Working

LICHENS AND AIR QUALITY

IN

PICTURED ROCKS NATIONAL LAKESHORE

FINAL REPORT

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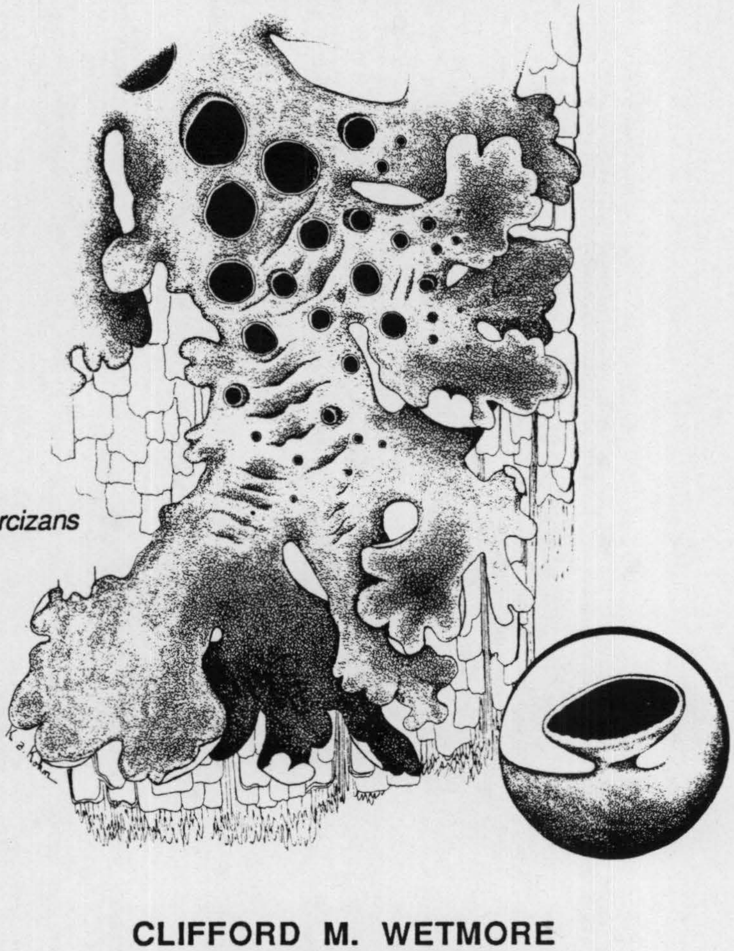

Lobaria quercizans

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Final Report

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

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LICHENS OF PICTURED ROCKS NATIONAL LAKESHORE

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.

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 13ug/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. 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) 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 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.

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 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.

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 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 schaereri 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.
1 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 nylanderi* (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
1 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.) Fürnr.
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 sorediata (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

The locality with the greatest number is south of Miners Falls in a <u>Thuja</u> 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 <u>Bryoria furcellata</u> (Fr.) Brodo & Hawksw.
S <u>Bryoria trichodes</u> (Michx.) Brodo & Hawksw.
S <u>Dimerella lutea</u> (Dicks.) Trev.
S <u>Hypogymnia tubulosa</u> (Schaer.) Hav.
S <u>Lecidea nylanderi</u> (Anzi) Th. Fr.
S <u>Lecidea vernalis</u> (L.) Ach.
S <u>Lobaria pulmonaria</u> (L.) Hoffm.
S <u>Ochrolechia rosella</u> (Müll. Arg.) Vers.
S <u>Parmelia squarrosa</u> Hale
(S) <u>Parmelia subaurifera</u> Nyl.
S <u>Ramalina americana</u> Hale
S <u>Usnea ceratina</u> Ach.
S <u>Usnea filipendula</u> Stirt.

The distributions of these species are mapped Fig. 2-14. <u>Parmelia subaurifera</u> 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 <u>Dimerella lutea</u>, <u>Lobaria pulmonaria</u> and <u>Lecidea nylanderi</u>.

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 detritis 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
<u>C. rangiferina</u>	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 L
<u>C. rangiferina</u>	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
<u>C. rangiferina</u>	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
<u>C. rangiferina</u>	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
<u>C. rangiferina</u>	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
<u>C. rangiferina</u>	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
<u>C. rangiferina</u>	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 @
<u>C. rangiferina</u>	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 @
<u>C. rangiferina</u>	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 @
<u>C. rangiferina</u>	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.
<u>C. rangiferina</u>	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.
<u>C. rangiferina</u>	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.
<u>E. mesomorpha</u>	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
<u>E. mesomorpha</u>	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
<u>E. mesomorpha</u>	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
<u>E. mesomorpha</u>	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 @
<u>E. mesomorpha</u>	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 @
<u>E. mesomorpha</u>	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 @
<u>E. mesomorpha</u>	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
<u>E. mesomorpha</u>	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
<u>E. mesomorpha</u>	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
<u>E. mesomorpha</u>	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.
<u>E. mesomorpha</u>	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.
<u>E. mesomorpha</u>	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.
<u>H. physodes</u>	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
<u>H. physodes</u>	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
<u>H. physodes</u>	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
<u>H. physodes</u>	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
<u>H. physodes</u>	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
<u>H. physodes</u>	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
<u>H. physodes</u>	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 @
<u>H. physodes</u>	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 @
<u>H. physodes</u>	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 @
<u>H. physodes</u>	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.
<u>H. physodes</u>	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.
<u>H. physodes</u>	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

Cladonia rangiferina

	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.

Evernia mesomorpha

	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	40	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.

Hypogymnia physodes

	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

58711-58761 North side of Grand Sable Lake, 2 miles west of Grand Marais. On ridges with jack pines and openings. Sec. 10, T49N, R14W. 10 July 1987. Chemical analysis.

58762-58803 South of Grand Sable Dunes, 4 miles west-southwest of Grand Marais. In maple-beech forest with some old balsam fir. Sec. 16, T49N, R14W. 10 July 1987.

58804-58851 West of the log slide on shore of Lake Superior (6 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.

58852-58898 At mouth of Sable Creek 1.5 miles west of Grand Marais. Along lowland near shore with balsam fir, maple and some balsam poplar. Sec. 2, T49N, R14W. 11 July 1987.

58899-58943 East side of Grand Sable Lake half mile south of boat landing. Maple-beech woods with wet area with black ash. Sec. 14, T49N, R14W. 11 July 1987.

58944-58998 Half mile south of Twelvemile Beach Campground. In jack pine forest near junction of campground road and highway 58. Sec. 17, T49N, R15W. 13 July 1987. Chemical analysis.

58999-59054 Twelvemile Beach 1 mile northeast of Twelvemile Beach Campground. Along shore in mixed forest of white pine, white birch, balsam fir and maple. Sec. 16, T49N, R15W. 13 July 1987.

59055-59109 Au Sable Point. In edge of swamp behind point with balsam fir, *Thuja*, some white birch and hemlock. Sec. 2, T49N, R15W. 13 July 1987.

59110-59164 Around mouth of Sevenmile Creek at Twelvemile Beach. 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

59215 along Lake Superior. In open white birch forest near shore with pine stumps. Sec. 19, T49N, R15W. 14 July 1987

59216-59275 1 mile north of Kingston Lake just outside Pictured Rocks NL. In pine barrens with jack pine, stumps and open sandy areas. Sec. 32, T49N, R15W. 15 July 1987.

59276-59321 Half mile southwest of Hurricane River Campground. Back from shore of Lake Superior in low area with Thuja, balsam fir, maple and white birch. Sec. 10, T49N, R15W. 15 July 1987.

59322-59360 South of Beaver Lake along Lowney Creek. Along stream and edge of bog with Thuja and alder. Sec. 17, T48N, R16W. 16 July 1987.

59361-59396 South of Beaver Lake at end of road on ridgetop. In maple forest east of road. Sec. 15, T48N, R16W. 16 July 1987.

59397-59449 West of Beaver Lake near shore of Lake Superior. On cliffs in hemlock, yellow birch and red maple forest. Sec. 12, T48N, R17W. 17 July 1987.

59450-59487 Northwest of Beaver Lake on ridge south of Lake Superior. Pine forest with openings, red pine, spruce and white birch. Sec. 7, T48N, R16W. 17 July 1987. Chemical analysis.

