Working

LICHENS AND AIR QUALITY IN

SLEEPING BEAR DUNES NATIONAL LAKESHORE

FINAL REPORT

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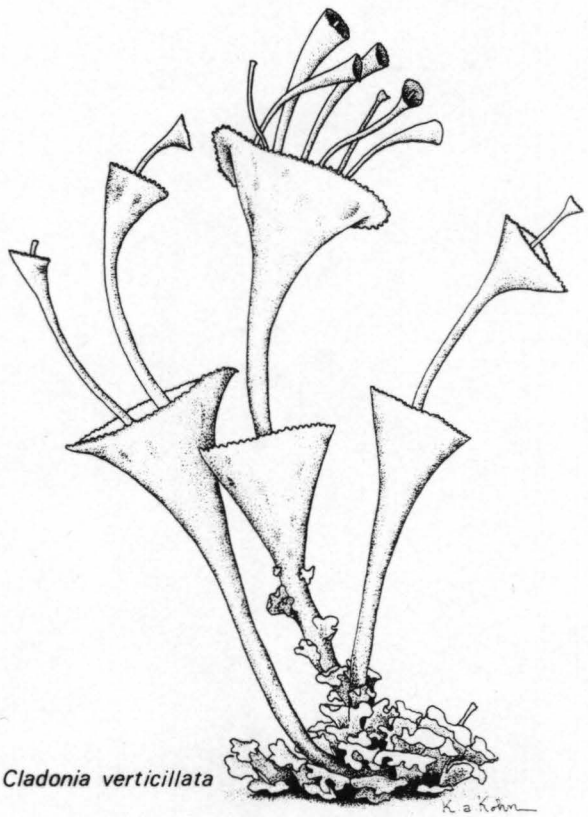

Cladonia verticillata

CLIFFORD M. WETMORE
BOTANY DEPARTMENT
UNIVERSITY OF MINNESOTA
ST. PAUL, MN 55108

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IN
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Final Report

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

National Park Service - AIR
P. O. Box 25287
Denver, Colo. 80225

and

Chief Scientist, Midwest Region
1709 Jackson St.
Omaha, Neb. 68102

by

Clifford M. Wetmore
Botany Department
University of Minnesota
St. Paul, Minnesota

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LICHENS OF SLEEPING BEAR DUNES 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 Sleeping Bear Dunes 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 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 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.

Sleeping Bear Dunes NL is located along the eastern shore of northern Lake Michigan west of Traverse City. The park is comprised of three areas along the Lake Michigan shore and also North Manitou and South Manitou Islands. The mainland shore extends from the shore with the dunes back inland to hardwood forests and abandoned farmlands. The foredunes range from lake level to the highest at Sleeping Bear that is over 450 feet above the lake. These active foredune areas have moving sand and few lichens. Behind the foredunes and on the secondary dunes there is less sand movement and the vegetation is of scattered balsam poplar (Populus balsamifera), juniper (Juniperus communis and Juniperus horizontalis), various shrub cherries (Prunus spp.) and jack pines (Pinus banksiana). On the older undisturbed dunes a mixed hardwood forest is developed with sugar maple (Acer saccharum), red maple (Acer rubrum), basswood (Tilia americana), and beech (Fagus grandifolia) with dense shade and poor lichen growth. Along some of the streams and smaller lakes bogs have developed with black ash (Fraxinus nigra), white cedar (Thuja occidentalis) and willows (Salix spp.). There are many abandoned farms and

orchards in the park and some scattered gravel pits.

The only lichens known from the park were included in a technical report by Armentano, et al. (1985) where they reported 23 species. There may also be a few scattered collections in the Michigan herbaria. There is no published lichen flora for this section of the state but Harris (1978) provided keys to the lichens of the five counties immediately bordering the Mackinac Straits and noted some species from a wider area but the locality information provided is not precise enough for comparison with Sleeping Bear Dunes.

