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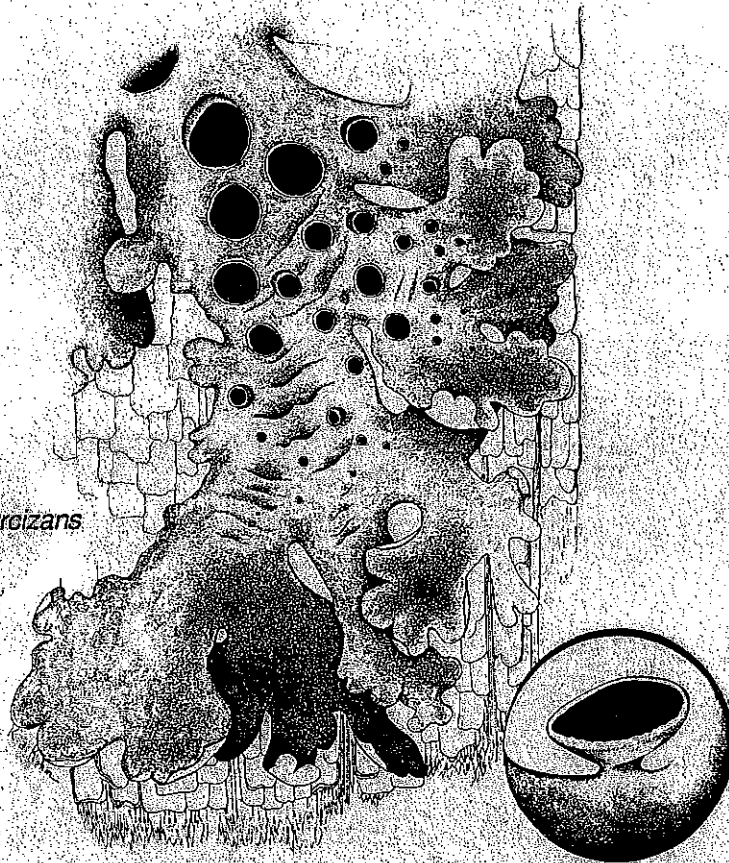
# LICHENS AND AIR QUALITY IN

## PICTURED ROCKS NATIONAL LAKESHORE

### FINAL REPORT

CONTRACT # CX0001-22-0034  
AND  
USDI PX6000-7-0731

*Lobaria quercizans*



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IN  
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National Park Service  
Contract CX 0001-2-0034  
and USDI-PX6000-7-0731

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## PREFACE

Under grants from the National Park Service (USDI CX 0001-2-0034 and USDI-PX6000-7-0731) a lichen study was to be performed in Pictured Rocks National Lakeshore. 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 is to establish baseline data for future restudy and determine the presence of any air quality problems as 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, NPS-AIR, Denver and with personnel in the park.

The park 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 National Park Service. The assistance of all of these is gratefully acknowledged.

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<sup>ation</sup> and death of the algae (<sup>manifest in</sup> causing bleached lobes) <sup>This</sup> which quickly leads to the death of the lichen. Dead lichens disappear from the substrate within a few months to a year as they disintegrate and decompose (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) <sup>They</sup> and are more sensitive 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 environ-

mental 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.

Pictured Rocks NL is located along the southern shore of Lake Superior east of the Keweenaw Peninsula. The park extends in a narrow strip about <sup>40</sup>(.75) miles along the shore. The eastern part has sand bluffs along the lake and the western part has sandstone rock cliffs. Many of the sand beach areas have stands of jack pine (Pinus banksiana), red pine (Pinus resinosa) and some white pine (Pinus strobus). In some areas there are hemlock (Tsuga canadensis) ~~and~~ balsam fir (Abies balsamea) and white spruce (Picea glauca). Above the rock cliffs there is hardwood forest of beech (Fagus grandifolia), sugar maple (Acer saccharum) and red maple (Acer rubrum). Areas of quaking aspen (Populus tremuloides) occur in many areas of second growth forest. Along the streams and in some low areas are stands of white cedar (Thuja occidentalis) and balsam fir with some black ash (Fraxinus nigra). The whole area was extensively logged earlier this century and most of the vegetation is second growth. On the sand plains south of the park regrowth has been very slow and large areas remain of stumps and small open pines. not  
part of

There are no literature records for lichens in the park

although there are probably unreported collections in some herbaria (Michigan State, University of Michigan). The lichen flora prior to logging may have been richer in some groups but the sand plain regrowth areas are probably richer now due to the large areas of open poorly vegetated sand.

#### METHODS

Field work was done during July, 1987. Collections in the park were made at 25 localities and 1231 lichen collections were obtained. One locality (one mile north of Kingston Lake) is in the buffer area outside of the ~~main-park~~<sup>fee zone</sup> boundary but the species collected there are included in the list. 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. Disturbed as well as undisturbed areas were included. 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 will be 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. Lists of species found at each locality are available from this data base at any time on request.

#### LICHEN FLORA

The following list of lichens is based on my collections since there are no literature reports of lichens previously collected in the park. The species found only once in the park 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 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

- Anaptychia palmulata (Michx.) Vain.
- S-I Anaptychia setifera Räs.
- Arthonia caesia (Flot.) Körb.
- Arthonia didyma Körb. Rare
- Arthonia diffusella Fink in Hedr. Rare
- Arthonia fuliginosa (Schaer.) Flot.



- Arthonia patellulata Nyl. Rare  
Arthonia punctiformis Ach. Rare  
 I Arthonia radiata (Pers.) Ach.  
     1 additional unidentified species of Arthonia  
     1 unidentified species of Arthothelium  
Bacidia accedens (Arn.) Lett. Rare  
Bacidia epixanthoides (Nyl.) Lett. Rare  
Bacidia naegelii (Hepp) Zahlbr. Rare  
Bacidia polychroa (Th. Fr.) Körb. Rare  
 I Bacidia rubella (Hoffm.) Mass.  
Bacidia schweinitzii (Tuck.) Schneid.  
Bacidia sphaeroides (Dicks.) Zahlbr. Rare  
Bacidia suffusa (Fr.) Schneid.  
 S Bryoria furcellata (Fr.) Brodo & Hawksw.  
Bryoria nadvornikiana (Gyeln.) Brodo & Hawksw. Rare  
 S Bryoria trichodes (Michx.) Brodo & Hawksw.  
Buellia arnoldii Serv.  
Buellia disciformis (Fr.) Mudd  
 T Buellia punctata (Hoffm.) Mass.  
Buellia schaeereri De Not.  
 I Buellia stillingiana Steiner  
Calicium abietinum Pers. Rare  
Calicium trabinellum (Ach.) Ach.  
     1 additional unidentified species of Calicium  
 S-I Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr.  
Caloplaca chrysophthalma Degel. Rare  
 I Caloplaca holocarpa (Hoffm.) Wade  
 S-I Candelaria concolor (Dicks.) B. Stein  
Candelariella efflorescens R. Harris & Buck  
Candelariella vitellina (Hoffm.) Müll. Arg. Rare  
Catillaria nigroclavata (Nyl.) Schuler  
Catinlaria laureri (Hepp ex Th. Fr.) Degel.  
Cetraria arenaria Kärnef. Rare  
Cetraria halei W. & C. Culb.  
Cetraria oakesiana Tuck.  
 I Cetraria orbata (Nyl.) Fink  
 I Cetraria pinastri (Scop.) Gray  
 I Cetraria sepincola (Ehrh.) Ach.  
Cetrelia chicitae (W. Culb.) W. & C. Culb. Rare  
Cetrelia olivetorum (Nyl.) W. & C. Culb.  
Chaenotheca brunneola (Ach.) Müll. Arg.  
Chaenotheca chrysocephala (Turn. ex Ach.) Th. Fr.  
 I Chaenotheca ferruginea (Turn. ex Sm.) Mig.  
Chaenotheca laevigata Nadv. Rare  
Chaenotheca stemonea (Ach.) Zw.  
Chaenotheca trichialis (Ach.) Th. Fr.  
Chaenothecopsis savonica (Räs.) Tibell  
     1 additional unidentified species of Chaenothecopsis  
 I Chrysothrix candelaris (L.) Laund.  
Cladina arbuscula (Wallr.) Hale & W. Culb.  
Cladina mitis (Sandst.) Hustich  
Cladina rangiferina (L.) Nyl.  
Cladina stellaris (Opiz) Brodo  
Cladina stygia (Fr.) Ahti

- Cladonia botrytes (Hagen) Willd. Rare  
Cladonia caespiticia (Pers.) Flörke  
Cladonia cenotea (Ach.) Schaer.  
Cladonia chlorophaea (Flörke ex Somm.) Spreng.  
I Cladonia coniocraea (Flörke) Spreng.  
Cladonia cornuta (L.) Hoffm.  
Cladonia crispata (Ach.) Flot.  
I Cladonia cristatella Tuck.  
Cladonia cryptochlorophaea Asah.  
Cladonia deformis (L.) Hoffm.  
Cladonia digitata (L.) Hoffm.  
S-I Cladonia fimbriata (L.) Fr.  
Cladonia floerkeana (Fr.) Flörke Rare  
Cladonia gracilis (L.) Willd.  
Cladonia macilenta Hoffm.  
Cladonia merochlorophaea Asah.  
Cladonia phyllophora Ehrh. ex Hoffm.  
Cladonia pleurota (Flörke) Schaer.  
Cladonia pyxidata (L.) Hoffm.  
Cladonia ramulosa (With.) Laundon Rare  
Cladonia rei Schaer.  
Cladonia scabriuscula (Del.in Duby) Leight.  
Cladonia squamosa (Scop.) Hoffm.  
Cladonia subulata (L.) Web. ex Wigg.  
Cladonia sulphurina (Michx.) Fr. Rare  
Cladonia symphycarpa (Ach.) Fr.  
Cladonia turgida Ehrh. ex Hoffm. Rare  
Cladonia uncialis (L.) Web. ex Wigg.  
Cladonia verticillata (Hoffm.) Schaer.  
Collema subflaccidum Degel.  
Collema tenax (Sw.) Ach. Rare  
Conotrema urceolatum (Ach.) Tuck.  
Cyphelium tigillare (Ach.) Ach. Rare  
S Dimerella lutea (Dicks.) Trev.  
Dimerella pineti (Schrad. ex Ach.) Vezda Rare  
Diploschistes scruposus (Schreb.) Norm. Rare  
Eopyrenula leucoplaca (Wallr.) R. Harris Rare  
I Evernia mesomorpha Nyl.  
I Graphis scripta (L.) Ach.  
Gyalecta truncigena (Ach.) Hepp Rare  
Haematomma elatinum (Ach.) Mass. Rare  
Haematomma pustulatum Brodo & W. Culb.  
Hypocenomyce anthracophila (Nyl.) James & G. Schneid.  
Hypocenomyce friesii (Ach. in Lilj.) James & G. Schneid.  
I Hypocenomyce scalaris (Ach. ex Lilj.) Choisy  
I Hypogymnia physodes (L.) Nyl.  
S Hypogymnia tubulosa (Schaer.) Hav.  
Icmadophila ericetorum (L.) Zahlbr.  
I Imshaugia aleurites (Ach.) S. F. Meyer  
Imshaugia placorodia (Ach.) S. F. Meyer  
Julella fallaciosa (Stizenb. ex Arn.) R. Harris  
Lecanactis chloroconia Tuck.  
I Lecanora allophana Nyl.  
Lecanora caesiorubella Ach. subsp. caesiorubella