59488-59537 1 mile east of Miners Castle Point near shore of Lake Superior. In jack pine woods with some red pines and open areas. Sec. 3, T47N, R18W. 18 July 1987. Chemical analysis.

59538-59583 Just south of Miners Falls. In Thuja bog with stream and some tamarack. Sec. 15, T47N, R18W. 18 July 1987.

59584-59615 Half mile south-southwest of Miners Castle Point. On upland in open beech-maple forest. Sec. 9, T47N, R18W. 18 July 1987.

59616-59664 Munising Falls at eastern edge of Munising. Along stream and cliffs with mixed hardwoods and conifers. Sec. 36, T47N, R18W. 19 July 1987.

59665-59725 Sand Point 2 miles northeast of Munising. In swamp at north side of point with Thuja, black spruce and balsam fir. Sec. 19, T47N, R18W. 19 July 1987.

59726-59774 Along shore of Lake Superior 1 mile east of mouth of Chapel River. On cliffs with red maple, yellow birch and some spruce. Sec. 15, T48N, R17W. 20 July 1987.

59775- 59827 Grand Portal Point. On points on east side with hemlock, white pine, yellow birch and some *Thuja*. Sec. 17, T48N, R17W. 20 July 1987.

59828- 59879 Near shore of Lake Superior along Mosquito River. In mixed woods along stream with hemlock, birch, maple, balsam fir and *Thuja*. Sec. 25, T48N, R18W. 21 July 1987.

59880- 59941 2 miles south of Grand Portal Point at junction of 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.

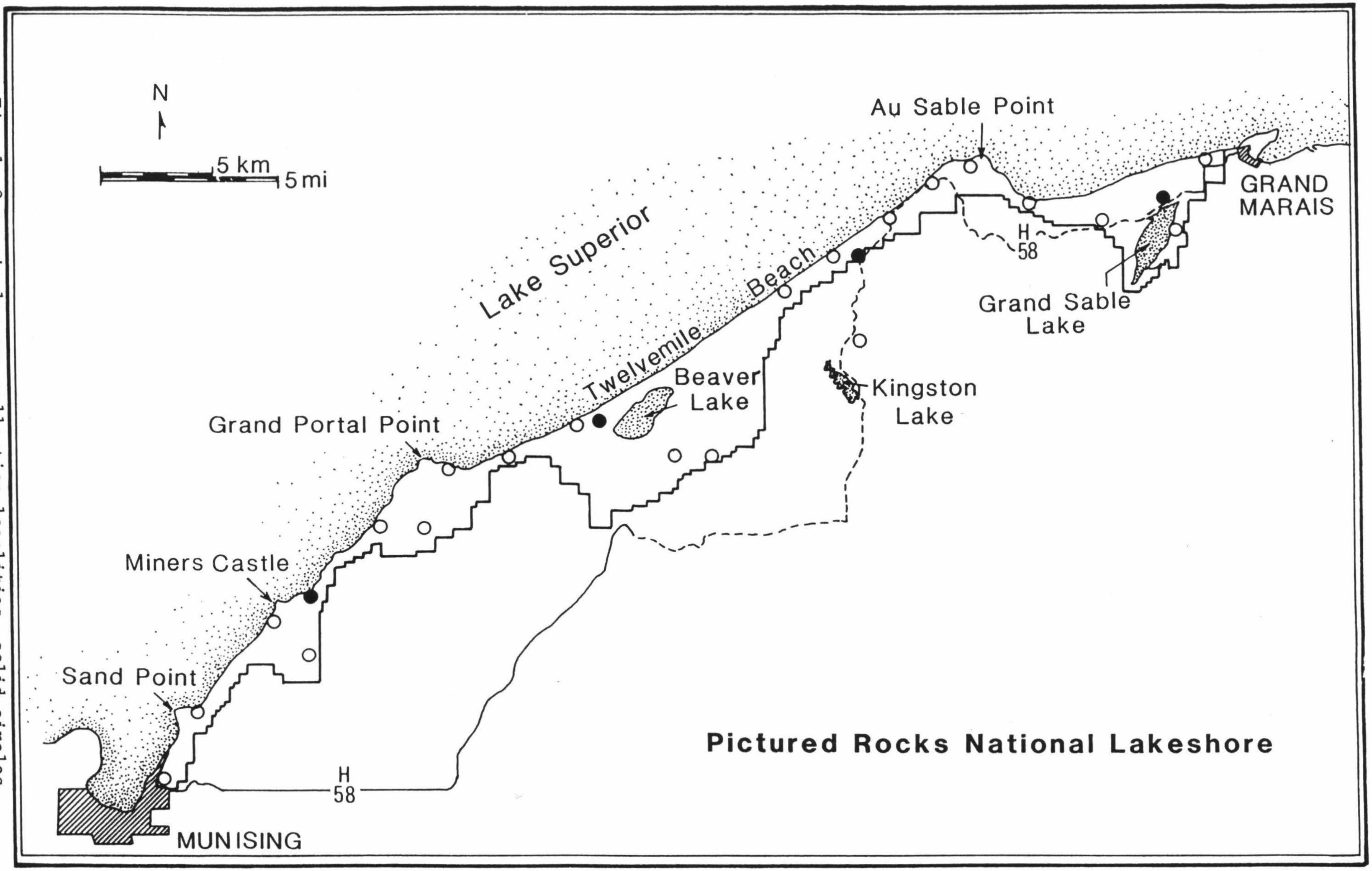


Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities.

APPENDIX II

Species Sensitive to Sulfur Dioxide

ased on the list of lichens with known sulfur dioxide ensitivity 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.