METHODS

Field work was done during June and July, 1987 when 847 collections were made at 27 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. 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 and the reports by Armentano, et al. (1985). The species reported by Armentano, et al. but not found by me are enclosed in brackets. Species found only once are indicated by "Rare". In the first columns the letters indicate the sensitivity to sulfur dioxide, if known, according to the categories proposed by Wetmore (1983): S=Sensitive, I=Intermediate, T=Tolerant. S-I is intermediate between Sensitive and Intermediate and I-T is intermediate between Intermediate and Tolerant. Species in the Sensitive category are absent when annual average levels of sulfur dioxide are above 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 fuscata (Nyl.) Arn.
[Anaptychia palmulata (Michx.) Vain. (Armentano et al, 1985)]
S-I Anaptychia setifera Räs. (Armentano et al., 1985)
I Anisomeridium biforme (Borr.) R. Harris
Anisomeridium nyssaegenum (Ell. & Ev.) R. Harris Rare
Arthonia caesia (Flot.) Körb.
Arthonia fuliginosa (Schaer.) Flot. Rare
I Arthonia radiata (Pers.) Ach.
Arthothelium spectabile Flot. ex Mass. Rare
Bacidia bagliettoana (Mass. & De Not.) Jatta Rare
Bacidia circumspecta (Nyl. ex Vain.) Malme Rare
Bacidia naegelii (Hepp) Zahlbr. Rare
Bacidia schweinitzii (Tuck.) Schneid.
Bacidia suffusa (Fr.) Schneid. Rare
S Bryoria furcellata (Fr.) Brodo & Hawksw. Rare
Buellia arnoldii Serv.
T Buellia punctata (Hoffm.) Mass.
Buellia schaereri De Not.
I Buellia stillingiana Steiner
Calicium abietinum Pers. Rare
Calicium trabinellum (Ach.) Ach. Rare
S-I Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr.
Caloplaca chrysophthalma Degel.
S Caloplaca flavorubescens (Huds.) Laund.
I Caloplaca holocarpa (Hoffm.) Wade
Caloplaca pollinii (Mass.) Jatta Rare
S-I Candelaria concolor (Dicks.) B. Stein (Armentano et al., 1985)
Candelaria fibrosa (Fr.) Müll. Arg.
Candelariella effloresçens R. Harris & Buck
I Candelariella vitellina (Hoffm.) Müll. Arg. Rare
Catillaria nigroclavata (Nyl.) Schuler
Catinaria laureri (Hepp ex Th. Fr.) Degel. Rare
Cetraria arenaria Kärnef.
Cetraria fendleri (Nyl.) Tuck.
Cetraria halei W. & C. Culb.
I Cetraria orbata (Nyl.) Fink Rare
I Cetraria pinastri (Scop.) Gray Rare
I Chaenotheca ferruginea (Turn. ex Sm.) Mig. Rare
Chaenothecopsis savonica (Räs.) Tibell Rare
Cladina mitis (Sandst.) Hustich
Cladina rangiferina (L.) Nyl.
Cladina stellaris (Opiz) Brodo
Cladonia acuminata (Ach.) Norrl.
Cladonia bacillaris Nyl.
Cladonia bacilliformis (Nyl.) Glück Rare
Cladonia caespiticia (Pers.) Flörke Rare
Cladonia cariosa (Ach.) Spreng. Rare
Cladonia cenotea (Ach.) Schaer. Rare
Cladonia chlorophaea (Flörke ex Somm.) Spreng.
I Cladonia coniocraea (Flörke) Spreng.

Cladonia crispata (Ach.) Flot.
I Cladonia cristatella Tuck.
Cladonia cryptochlorophaea Asah.
Cladonia deformis (L.) Hoffm. Rare
Cladonia digitata (L.) Hoffm. Rare
S-I Cladonia fimbriata (L.) Fr.
Cladonia gracilis (L.) Willd.
Cladonia grayi G. K. Merr. ex Sandst.
Cladonia macilenta Hoffm. Rare
Cladonia multiformis G. K. Merr. Rare
Cladonia parasitica (Hoffm.) Hoffm. Rare
Cladonia phyllophora Ehrh. ex Hoffm.
Cladonia pleurota (Flörke) Schaer.
Cladonia polycarpoides Nyl.
Cladonia pyxidata (L.) Hoffm.
Cladonia ramulosa (With.) Laundon
Cladonia rei Schaer.
Cladonia squamosa (Scop.) Hoffm.
Cladonia symphycarpa (Ach.) Fr.
Cladonia turgida Ehrh. ex Hoffm.
Cladonia uncialis (L.) Web. ex Wigg.
Cladonia verticillata (Hoffm.) Schaer.
Collema limosum (Ach.) Ach. Rare
Collema tenax (Sw.) Ach. Rare
Cyphelium tigillare (Ach.) Ach.
I Evernia mesomorpha Nyl.
I Graphis scripta (L.) Ach. (Armentano et al., 1985)
Gyalecta truncigena (Ach.) Hepp Rare
Haematomma pustulatum Brodo & W. Culb. Rare
Heterodermia obscurata (Nyl.) Trev. Rare
Hypocenomyce anthracophila (Nyl.) James & G. Schneid. Rare
Hypocenomyce friesii (Ach. in Lilj.) James & G. Schneid.
I Hypocenomyce scalaris (Ach. ex Lilj.) Choisy
I Hypogymnia physodes (L.) Nyl.
I Imshaugia aleurites (Ach.) S. F. Meyer Rare
Imshaugia placorodia (Ach.) S. F. Meyer
Julella fallaciosa (Stizenb. ex Arn.) R. Harris
I Lecanora allophana Nyl.
Lecanora caesiorubella Ach. subsp. caesiorubella
Lecanora hybocarpa (Tuck.) Brodo
Lecanora meridionalis Magn.
I Lecanora pallida (Schreb.) Rabenh. var. pallida
Lecanora pallida var. rubescens Imsh. & Brodo
Lecanora polytropa (Hoffm.) Rabenh. Rare
I Lecanora pulicaris (Pers.) Ach.
I Lecanora saligna (Schrad.) Zahlbr. Rare
Lecanora sambuci (Pers.) Nyl.
Lecanora strobilina (Spreng.) Kieff.
I Lecanora symmicta (Ach.) Ach.
Lecanora thysanophora Harris ined.
1 additional unidentified species of Lecanora
Lecidea erratica Körb. Rare
1 additional unidentified species of Lecidea
Lecidella euphorea (Flörke) Hert.