- I Lecanora carpinea (L.) Vain.  
 I Lecanora circumborealis Brodo & Vitik.  
Lecanora hybocarpa (Tuck.) Brodo  
Lecanora impudens Degel.  
 I Lecanora pallida (Schreb.) Rabenh. var. pallida  
 I Lecanora pallida var. rubescens Imsh. & Brodo  
 I Lecanora pulicaris (Pers.) Ach.  
Lecanora rugosella Zahlbr.  
 I Lecanora saligna (Schrad.) Zahlbr. Rare  
Lecanora strobilina (Spreng.) Kieff. Rare  
 I Lecanora symmicta (Ach.) Ach.  
Lecanora thysanophora Harris ined.  
Lecanora wisconsinensis Magn.  
 I additional unidentified species of Lecanora  
Lecidea albohyalina (Nyl.) Th. Fr. Rare  
Lecidea caeca Lowe  
Lecidea elabens Fr.  
Lecidea epixanthoidiza Nyl. Rare  
Lecidea erratica Körb. Rare  
Lecidea erythrophaea Flörke ex Somm.  
Lecidea helvola (Körb. ex Hellb.) Oliv.  
Lecidea hypnorum Lib. Rare  
 S Lecidea nylanderii (Anzi) Th. Fr.  
Lecidea plebeja Nyl.  
 S Lecidea vernalis (L.) Ach.  
Lecidella euphorea (Flörke) Hert.  
Lecidella stigmatea (Ach.) Hert. & Leuck. Rare  
Lepraria finkii (B. de Lesd. in Hue) R. Harris  
 I additional unidentified species of Lepraria  
Leptogium cyanescens (Rabenh.) Körb.  
Leptogium tenuissimum (Dicks.) Körb.  
Leptorhaphis epidermidis (Ach.) Th. Fr.  
 S Lobaria pulmonaria (L.) Hoffm.  
Lobaria quercizans Michx.  
 I Lopadium pezizoideum (Ach.) Körb.  
Menegazzia terebrata (Hoffm.) Mass. Rare  
Micarea denigrata (Fr.) Hedl. Rare  
Micarea melaena (Nyl.) Hedl.  
Micarea peliocarpa (Anzi) Coppins & R. Sant.  
Microcalicium disseminatum (Ach.) Vain.  
 I Mycoblastus sanguinarius (L.) Norm.  
Mycocalicium subtile (Pers.) Szat.  
Nephroma parile (Ach.) Ach. Rare  
Ochrolechia arborea (Kreyer) Almb.  
Ochrolechia pseudopallescens Brodo  
 S Ochrolechia rosella (Müll. Arg.) Vers.  
Opegrapha niveoatra (Borr.) Laund. Rare  
 S-I Opegrapha varia Pers. Rare  
Pachyospora verrucosa (Ach.) Mass.  
Parmelia aurulenta Tuck.  
 I Parmelia caperata (L.) Ach.  
Parmelia crinita Ach.  
 I Parmelia exasperatula Nyl.  
Parmelia galbina Ach.

- I Parmelia olivacea (L.) Ach.  
 I Parmelia rudecta Ach.  
 I Parmelia septentrionalis (Lynge) Ahti  
 S Parmelia squarrosa Hale  
 I-T Parmelia subargentifera Nyl.  
 (S) Parmelia subaurifera Nyl.  
Parmelia subolivacea Nyl. in Hasse Rare  
 I Parmelia subrudecta Nyl.  
 I-T Parmelia sulcata Tayl.  
 I Parmeliopsis ambigua (Wulf. in Jacq.) Nyl.  
 I Parmeliopsis hyperopta (Ach.) Arn.  
Peltigera canina (L.) Willd.  
Peltigera didactyla (With.) Laundon  
Peltigera elisabethae Gyeln.  
Peltigera evansiana Gyeln.  
 I Peltigera horizontalis (Huds.) Baumg. Rare  
Peltigera neckeri Hepp ex Müll. Arg.  
Peltigera polydactyla (Neck.) Hoffm.  
Peltigera praetextata (Flörke ex Somm.) Zopf  
Peltigera rufescens (Weis.) Humb. Rare  
Pertusaria alpina Hepp ex Ahles  
 I Pertusaria amara (Ach.) Nyl.  
Pertusaria consocians Dibb.  
Pertusaria macounii (Lamb) Dibb.  
 I Pertusaria multipunctoides Dibb. Rare  
Pertusaria ophthalmiza (Nyl.) Nyl.  
Pertusaria rubefacta Erichs. Rare  
Pertusaria trachythallina Erichs.  
Pertusaria velata (Turn.) Nyl.  
Pertusaria waghornei Hult. Rare  
 3 additional unidentified species of Pertusaria  
Phaeocalicium populneum (Brond. ex Duby) Schmidt Rare  
Phaeophyscia chloantha (Ach.) Moberg Rare  
Phaeophyscia imbricata (Vain.) Essl. Rare  
 I Phaeophyscia orbicularis (Neck.) Moberg Rare  
Phaeophyscia pusilloides (Zahlbr.) Essl.  
Phaeophyscia rubropulchra (Degel.) Moberg  
 I Phlyctis argena (Spreng.) Flot.  
 I Physcia adscendens (Th. Fr.) Oliv.  
 I Physcia aipolia (Ehrh. ex Humb.) Fűrnr.  
 I Physcia stellaris (L.) Nyl.  
 I Physconia detersa (Nyl.) Poelt  
Placynthiella icmalea (Ach.) Coppins & James  
Placynthiella oligotropha (Laund.) Coppins & James  
Plagiocarpa hyalospora (Nyl.) R. Harris  
Platismatia tuckermanii (Oakes) W. & C. Culb.  
Porpidia albocaerulescens (Wulf.) Hert. & Knoph  
Porpidia macrocarpa (DC. in Lam. & DC.) Hert. & Schwab  
Pseudevernia consocians (Vain.) Hale & W. Culb.  
Pyrenula pseudobufonia (Rehm) R. Harris Rare  
Pyxine soredata (Ach.) Mont.  
 S Ramalina americana Hale  
 I Ramalina dilacerata (Hoffm.) Hoffm. Rare  
Ramalina intermedia (Del. ex Nyl.) Nyl.

- S Ramalina pollinaria (Westr.) Ach. Rare  
Rinodina ascociscana Tuck.  
Rinodina subminuta Magn.
- I Scoliciosporum chlorococcum (Graewe ex Stenh.) Vezda  
Sphinctrina turbinata (Pers.) De Not.
- I Stenocybe major Nyl. ex KÖrb.  
Stenocybe pullatula (Ach.) B. Stein.  
Strigula stigmatella (Ach.) R. Harris  
Trapelia involuta (Tayl.) Hert. Rare  
Trapeliopsis flexuosa (Fr.) Coppins & James Rare  
Trapeliopsis granulosa (Ehrh.) Lumbsch  
Trapeliopsis viridescens (Schrad.) Coppins & James  
Usnea cavernosa Tuck.
- S Usnea ceratina Ach.
- S Usnea filipendula Stirt. Rare
- S-I Usnea hirta (L.) Weber ex Wigg.
- S-I Usnea subfloridana Stirt.  
Verrucaria muralis Ach.
- I Xanthoria polycarpa (Hoffm.) Rieber  
Xylographa disseminata Will. Rare

#### DISCUSSION OF FLORA

This list of 235 taxa presents the first listing of lichens for the park and includes some species rare in the Great Lakes Region. Some of the 9 unidentified species may be undescribed. The most common species are Cladina rangiferina, Cladonia coniocraea, Hypogymnia physodes, Parmelia caperata, P. subaurifera, Phaeophyscia rubropulchra and Usnea subfloridana. Lobaria pulmonaria and L. quercizans are not uncommon in the hardwood forests.

The lack of rocks limits the number of species in the park. Some lichens were found on pebbles but hardly any were found on the soft sandstone along the shores. Some of the lakeshore areas have good lichen floras near the lake and the open sand plains are rich in lichens also but the shady hardwood forests have fewer species. The lake influence on the lichen flora is very obvious along most of the shore and many northern species are found only in a narrow zone near Lake

Superior.

An interesting tabulation indicates the uniqueness of different localities in the park. In the following list the number in the first column indicates the number of species that were found only once in the park at that particular locality (these are the species that are indicated by "Rare" in the species list). The second column indicates the locality number, followed by a brief locality description. The localities are listed in the same order as in the locality list in Appendix I.

#	Loc #	
5	- 1	N side Grand Sable Lake
2	- 2	S of Grand Sable Dunes
2	- 3	W of Log Slide
3	- 4	Mouth of Sable Creek
2	- 5	E side Grand Sable Lake
2	- 6	Half mile S Twelvemile Beach CG
2	- 7	Twelvemile Beach 1 mile NE of CG
4	- 8	Au Sable Point
3	- 9	Mouth of Sevenmile Creek
1	- 10	1.5 miles SW Twelvemile Beach CG
3	- 11	1 mile N of Kingston Lake
0	- 12	Half mile S of Hurricane River CG
3	- 13	S of Beaver L along Lowney Creek
0	- 14	S of Beaver Lake on ridge
3	- 15	W of Beaver L, L. Superior shore
1	- 16	NW of Beaver L, ridge
2	- 17	1 mile E of Miners Castle Point
6	- 18	S of Miners Falls
1	- 19	Half mile SSW of Miners Castle Point
5	- 20	Munising Falls
2	- 21	Sand Point
1	- 22	Chapel River, 1 mile E
4	- 23	Grand Portal Point
1	- 24	L. Superior at Mosquito River
3	- 25	2 miles S of Grand Portal Point

*Cedar likes  
alkaline condition  
"bog"  
? implies acidic  
condition*

The locality with the greatest number is south of Miners Falls in a Thuja bog. These bogs are always rich in lichen species. It is unknown why this bog has more rare species than

the other similar bogs. The second highest number was at Munising Falls and at the north side of Grand Sable Lake. At Munising Falls the rock outcrops added a rare substrate and several of the rare species were found on the rocks. At Grand Sable Lake the open jack pines and bare soil provided many good habitats for lichens.

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 park, but until additional collecting proves otherwise, the localities with the highest number of unique finds deserve special protection.

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.

There are many lichens in the park with known sensitivity to sulfur dioxide according to the list presented in Wetmore (1983) and some of these are quite common. Species in the most sensitive category are usually absent when sulfur dioxide levels are above 50ug per cubic meter average annual concentrations. The following species are in the most sensitive category:

- S Bryoria furcellata (Fr.) Brodo & Hawksw.
- S Bryoria trichodes (Michx.) Brodo & Hawksw.
- S Dimerella lutea (Dicks.) Trev.
- S Hypogymnia tubulosa (Schaer.) Hav.
- S Lecidea nylanderii (Anzi) Th. Fr.
- S Lecidea vernalis (L.) Ach.
- S Lobaria pulmonaria (L.) Hoffm.
- S Ochrolechia rosella (Müll. Arg.) Vers.
- S Parmelia squarrosa Hale
- (S) Parmelia subaurifera Nyl.
- S Ramalina americana Hale
- S Usnea ceratina Ach.
- S Usnea filipendula Stirt.