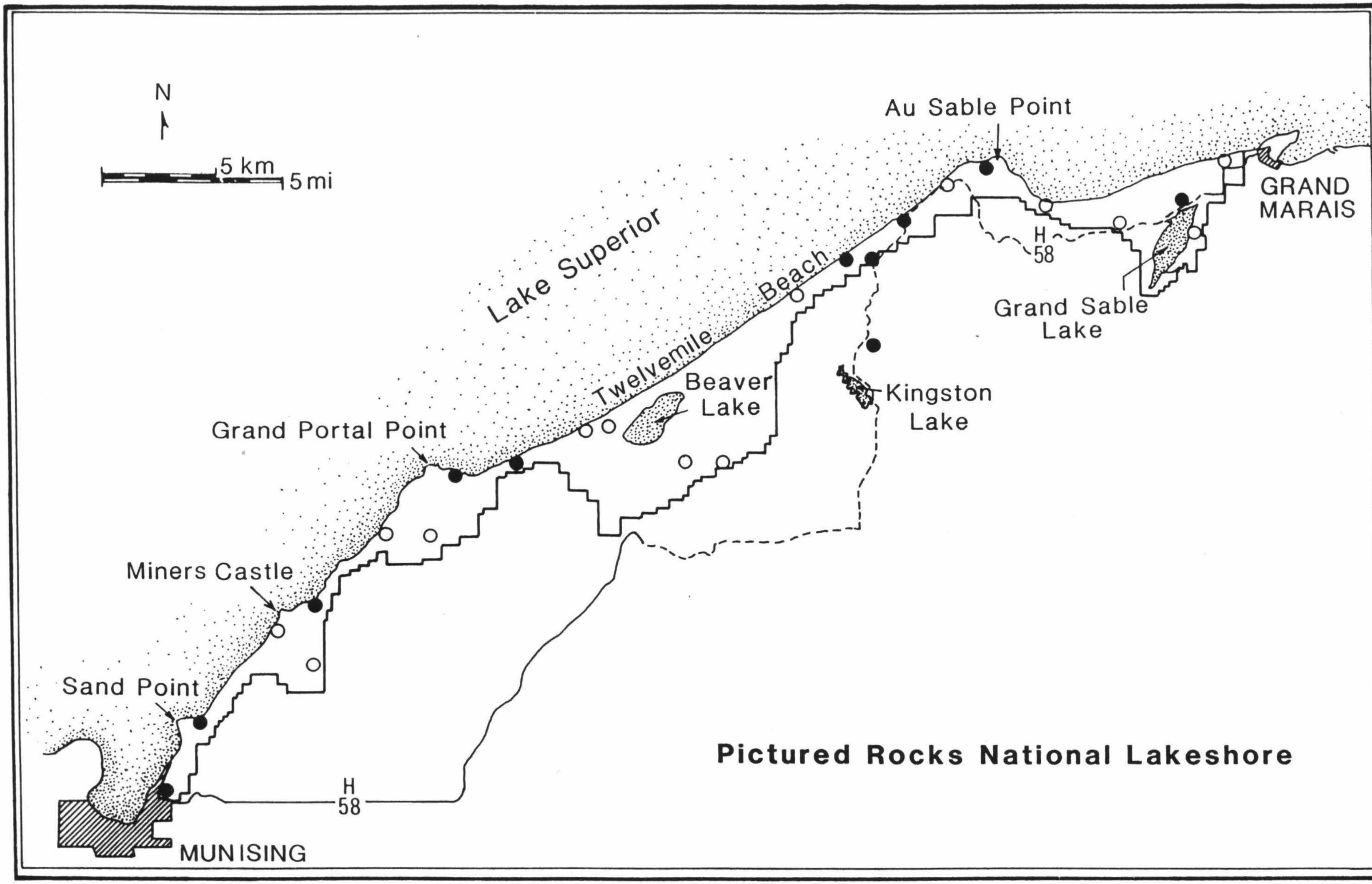


Fig. 2. Distribution of *Bryoria furcellata*

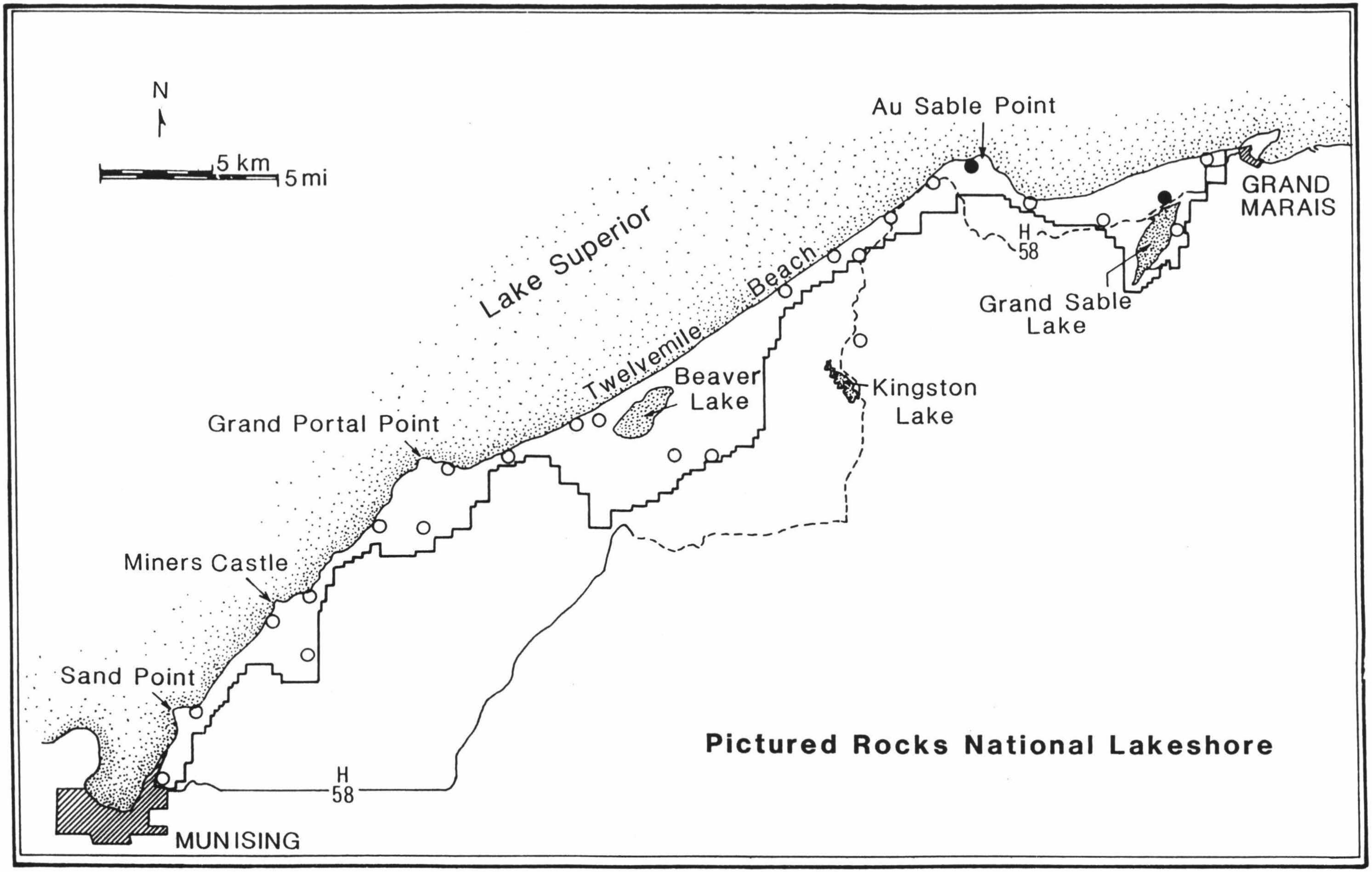


