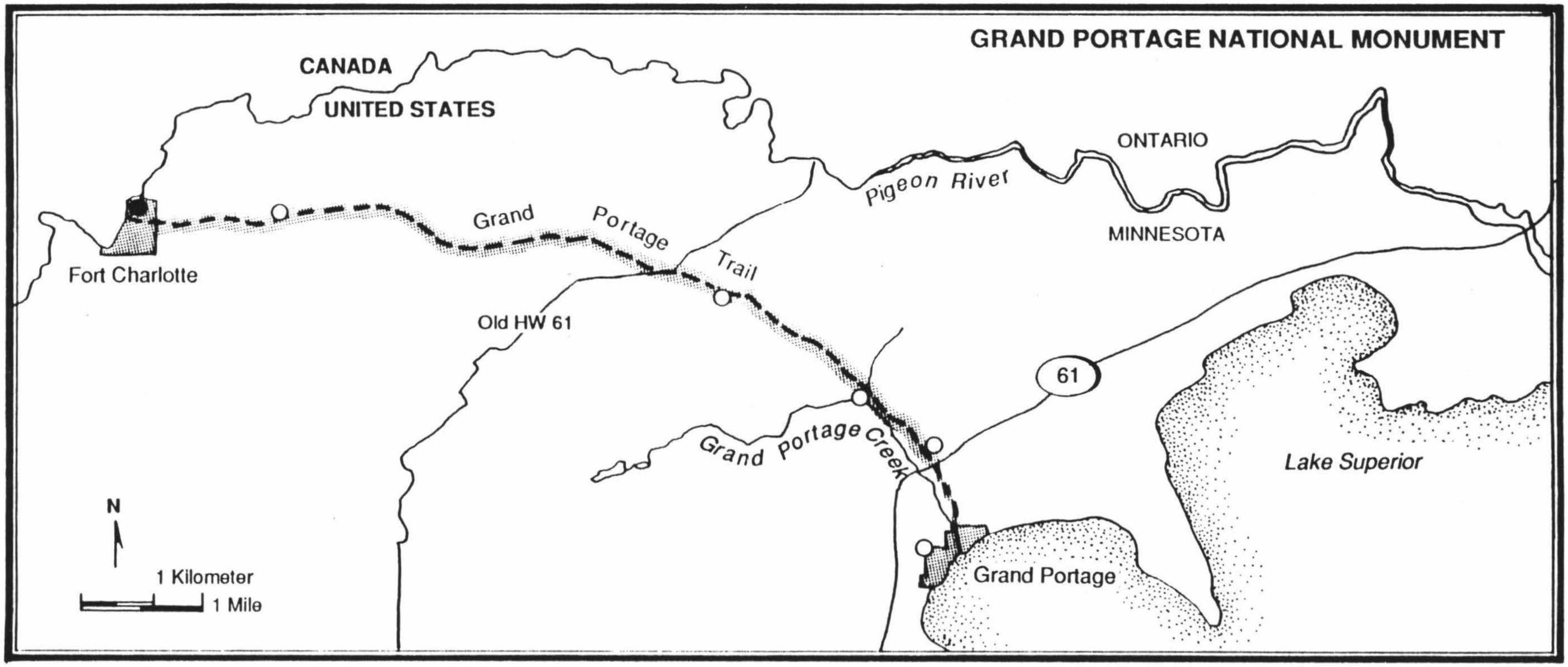


Fig. 7. Distribution of *Parmelia squarrosa*.