The distributions of these species are mapped Fig. 2-14. Parmelia subaurifera is included here although it probably belongs in the S-I category. Although these species are not found at all localities and some are quite rare, 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 Dimerella lutea, Lobaria pulmonaria and Lecidea nylanderii.

#### 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.

#### METHODS

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

Four localities were selected for elemental analysis and are indicated on the map of collection localities. These localities are: north side of Grand Sable Lake, half mile south of Twelvemile Beach Campground, northwest of Beaver Lake, and 1 mile east of Miners Castle Point. Ten to 20 grams of each species were collected at each locality.

Lichens were air dried and cleaned of all bark and detritus under a dissecting microscope but thalli were not washed. Three samples of each collection were submitted for analysis. In some cases the lichens were ground before being divided and this is indicated in the tables. 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 replicates arranged by species. Table 2 gives the means and standard deviations for each set of replicates. Some of the reported values are at or below the lower detection limits of the instruments and are indicated in the tables.

All of the levels found in the Pictured Rocks lichens are within typical limits for similar lichens. From these tables it can be seen that there is no good correlation between element levels and location in the park. The sulfur levels in Evernia mesomorpha and Hypogymnia physodes tend to increase with decreasing distance from Munising but the differences are slight and are not correlated with trends in other elements. This may reflect higher sulfur levels generated in Munising and should be closely monitored for changes.

The sulfur levels in lichens tested range from 425 to

Table 1. Analysis of Pictured Rocks Lichens  
Values in ppm of thallus

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
<i>C. rangiferina</i>	653	1965	1109	463	309	368	25.4	22.0	14.4	2.0	4.1	2.3	*0.3	0.4	0.2	580	N Grand Sable I
<i>C. rangiferina</i>	566	1698	1067	407	326	398	23.6	19.3	13.3	1.8	6.4	1.9	0.6	0.4	*0.6	470	N Grand Sable L
<i>C. rangiferina</i>	625	1864	1080	435	350	470	24.6	19.2	13.6	1.9	5.9	*0.8	0.5	0.5	0.1	535	N Grand Sable L
<i>C. rangiferina</i>	477	2302	397	296	170	168	18.3	47.9	21.4	2.4	5.6	2.1	#	0.3	0.2	620	S 12 mi Beach
<i>C. rangiferina</i>	444	2128	362	282	165	160	15.8	41.8	21.0	2.2	6.7	2.2	#	0.2	0.2	660	S 12 mi Beach
<i>C. rangiferina</i>	470	2235	402	297	163	155	17.6	53.7	22.0	2.3	6.0	1.7	#	0.2	0.1	730	S 12 mi Beach
<i>C. rangiferina</i>	346	1534	383	228	262	267	23.4	38.0	17.3	2.1	1.9	3.5	0.3	0.3	0.1	425	NW Beaver L @
<i>C. rangiferina</i>	333	1482	374	225	253	253	26.1	37.2	17.0	2.0	2.0	4.3	0.5	0.4	0.2	480	NW Beaver L @
<i>C. rangiferina</i>	389	1709	437	262	293	291	30.1	43.2	20.2	2.4	2.2	3.7	0.8	0.4	0.2	450	NW Beaver L @
<i>C. rangiferina</i>	324	1432	557	248	227	274	30.5	39.7	18.9	1.9	5.8	2.5	#	0.2	0.1	470	Miners Castle Pt.
<i>C. rangiferina</i>	323	1457	608	245	214	258	29.8	44.9	19.7	1.8	5.2	2.2	#	0.2	0.2	470	Miners Castle Pt.
<i>C. rangiferina</i>	373	1533	685	259	208	246	24.5	45.4	18.8	1.8	4.9	2.7	#	0.3	0.1	535	Miners Castle Pt.
<i>E. mesomorpha</i>	596	2466	1717	502	618	831	42.5	22.1	30.5	3.7	9.6	9.9	1.3	1.0	0.3	1370	N Grand Sable L
<i>E. mesomorpha</i>	545	2328	1626	475	531	691	39.1	21.0	26.9	3.5	8.5	6.3	0.8	0.8	0.3	1145	N Grand Sable L
<i>E. mesomorpha</i>	496	2160	1479	446	511	636	35.8	19.3	26.6	3.2	9.6	4.4	0.6	0.8	0.3	1040	N Grand Sable L
<i>E. mesomorpha</i>	416	2190	294	251	374	381	21.7	21.0	32.4	3.1	6.2	6.6	*0.3	0.5	0.2	1270	S 12 mi Beach @
<i>E. mesomorpha</i>	434	2218	301	260	386	515	23.8	22.1	34.6	3.4	6.2	7.3	0.9	6.1	0.3	1260	S 12 mi Beach @
<i>E. mesomorpha</i>	422	2136	289	259	405	459	24.0	21.2	33.0	3.3	6.6	7.1	0.7	1.5	0.3	1540	S 12 mi Beach @
<i>E. mesomorpha</i>	540	2682	474	283	327	347	21.4	32.7	30.2	3.5	8.0	3.7	0.7	0.5	0.1	1380	NW Beaver L
<i>E. mesomorpha</i>	550	2861	534	302	336	346	22.3	38.2	35.2	3.5	7.6	4.3	0.5	0.5	0.2	1430	NW Beaver L
<i>E. mesomorpha</i>	577	2824	505	294	304	309	18.6	32.5	34.9	3.4	6.9	5.3	0.6	0.4	0.2	1460	NW Beaver L
<i>E. mesomorpha</i>	447	2027	389	284	293	352	29.3	21.5	26.5	3.5	7.6	10.1	0.8	0.4	0.2	1420	Miners Castle Pt.
<i>E. mesomorpha</i>	460	1995	358	281	317	362	31.8	21.5	27.1	3.6	7.5	10.1	0.5	0.5	0.2	1350	Miners Castle Pt.
<i>E. mesomorpha</i>	439	1846	347	275	292	342	31.4	20.8	27.2	3.3	7.8	10.2	0.5	0.5	0.3	1525	Miners Castle Pt.
<i>H. physodes</i>	552	2399	18276	1141	623	781	29.6	68.9	46.9	4.2	7.1	18.1	1.9	1.0	0.6	920	N Grand Sable L
<i>H. physodes</i>	508	2270	16889	1077	611	799	30.2	63.8	45.5	4.2	6.6	17.7	1.5	0.9	0.6	930	N Grand Sable L
<i>H. physodes</i>	577	2511	16085	1086	561	728	35.1	64.0	47.1	4.2	6.9	14.4	1.7	1.0	0.6	960	N Grand Sable L
<i>H. physodes</i>	501	2471	4466	519	492	562	18.1	94.8	72.1	4.6	6.8	18.3	1.2	0.7	0.7	1230	S 12 mi Beach
<i>H. physodes</i>	486	2501	4638	505	474	514	15.5	94.6	74.0	4.5	7.1	18.1	1.1	0.5	0.9	1220	S 12 mi Beach
<i>H. physodes</i>	492	2456	4695	484	468	508	15.3	86.3	74.7	4.5	6.7	18.5	0.6	0.5	0.9	1160	S 12 mi Beach
<i>H. physodes</i>	703	3533	10436	610	329	397	24.1	90.9	92.6	4.6	5.4	23.7	0.9	0.4	0.4	1220	NW Beaver L @
<i>H. physodes</i>	730	3474	10609	618	311	388	22.9	91.3	93.6	4.6	5.3	24.7	0.8	0.5	0.5	1210	NW Beaver L @
<i>H. physodes</i>	729	3533	10565	610	318	395	21.1	91.9	90.1	4.5	5.1	23.5	0.9	0.5	0.4	1290	NW Beaver L @
<i>H. physodes</i>	583	2687	5909	580	432	565	19.7	95.0	77.1	4.9	7.5	19.4	0.9	0.6	0.8	1390	Miners Castle Pt.
<i>H. physodes</i>	588	2769	6597	572	429	544	18.7	98.0	79.5	4.9	7.7	18.2	0.9	0.7	0.9	1490	Miners Castle Pt.
<i>H. physodes</i>	582	2734	6395	575	434	553	17.9	97.7	79.7	5.2	7.3	18.3	0.8	0.7	0.9	1400	Miners Castle Pt.

\*= one value at or below detection limit; included as 0.7 of detection limit

#= two values at or below detection limit; not included in calculations

@= ground before dividing into replicates

Table 2. Summary of Pictured Rocks Analysis  
Values in ppm of thallus

<u>Cladonia rangiferina</u>																	
	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	615	1842	1085	435	329	412	24.6	20.1	13.7	1.9	5.5	*1.7	*0.5	0.4	*0.3	528 N Grand Sable L	
Std. dev.	44	134	22	28	21	53	0.9	1.6	0.6	0.1	1.2	0.8	0.2	0.1	0.2	55 N Grand Sable L	
Mean	464	2222	387	292	166	161	17.2	47.8	21.4	2.3	6.1	2.0	#	0.2	0.1	670 S 12 mi beach	
Std. dev.	17	88	22	8	4	7	1.3	6.0	0.5	0.1	0.5	0.3	#	<.1	0.1	56 S 12 mi beach	
Mean	356	1575	398	239	269	270	26.5	39.5	18.2	2.1	2.0	3.9	0.5	0.4	0.2	452 NW Beaver L @	
Std. dev.	29	119	34	20	21	20	3.4	3.3	1.8	0.2	0.2	0.4	0.2	<.1	0.1	28 NW Beaver L @	
Mean	340	1474	617	251	216	259	28.3	43.3	19.2	1.8	5.3	2.5	#	0.2	0.2	492 Miners Castle Pt.	
Std. dev.	28	53	64	8	10	14	3.3	3.2	0.5	<.1	0.5	0.3	#	0.1	<.1	38 Miners Castle Pt.	
<u>Evernia mesomorpha</u>																	
	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	546	2318	1607	474	553	719	39.1	20.8	28.0	3.5	9.2	6.9	0.9	0.9	0.3	1185 N Grand Sable L	
Std. dev.	50	153	120	28	57	100	3.4	1.4	2.1	0.3	0.6	2.8	0.4	0.1	<.1	169 N Grand Sable L	
Mean	424	2181	294	257	388	452	23.2	21.4	33.3	3.2	6.3	7.0	*0.6	2.7	0.2	1357 S 12 mi beach @	
Std. dev.	9	42	6	5	15	67	1.3	0.6	1.1	0.2	0.2	0.4	0.3	3.0	<.1	159 S 12 mi beach @	
Mean	556	2789	504	293	322	334	20.7	34.5	33.4	3.5	7.5	4.4	0.6	0.5	0.2	1423 NW Beaver L	
Std. dev.	19	94	30	10	16	22	1.9	3.2	2.8	0.1	0.5	0.8	0.1	0.1	<.1	48 NW Beaver L	
Mean	449	1956	364	280	301	352	30.9	21.3	26.9	3.5	7.6	10.1	0.6	0.5	0.3	1432 Miners Castle Pt.	
Std. dev.	11	97	22	5	14	10	1.3	0.4	0.4	0.1	0.2	0.1	0.2	0.1	<.1	88 Miners Castle Pt.	
<u>Hypogymnia physodes</u>																	
	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	545	2394	17083	1101	599	769	31.6	65.6	46.5	4.2	6.9	16.7	1.7	1.0	0.6	937 N Grand Sable L	
Std. dev.	35	121	1108	34	33	37	3.1	2.9	0.9	<.1	0.3	2.1	0.2	0.1	<.1	21 N Grand Sable L	
Mean	493	2476	4600	502	478	528	16.3	91.9	73.6	4.5	6.9	18.3	1.0	0.6	0.8	1203 S 12 mi beach	
Std. dev.	7	23	119	18	12	30	1.6	4.9	1.3	0.1	0.2	0.2	0.3	0.1	0.1	38 S 12 mi beach	
Mean	721	3513	10537	613	319	393	22.7	91.4	92.1	4.6	5.3	24.0	0.9	0.4	0.4	1240 NW Beaver L @	
Std. dev.	16	34	90	5	9	5	1.5	0.5	1.8	<.1	0.2	0.6	0.1	0.1	0.1	44 NW Beaver L @	
Mean	584	2730	6300	576	432	554	18.7	96.9	78.8	5.0	7.5	18.6	0.9	0.7	0.9	1427 Miners Castle Pt.	
Std. dev.	3	41	354	4	2	11	0.9	1.7	1.5	0.2	0.2	0.7	<.1	<.1	<.1	55 Miners Castle Pt.	