Fig. 3. Distribution of *Bryoria trichodes*

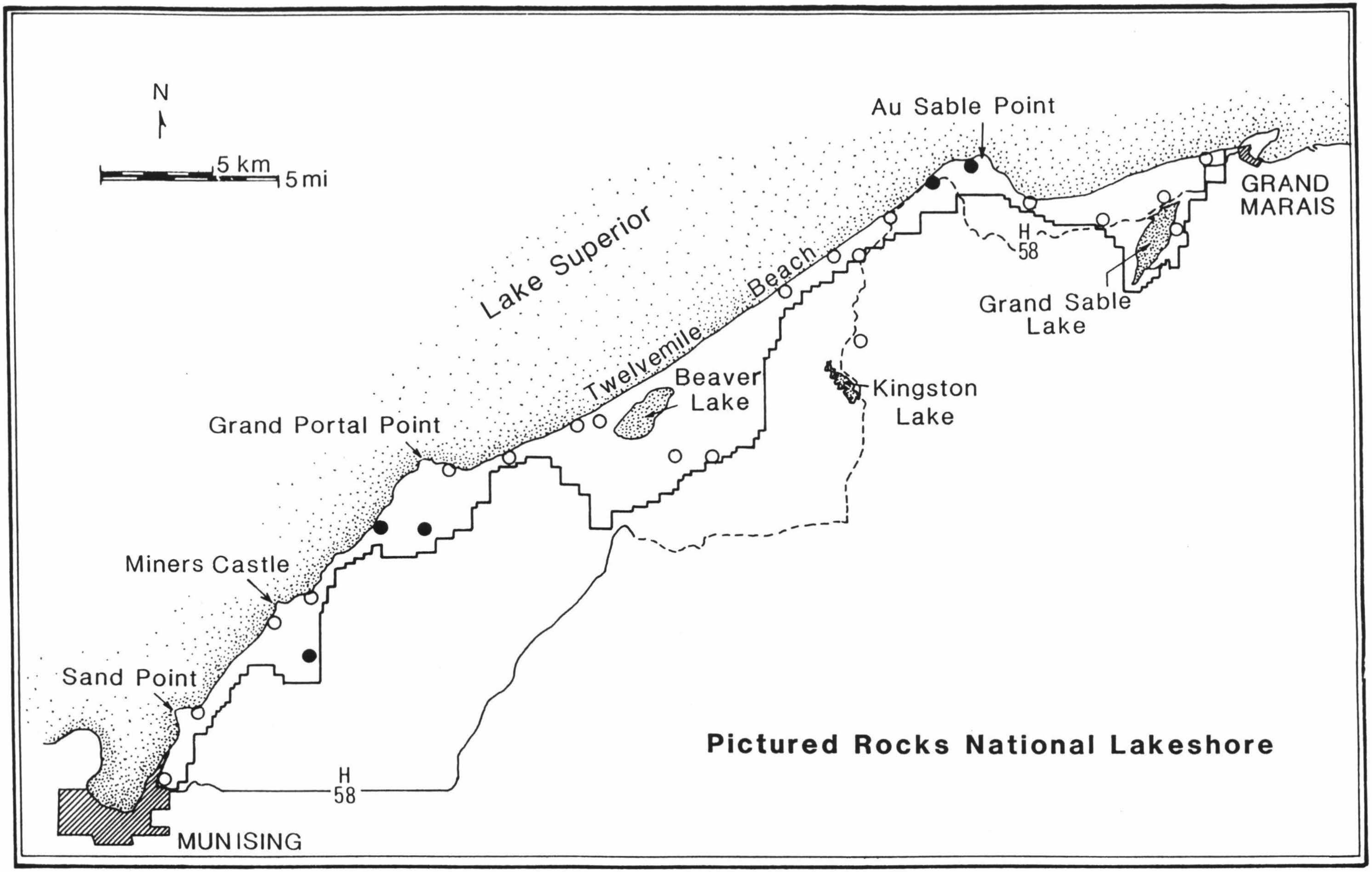


Fig. 4. Distribution of *Dimerella lutea*

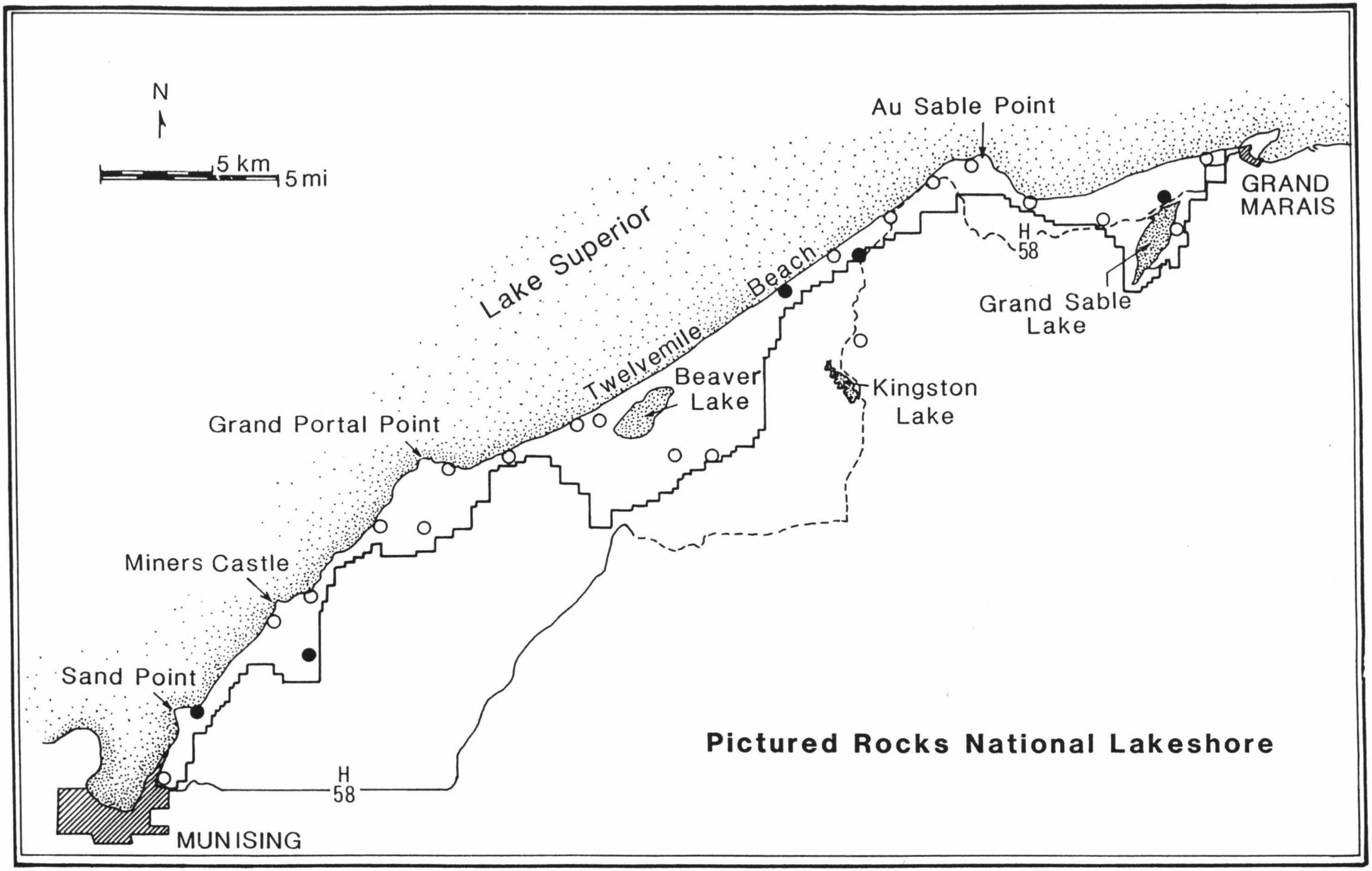