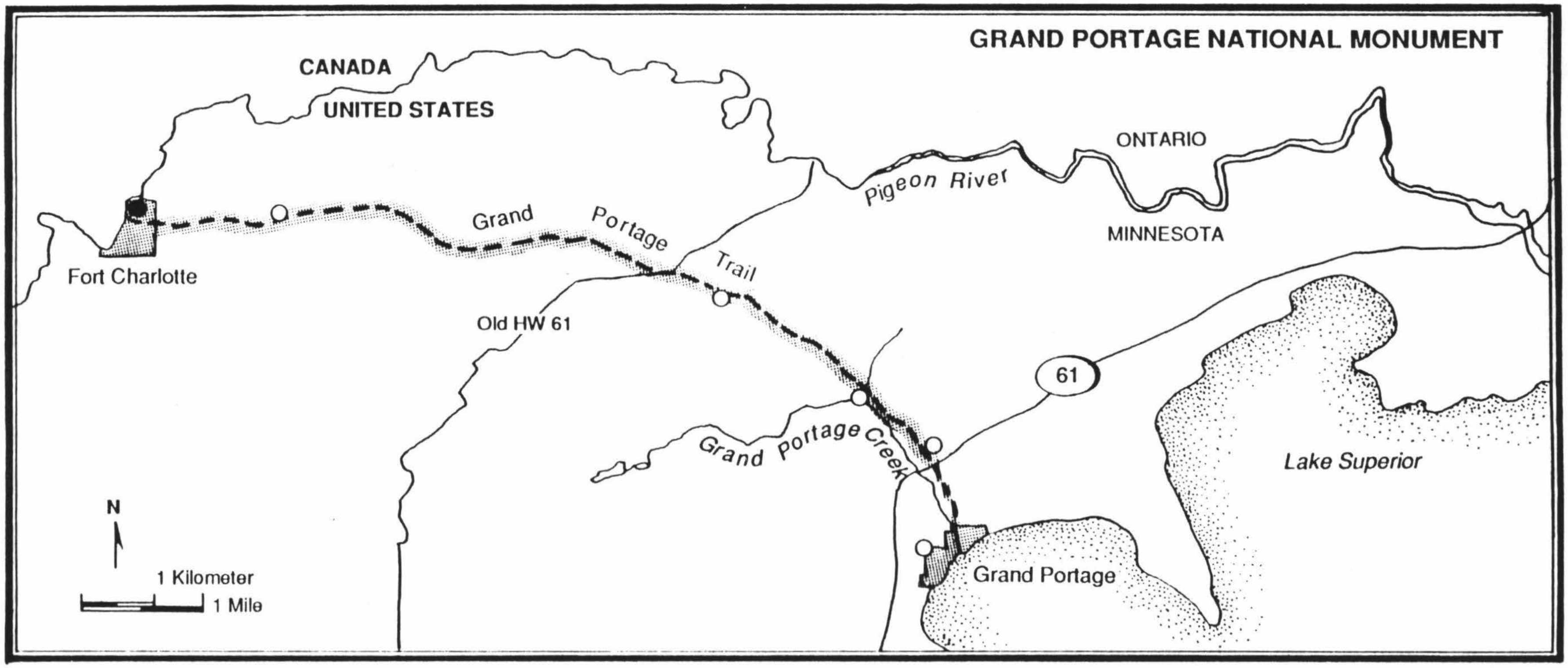


Fig. 8. Distribution of *Ramalina americana*.

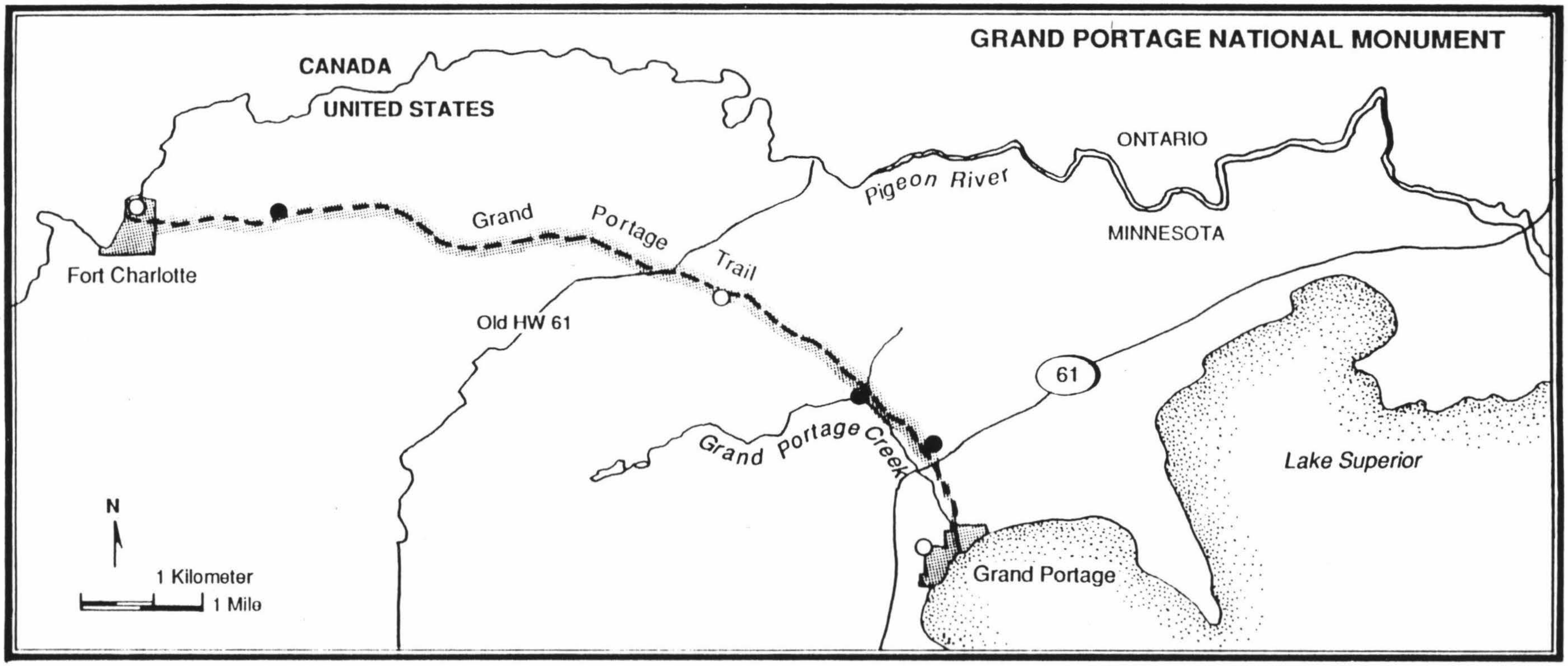


Fig. 9. Distribution of *Usnea filipendula*.