\*= one value at or below detection limit; included as 0.7 of detection limit  
 #= two values at or below detection limit; not included in calculations  
 @= ground before dividing into replicates

1540 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 the different species. Cladina rangiferina has lower levels than either of the other species.

None of the other elements show unusually high levels or trends of increasing concentrations.

#### CONCLUSIONS

There is no indication that the lichens of Pictured Rocks NL 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. At most localities many species occur and the actual species list depends on the habitat. 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 are more species in lakeshore habitats due to more moisture and light and there are many species in the open stumpland. In the hardwood forests there are fewer species, probably because of the dense shade. 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 a slight gradient of increasing sulfur closer to Munising that should be watched.

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## APPENDIX I

### Collection Localities

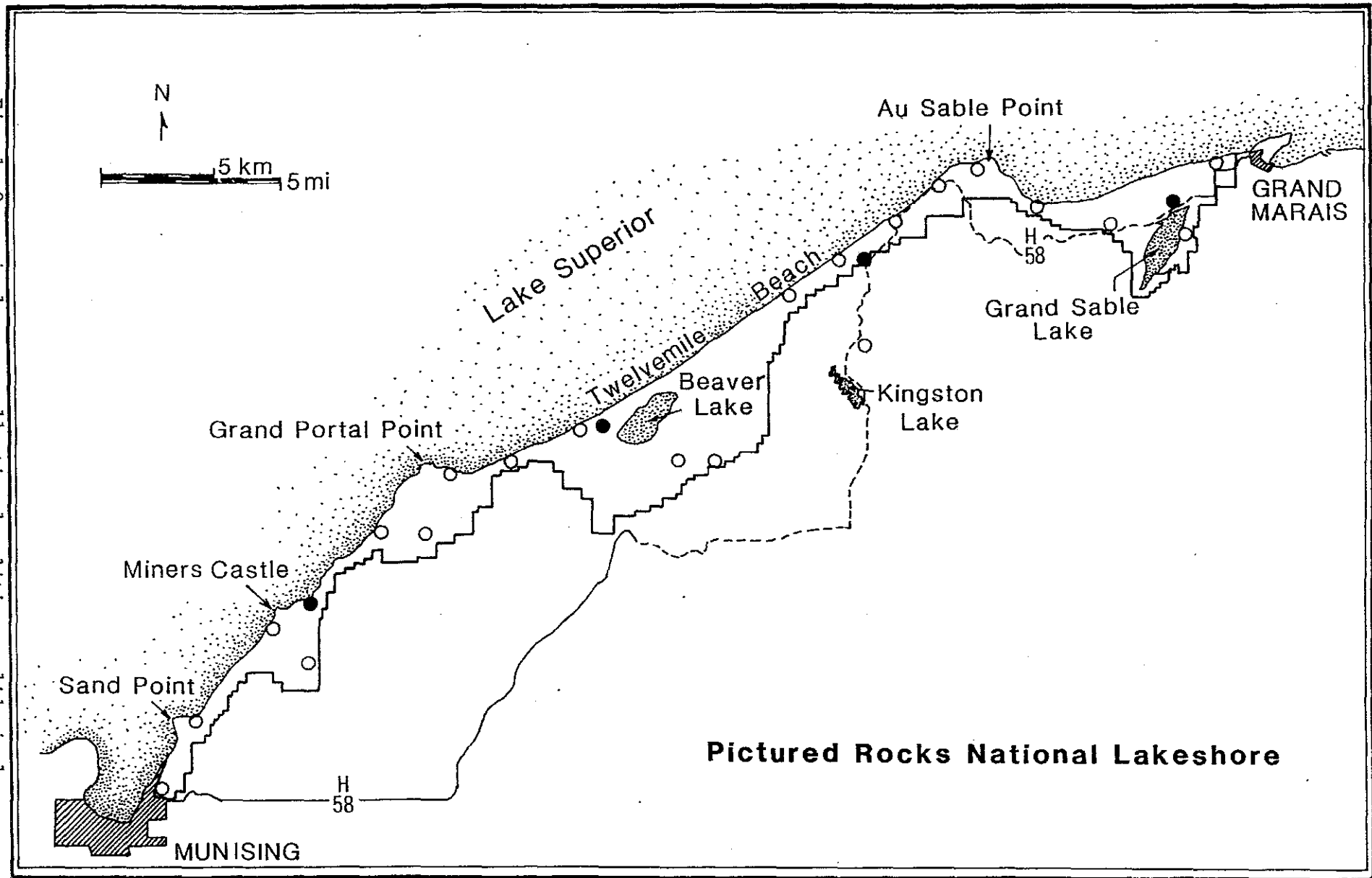
Collection numbers are those of Clifford Wetmore. All collections are listed in ascending order by collection number and date of collection.

#### Alger County

- 58711- North side of Grand Sable Lake, 2 miles west of Grand  
58761 Marais. On ridges with jack pines and openings. Sec.  
10, T49N, R14W. 10 July 1987. Chemical analysis.
- 58762- South of Grand Sable Dunes, 4 miles west-southwest of  
58803 Grand Marais. In maple-beech forest with some old  
balsam fir. Sec. 16, T49N, R14W. 10 July 1987.
- 58804- West of the log slide on shore of Lake Superior (6  
58851 miles west of Grand Marais). Maple-beech forest at edge  
of bluffs with some balsam poplar and birch. Sec. 12,  
T49N, R15W. 10 July 1987.
- 58852- At mouth of Sable Creek 1.5 miles west of Grand  
58898 Marais. Along lowland near shore with balsam fir, maple  
and some balsam poplar. Sec. 2, T49N, R14W. 11 July  
1987.
- 58899- East side of Grand Sable Lake half mile south of boat  
58943 landing. Maple-beech woods with wet area with black  
ash. Sec. 14, T49N, R14W. 11 July 1987.
- 58944- Half mile south of Twelvemile Beach Campground. In  
58998 jack pine forest near junction of campground road and  
highway 58. Sec. 17, T49N, R15W. 13 July 1987. Chemical  
analysis.
- 58999- Twelvemile Beach 1 mile northeast of Twelvemile Beach  
59054 Campground. Along shore in mixed forest of white pine,  
white birch, balsam fir and maple. Sec. 16, T49N, R15W.  
13 July 1987.
- 59055- Au Sable Point. In edge of swamp behind point with  
59109 balsam fir, Thuja, some white birch and hemlock. Sec.  
2, T49N, R15W. 13 July 1987.
- 59110- Around mouth of Sevenmile Creek at Twelvemile Beach.  
59164 Along stream with Thuja, balsam fir, white birch and  
maple. Sec. 25, T49N, R16W. 14 July 1987.
- 59165- 1.5 miles southwest of Twelvemile Beach Campground

- 59775- Grand Portal Point. On points on east side with  
59827 hemlock, white pine, yellow birch and some Thuja. Sec.  
17, T48N, R17W. 20 July 1987.
- 59828- Near shore of Lake Superior along Mosquito River. In  
59879 mixed woods along stream with hemlock, birch, maple,  
balsam fir and Thuja. Sec. 25, T48N, R18W. 21 July  
1987.
- 59880- 2 miles south of Grand Portal Point at junction of  
59941 trails to Chapel Lake and Mosquito Beach. On hillside  
and open area with red maples and some conifers. Sec.  
29, T48N, R17W. 21 July 1987.

Fig. 1. Open circles are collection localities, solid circles are elemental analysis 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 Pictured Rocks NL 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). The intermediate category includes species present between 50ug and 100ug. The S-I group falls between the Sensitive and Intermediate categories. Open circles on the maps are localities where the species was not found and solid circles are where it was found.

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

- Fig. 2 Bryoria furcellata (Fr.) Brodo & Hawksw.
- Fig. 3 Bryoria trichodes (Michx.) Brodo & Hawksw.
- Fig. 4 Dimerella lutea (Dicks.) Trev.
- Fig. 5 Hypogymnia tubulosa (Schaer.) Hav.
- Fig. 6 Lecidea nylanderii (Anzi) Th. Fr.
- Fig. 7 Lecidea vernalis (L.) Ach.
- Fig. 8 Lobaria pulmonaria (L.) Hoffm.
- Fig. 9 Ochrolechia rosella (Müll. Arg.) Vers.
- Fig. 10 Parmelia squarrosa Hale
- Fig. 11 Parmelia subaurifera Nyl.
- Fig. 12 Ramalina americana Hale
- Fig. 13 Usnea ceratina Ach.
- Fig. 14 Usnea filipendula Stirt.