Fig. 5. Distribution of *Hypogymnia tubulosa*

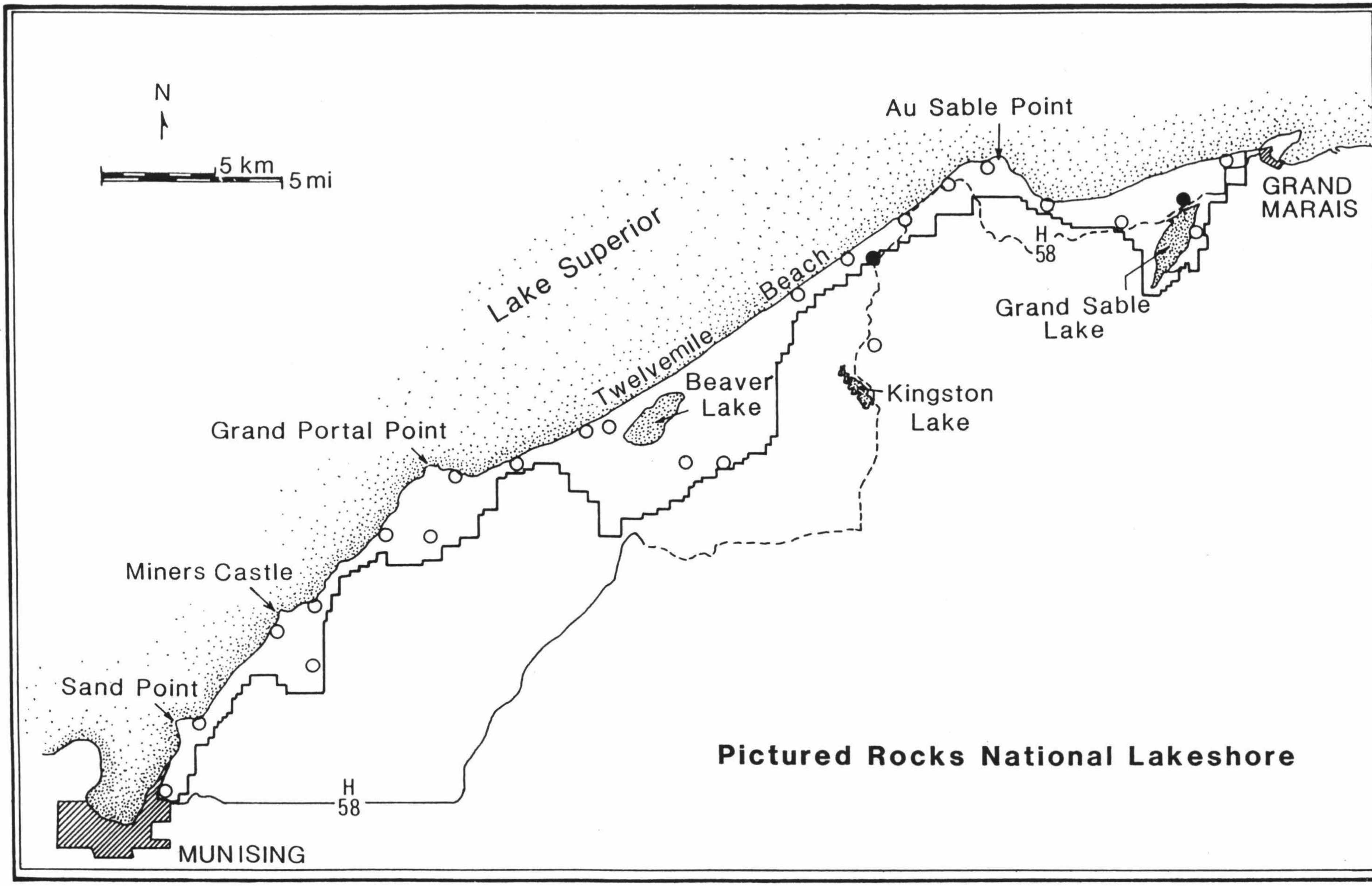


Fig. 6. Distribution of *Lecidea nylanderi*