Fig. 3. Distribution of *Bryoria trichodes*

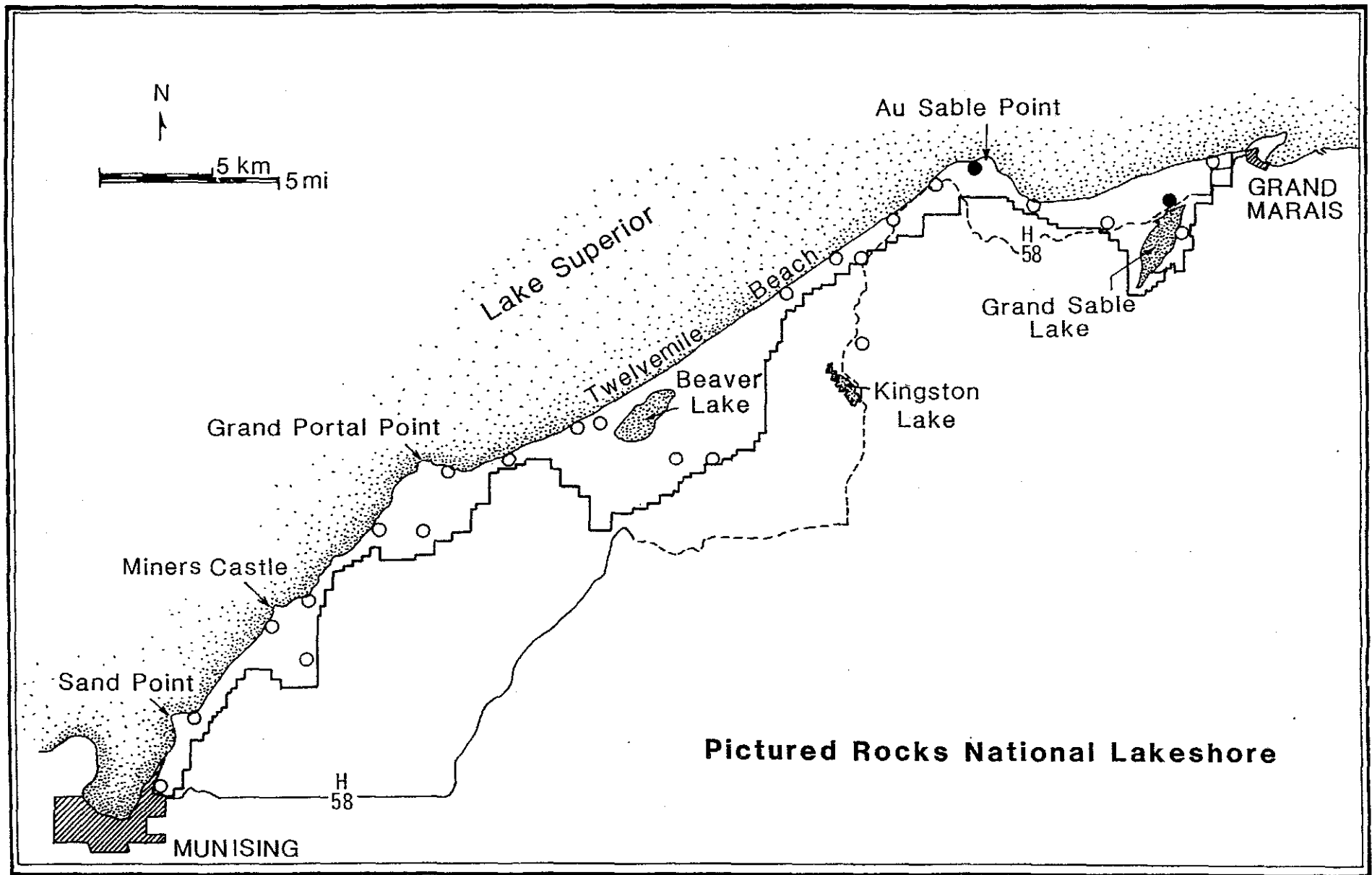


Fig. 2. Distribution of *Bryozoa furcellata*

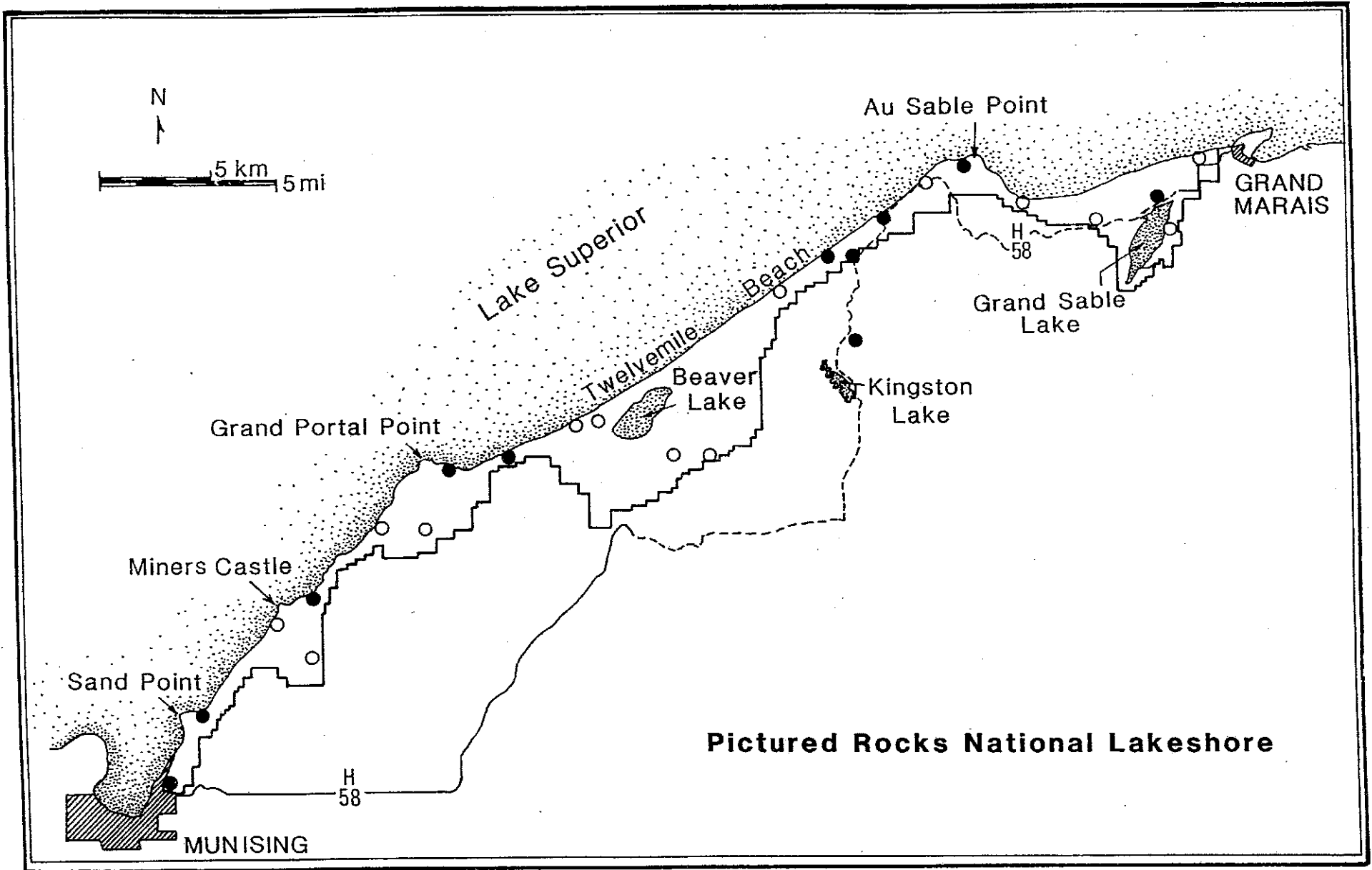


Fig. 4. Distribution of *Dimereila lutea*

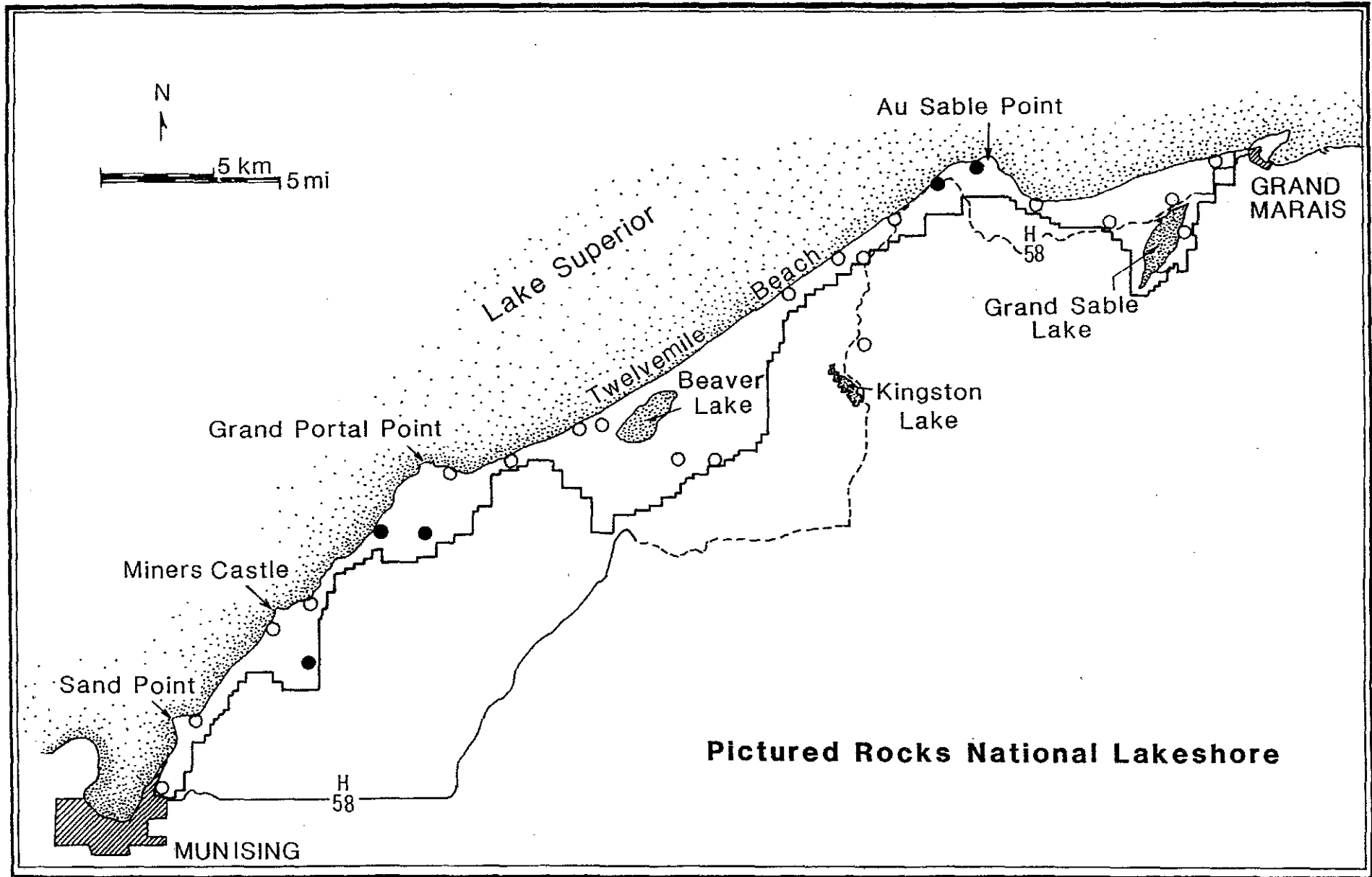




Fig. 5. Distribution of *Hypogymnia tubulosa*

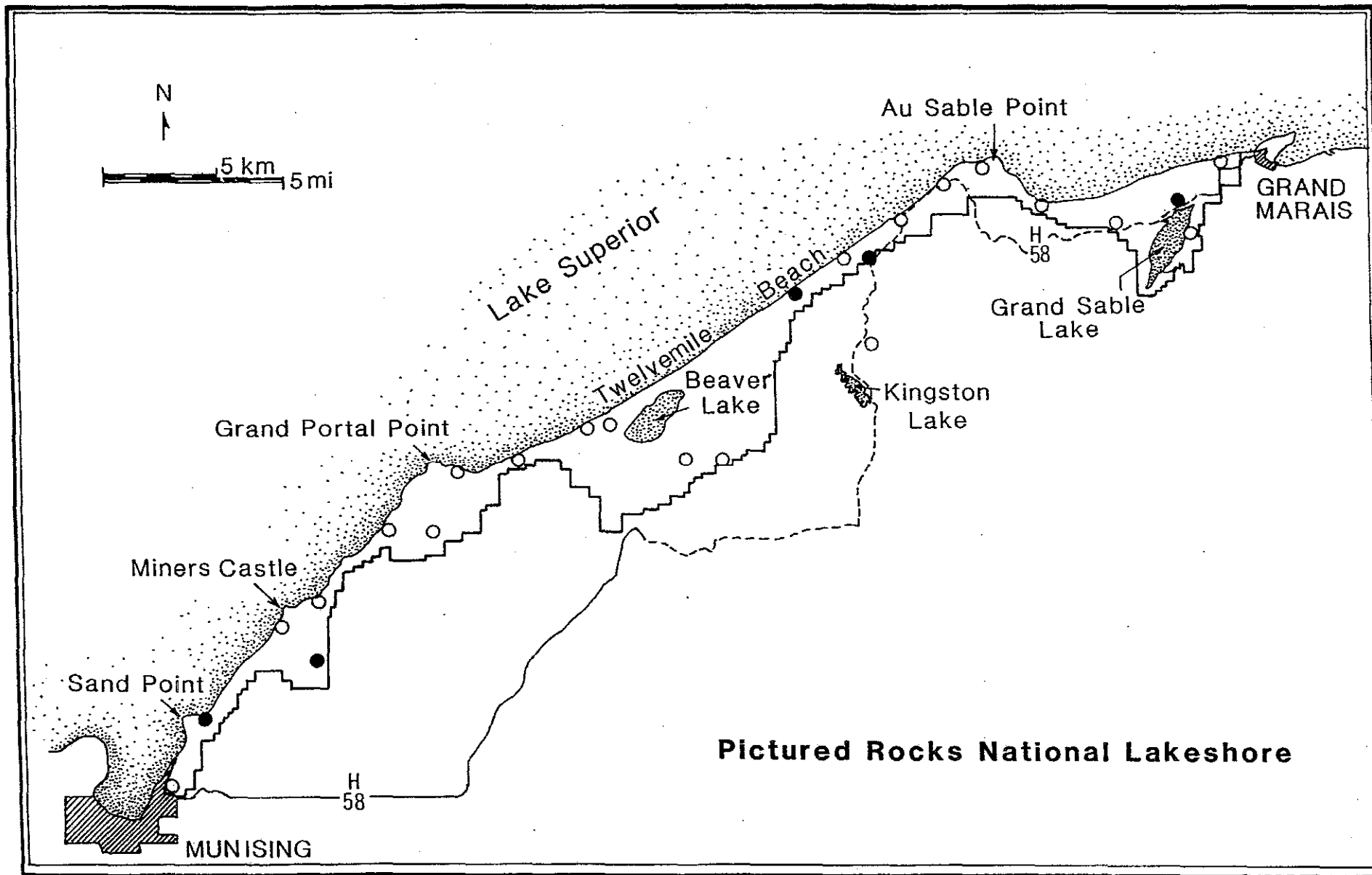


Fig. 6. Distribution of *Lecidea nylanderii*

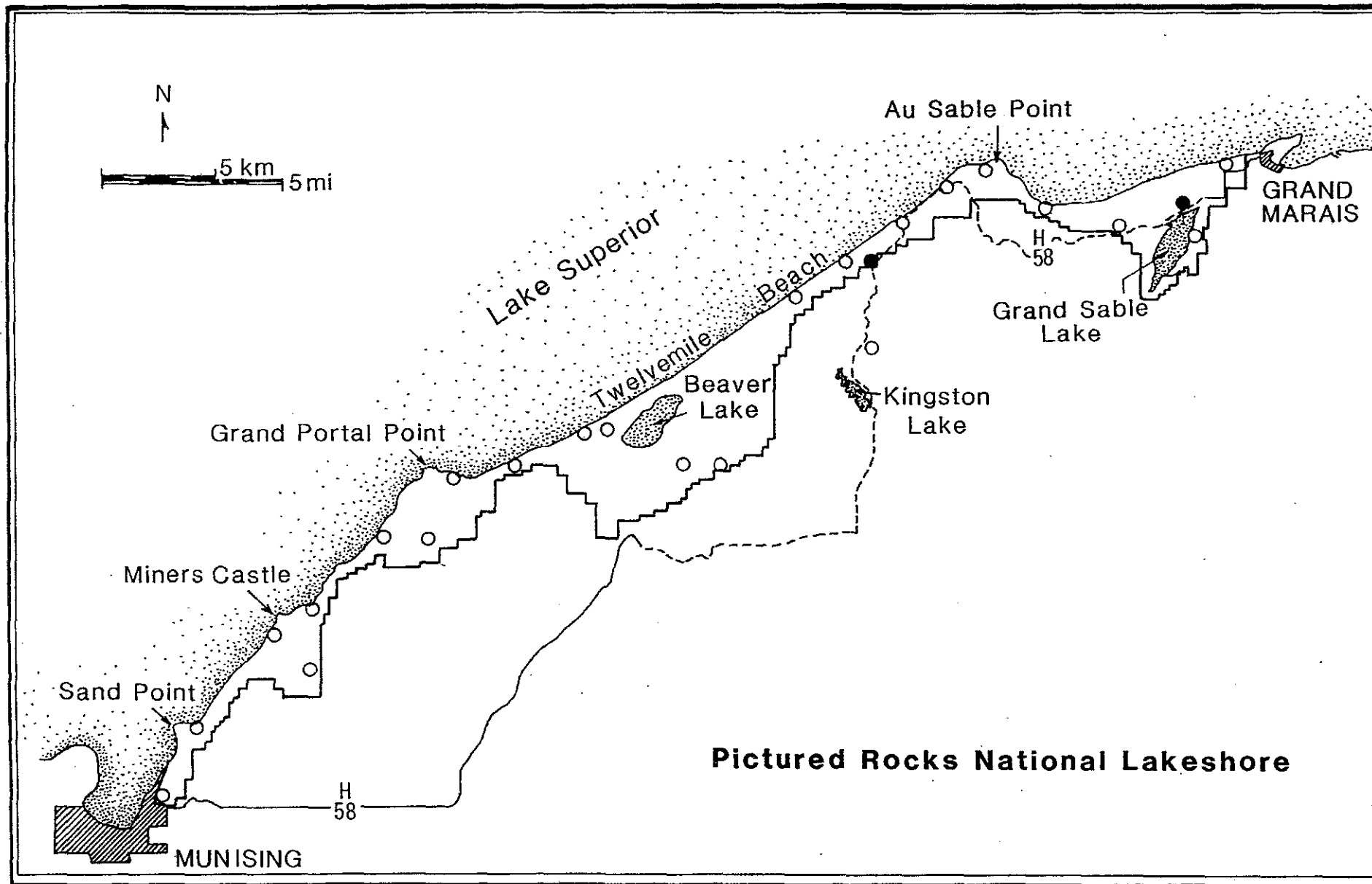


Fig. 7. Distribution of *Lecidea vernalis*

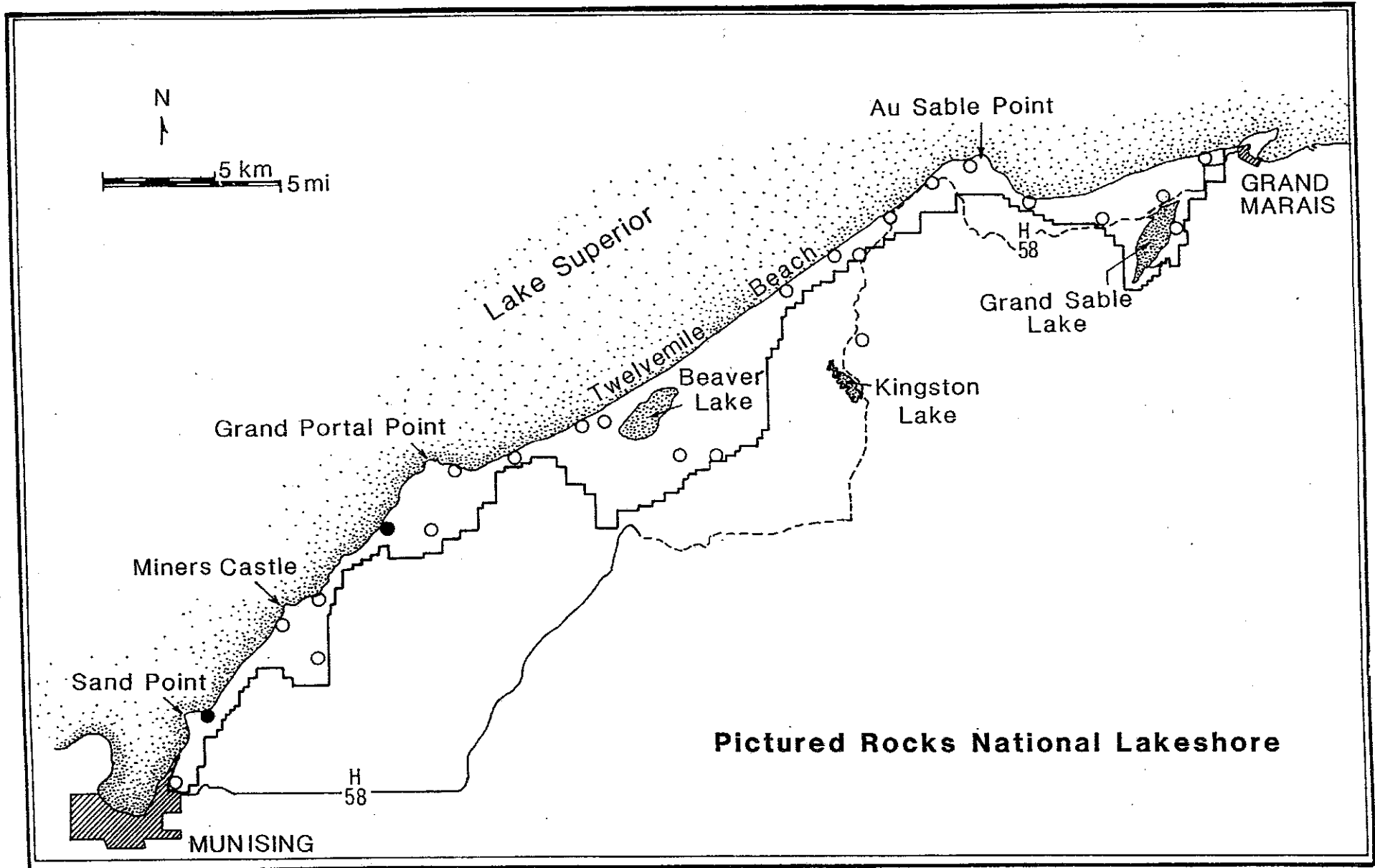


Fig. 8. Distribution of *Lobaria pulmonaria*