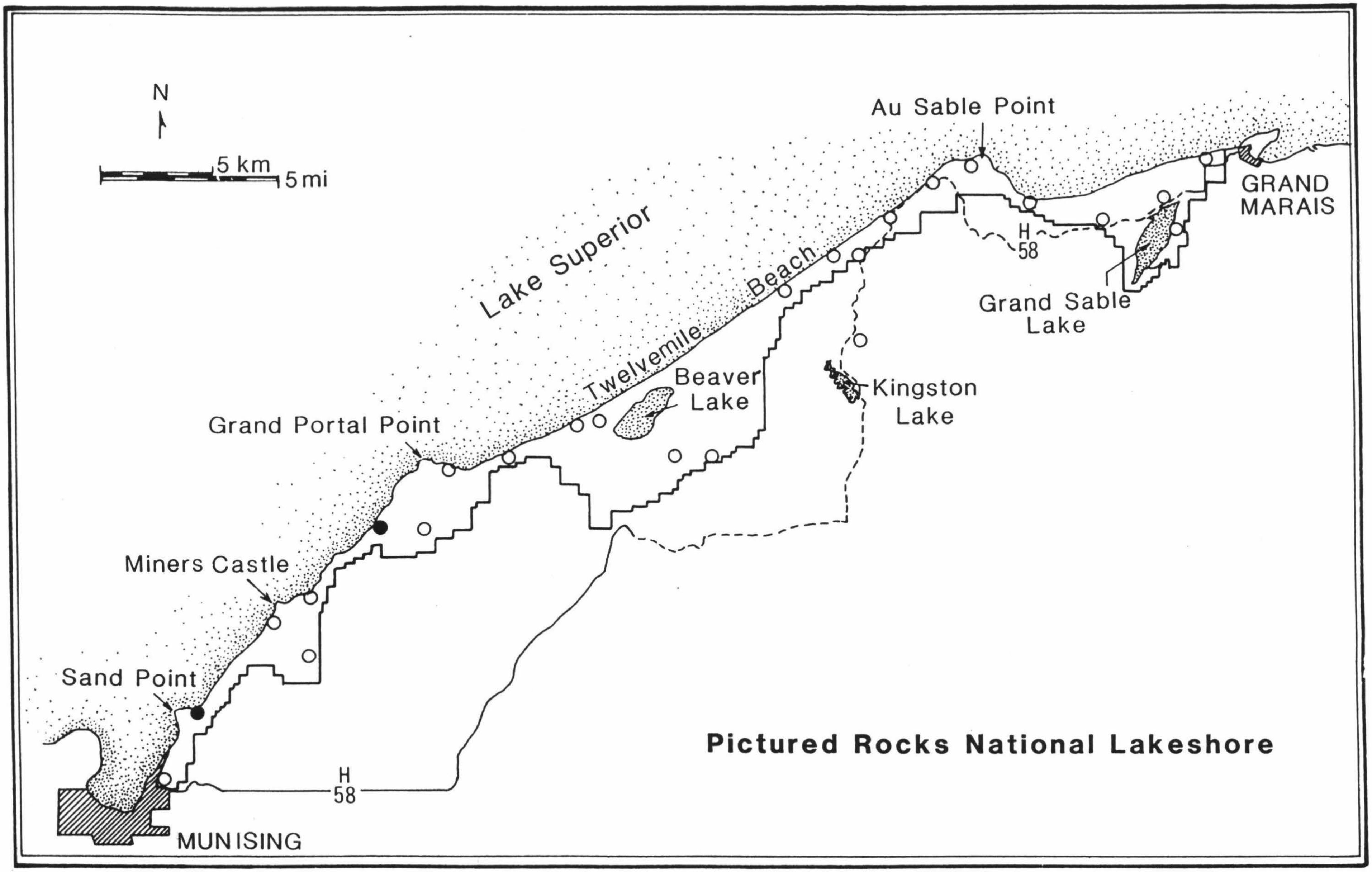


Fig. 7. Distribution of *Lecidea vernalis*

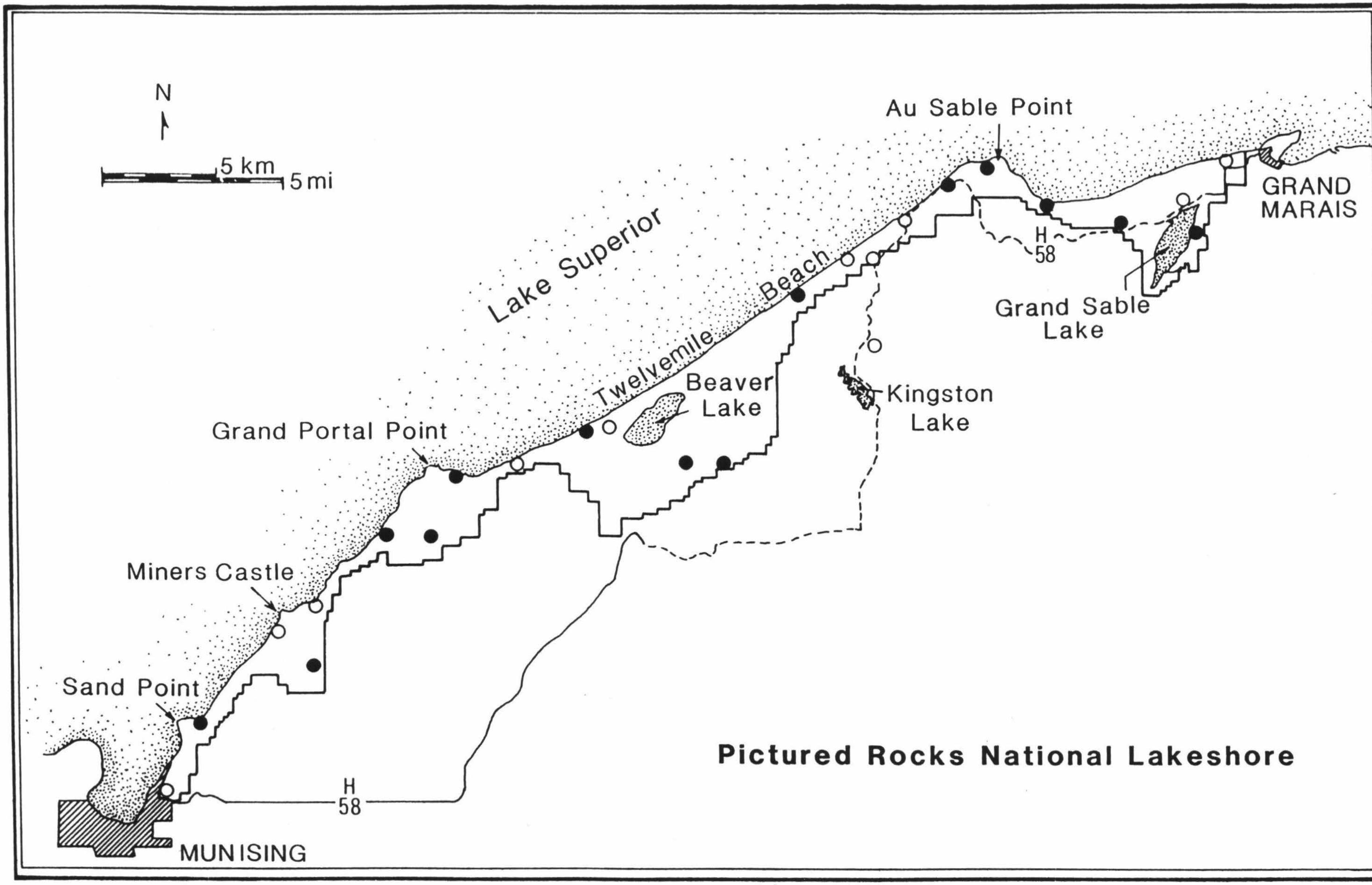
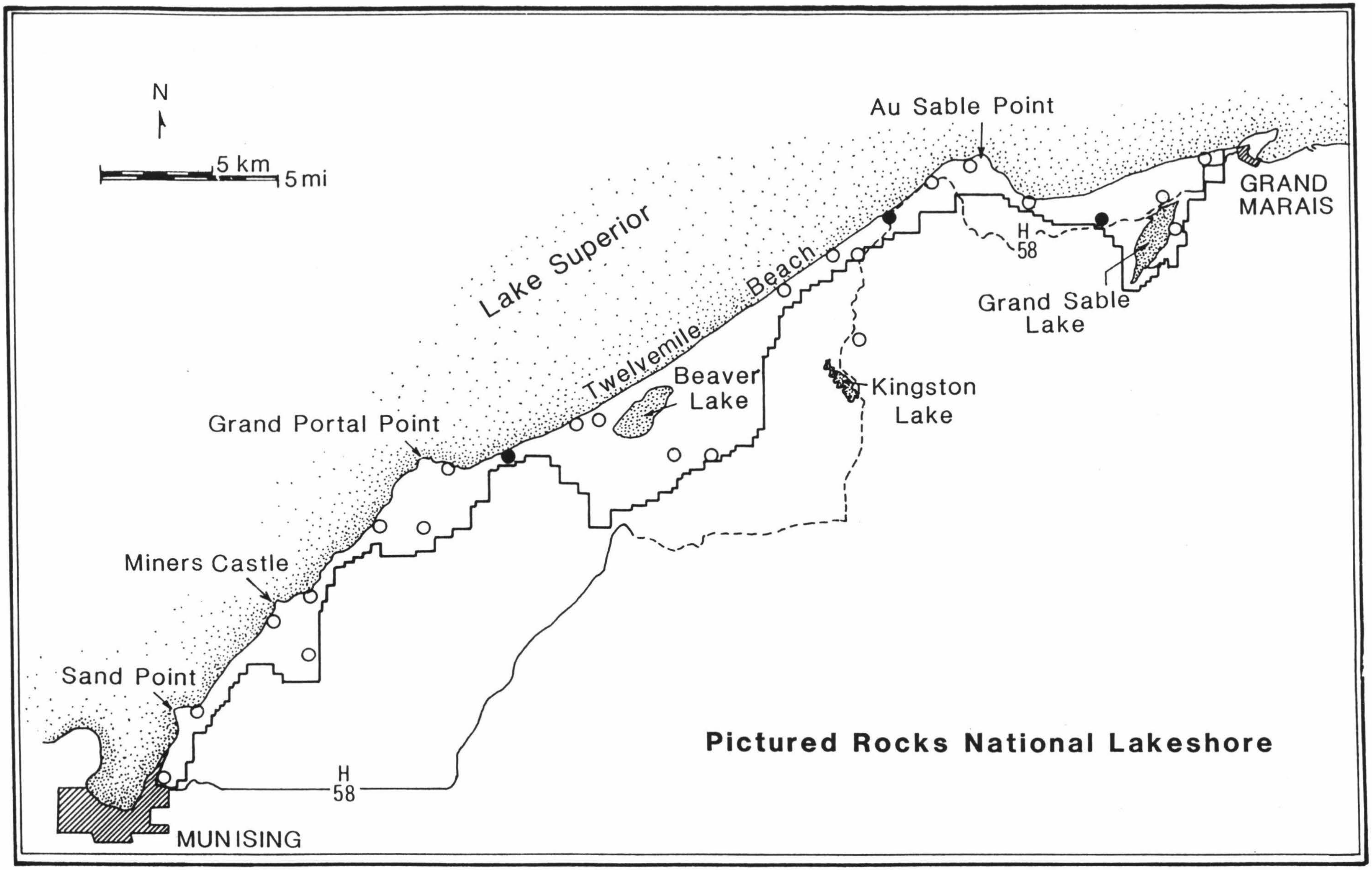


Fig. 8. Distribution of _Lobaria pulmonaria_

Fig. 9. Distribution of <u>Ochrolechia</u> <u>rosella</u>



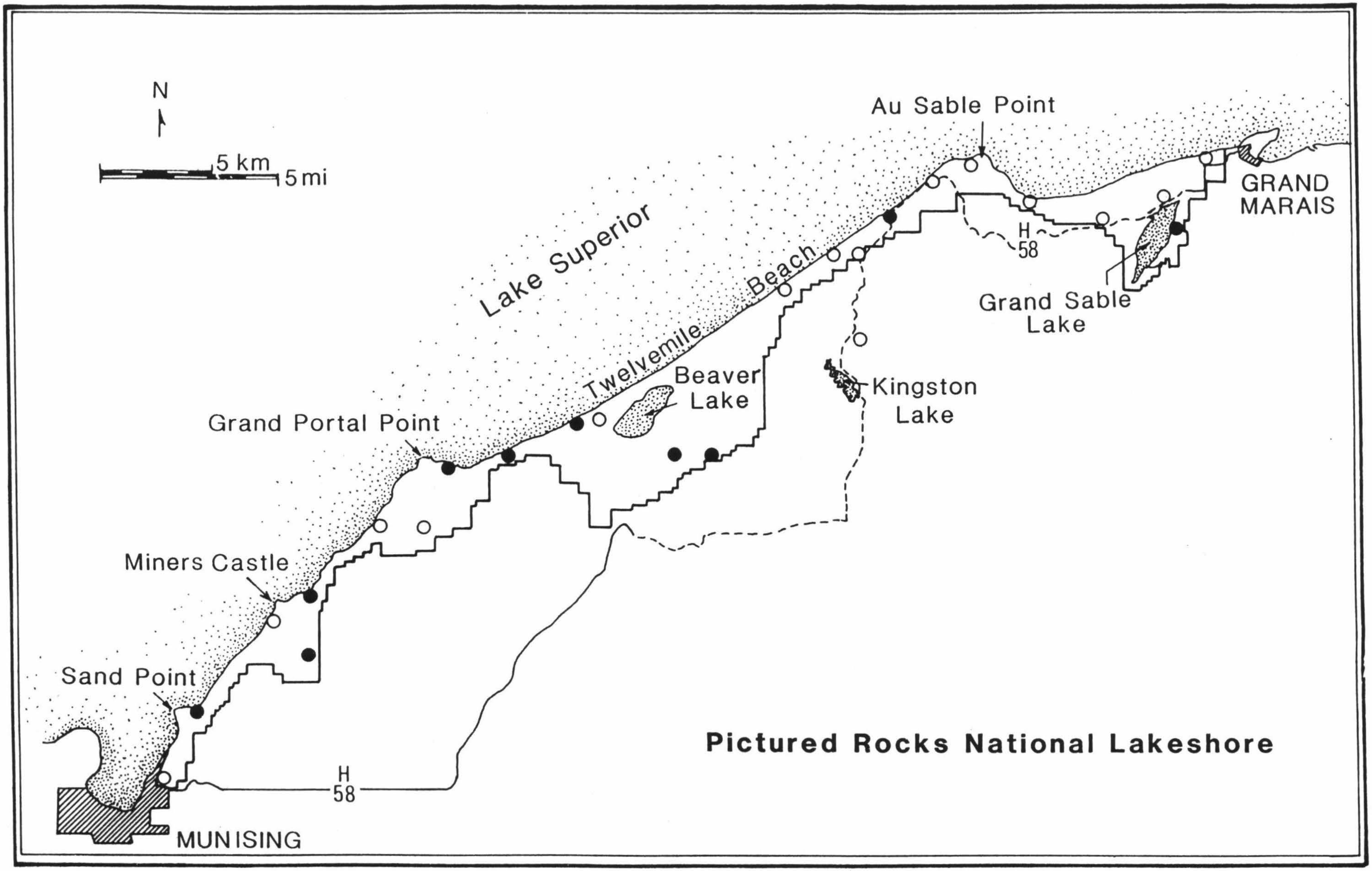


Fig. 10. Distribution of <u>Parmelia squarrosa</u>

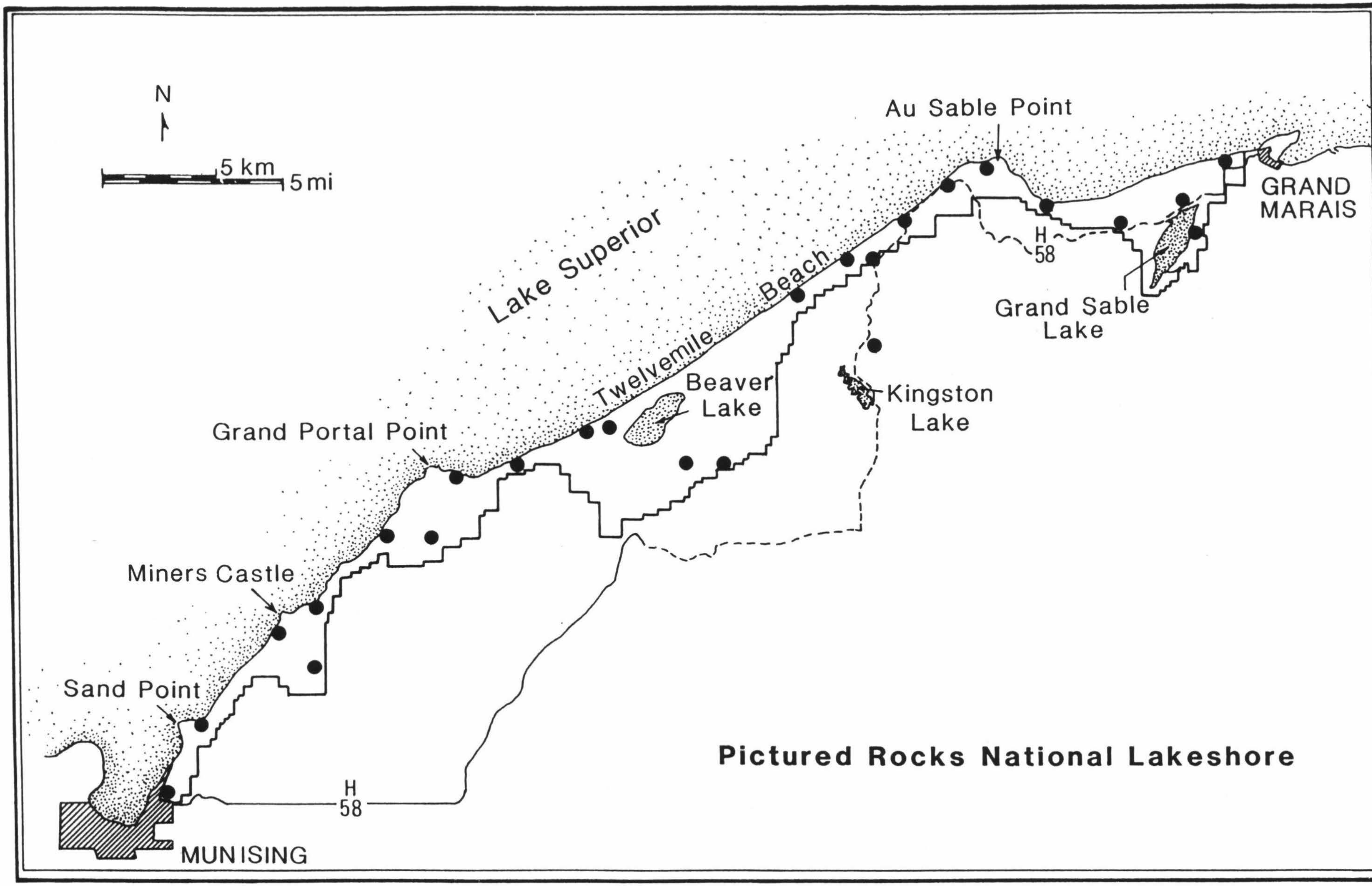


Fig. 11. Distribution of <u>Parmelia subaurifera</u>