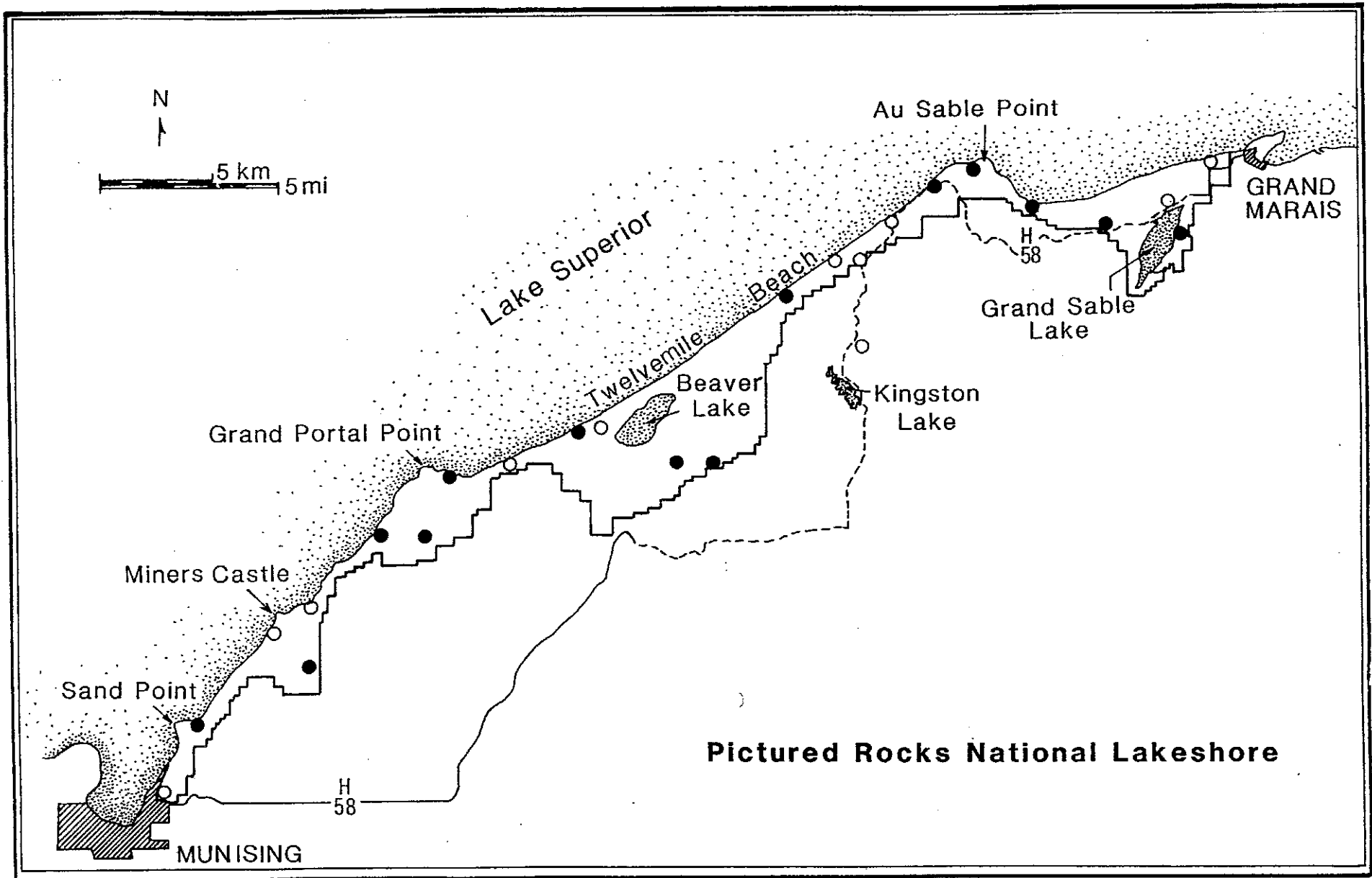


Fig. 9. Distribution of *Ochrolechia rosalia*

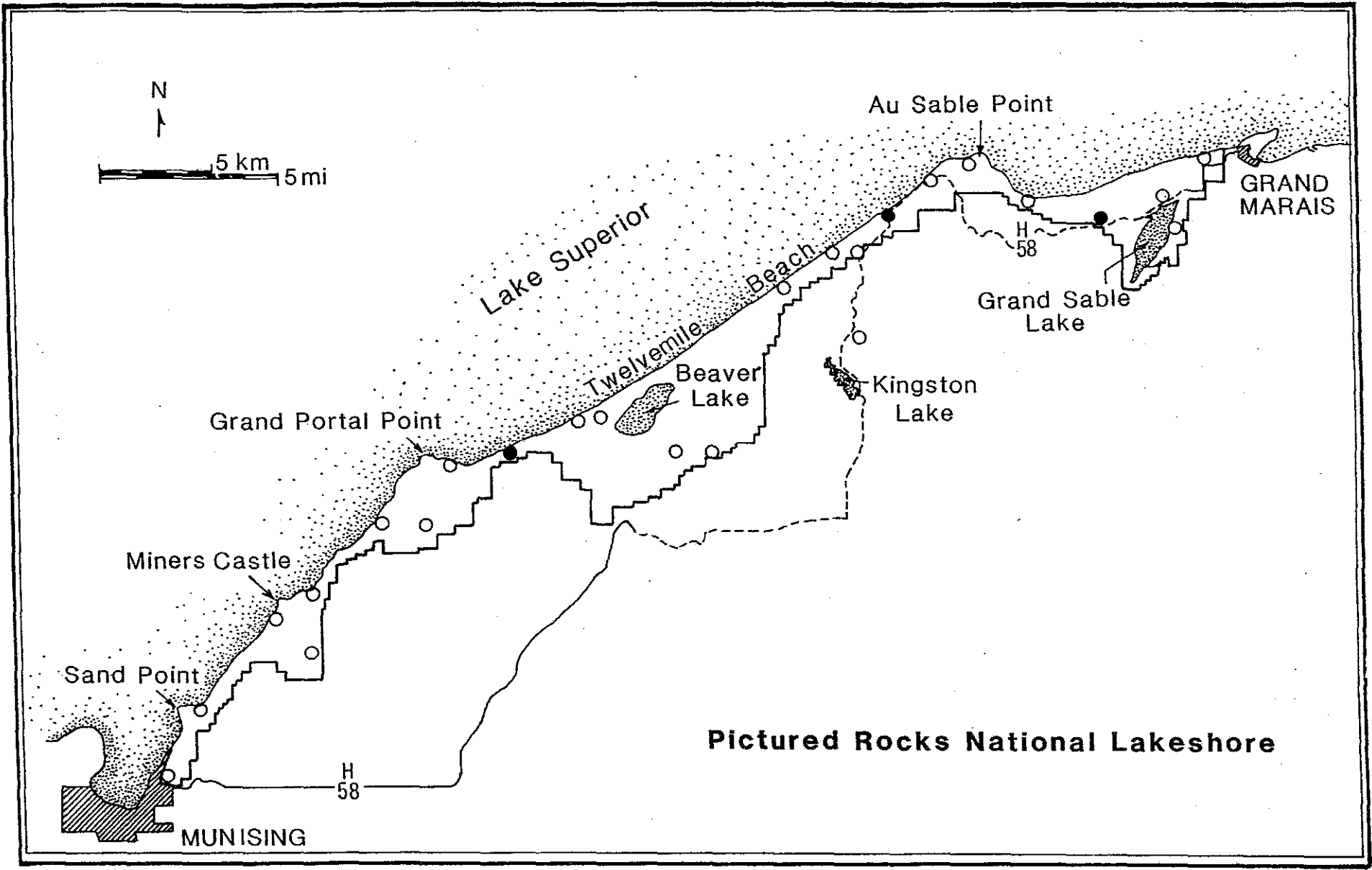


Fig. 10. Distribution of *Parmelia squarrosa*

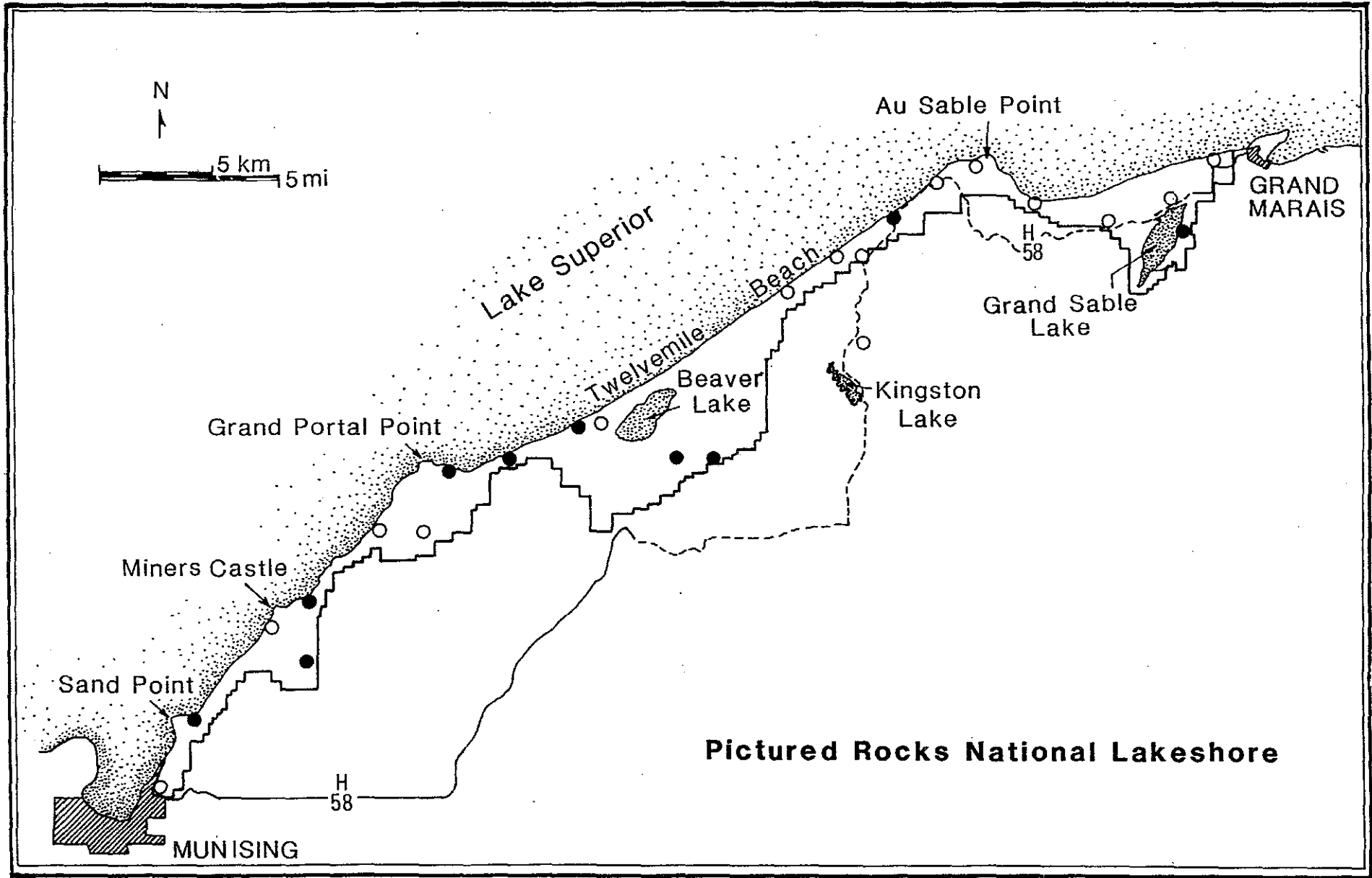


Fig. 11. Distribution of *Parmelia subaurifera*

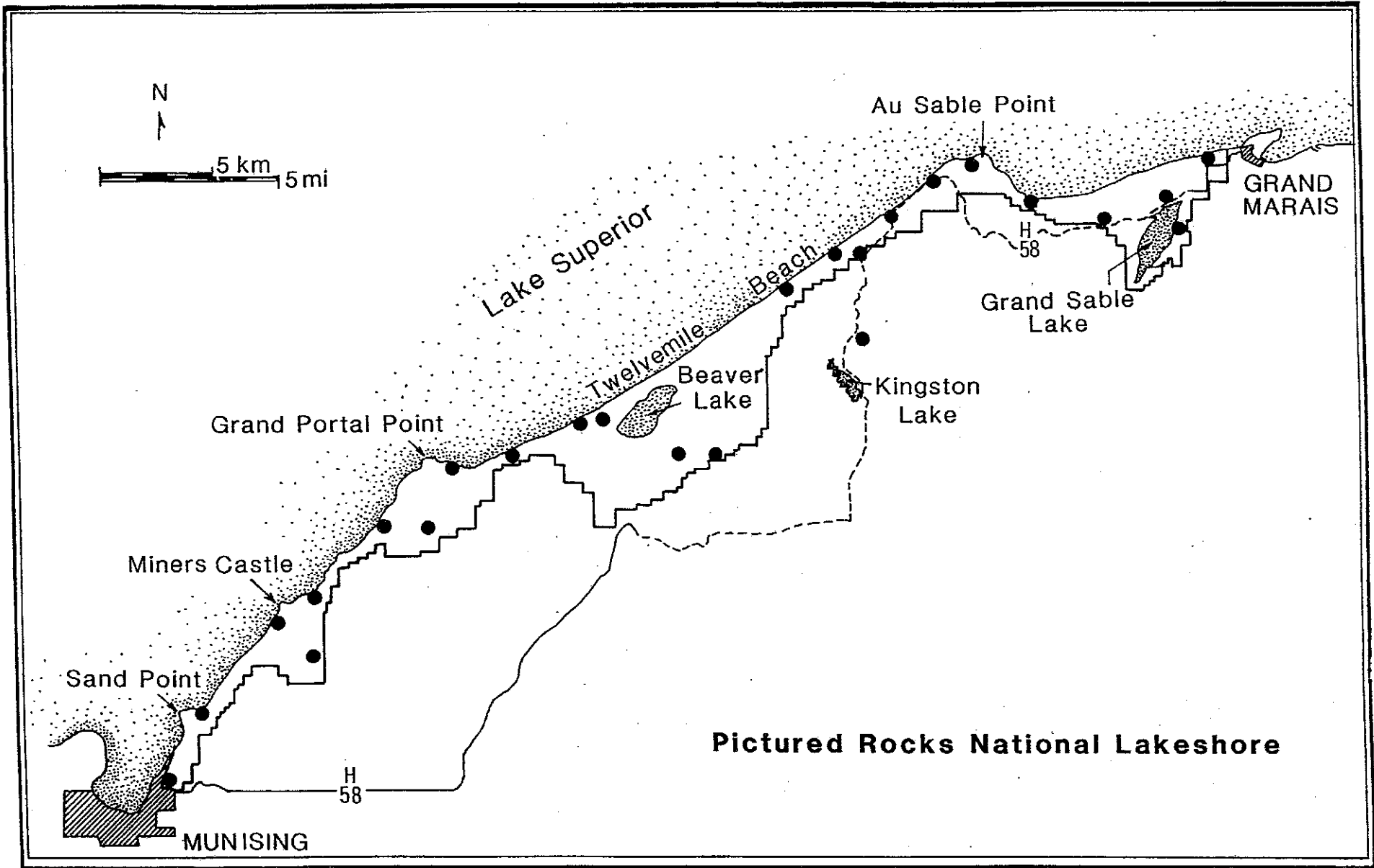


Fig. 12. Distribution of *Ramalina americana*

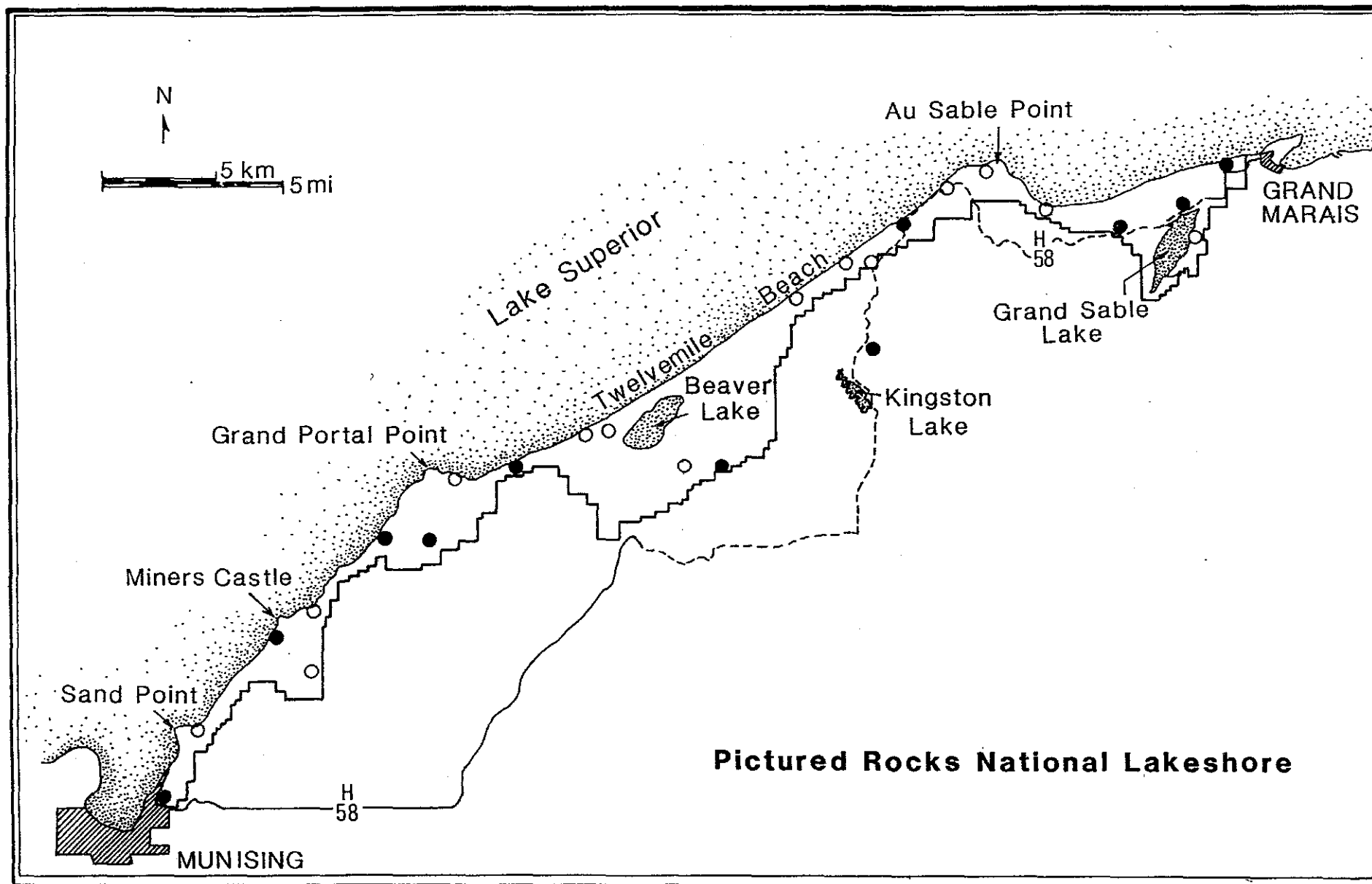




Fig. 13. Distribution of *Usnea ceratina*

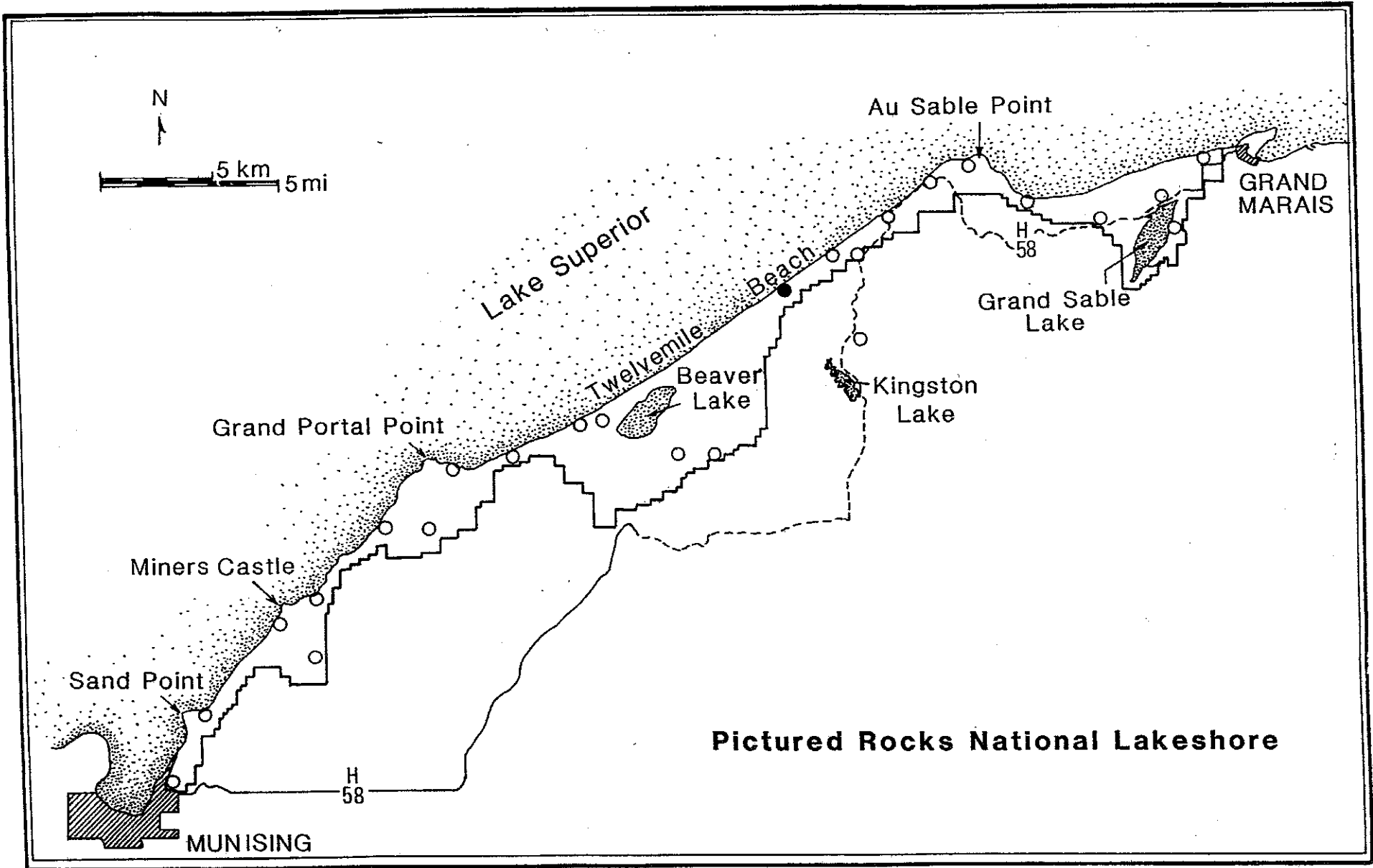


Fig. 14. Distribution of *Usnea Filipendula*