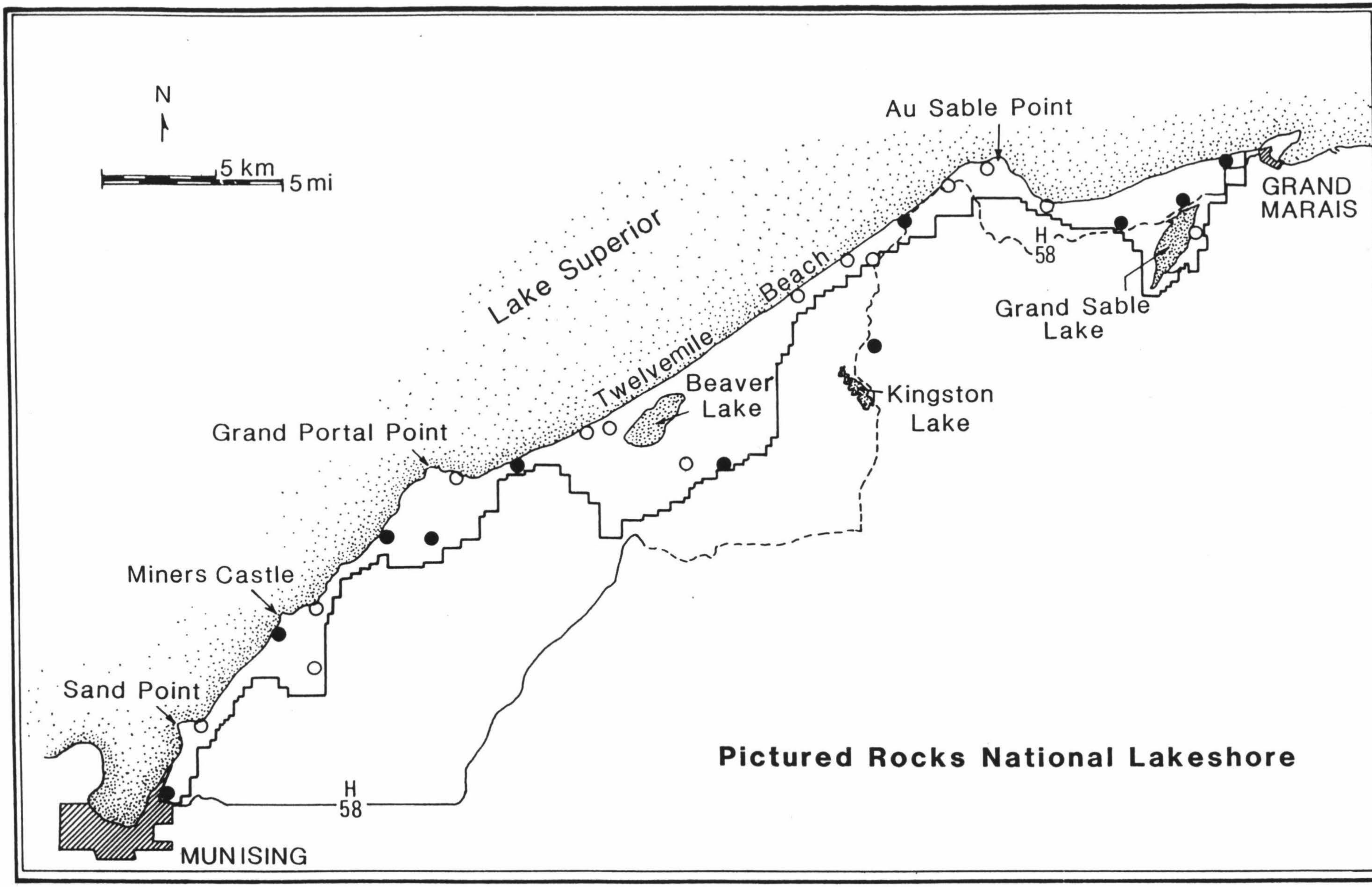


Fig. 12. Distribution of *Ramalina americana*

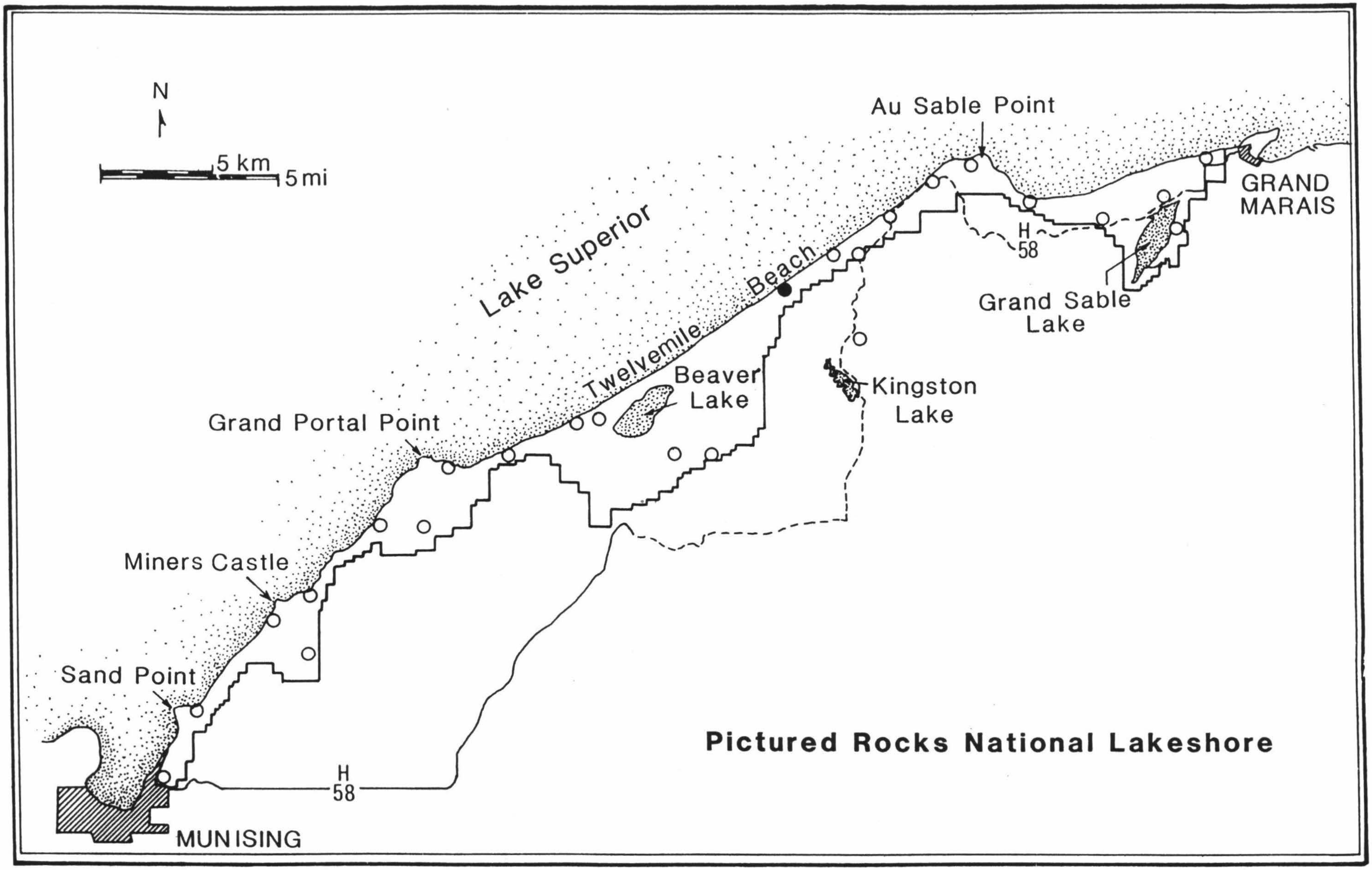


Fig. 13. Distribution of *Usnea ceratina*

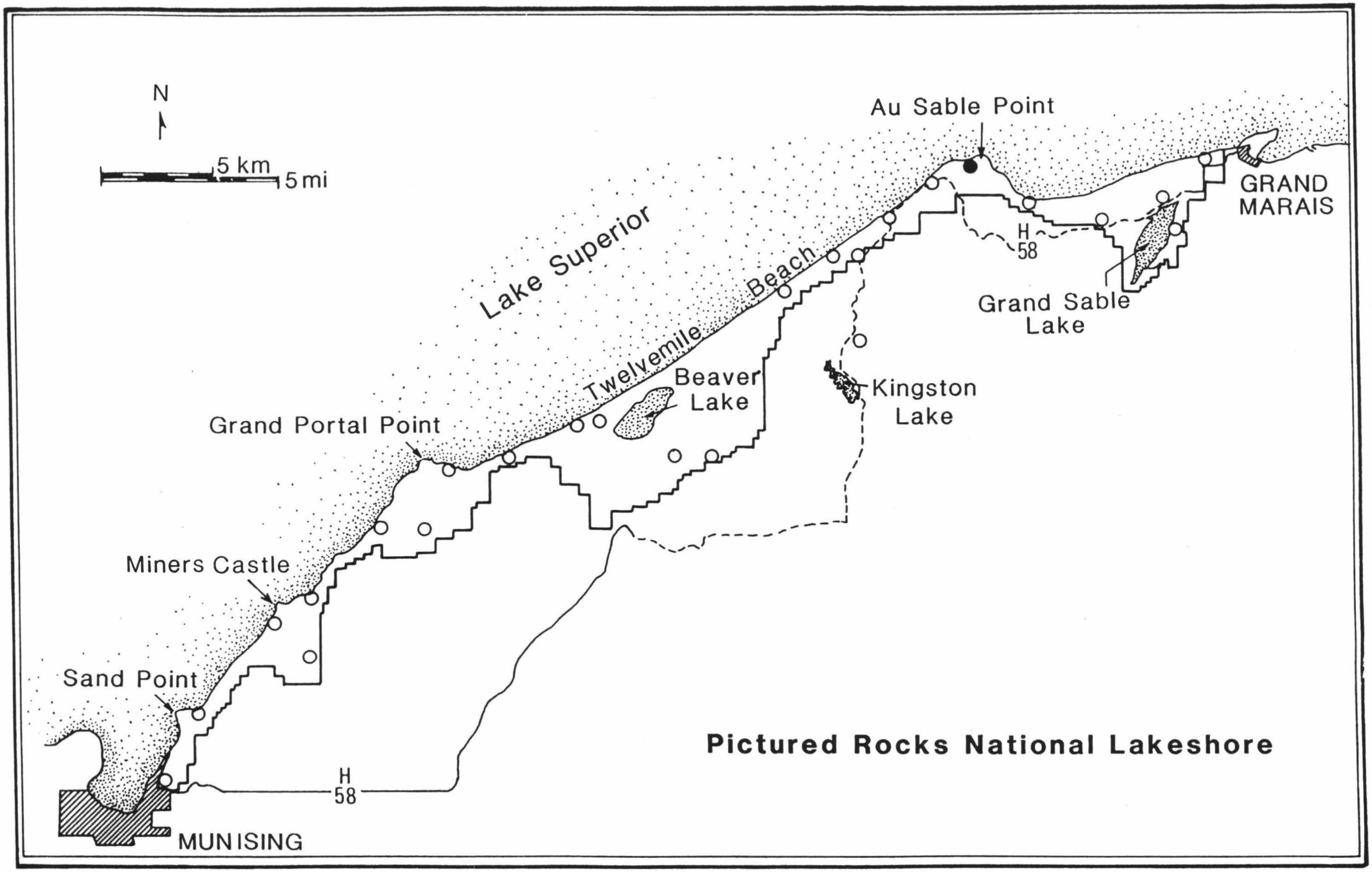


Fig. 14. Distribution of *Usnea fillipendula*