Lepraria finkii (B. de Lesd. in Hue) R. Harris
1 additional unidentified species of Lepraria
Leptorhaphis epidermidis (Ach.) Th. Fr.
S Lobaria pulmonaria (L.) Hoffm. Rare
Micarea melaena (Nyl.) Hedl. Rare
Micarea peliocarpa (Anzi) Coppins & R. Sant.
1 unidentified species of Microglaena
Mycocalicium subtile (Pers.) Szat. Rare
Ochrolechia arborea (Kreyer) Almb.
S-I Opegrapha varia Pers. Rare
Pachyospora verrucosa (Ach.) Mass.
Pachyphiale fagicola (Hepp ex Arn.) Zw. Rare
Parmelia aurulenta Tuck.
Parmelia bolliana Müll. Arg. (Armentano et al., 1985)
I Parmelia caperata (L.) Ach.
Parmelia crinita Ach. (Armentano et al., 1985)
Parmelia cumberlandia (Gyeln.) Hale Rare
I Parmelia exasperatula Nyl. Rare
Parmelia flaventior Stirt. (Armentano et al., 1985)
Parmelia hypoleucites Nyl.
I Parmelia olivacea (L.) Ach. Rare
I Parmelia rudecta Ach. (Armentano et al., 1985)
I Parmelia septentrionalis (Lynge) Ahti Rare
Parmelia soredica Nyl.
S Parmelia squarrosa Hale
I-T Parmelia subargentifera Nyl.
(S) Parmelia subaurifera Nyl. (Armentano et al., 1985)
I Parmelia subrudecta Nyl.
Parmelia subtinctoria Zahlbr. Rare
I-T Parmelia sulcata Tayl. (Armentano et al., 1985)
Peltigera canina (L.) Willd.
Peltigera didactyla (With.) Laundon
Peltigera elisabethae Gyeln.
Peltigera evansiana Gyeln.
Peltigera lepidophora (Nyl. ex Vain.) Bitter
Peltigera polydactyla (Neck.) Hoffm. Rare
Peltigera praetextata (Flörke ex Somm.) Zopf Rare
Peltigera rufescens (Weis.) Humb.
I Pertusaria amara (Ach.) Nyl.
Pertusaria macounii (Lamb) Dibb.
Pertusaria velata (Turn.) Nyl. Rare
Phaeocalicium curtisii (Tuck.) Tibell Rare
[Phaeophyscia adiastola (Essl.) Essl. (Armentano et al. 1985)]
Phaeophyscia cernohorskyi (Nadv.) Essl. Rare
Phaeophyscia chloantha (Ach.) Moberg
Phaeophyscia ciliata (Hoffm.) Moberg (Armentano et al., 1985)
Phaeophyscia hirsuta (Meresch.) Moberg Rare
[Phaeophyscioa hirtella Essl. (Armentano et al, 1985)]
Phaeophyscia imbricata (Vain.) Essl.
I Phaeophyscia orbicularis (Neck.) Moberg Rare
Phaeophyscia pusilloides (Zahlbr.) Essl. Rare
Phaeophyscia rubropulchra (Degel.) Moberg (Armentano et

al., 1985)
I Physcia adscendens (Th. Fr.) Oliv. (Armentano et al., 1985)
I Physcia aipolia (Ehrh. ex Humb.) Fürnr. (Armentano et al., 1985)
Physcia americana G. K. Merr. in Evans & Meyrow.
I Physcia millegrana Degel. (Armentano et al., 1985)
I Physcia stellaris (L.) Nyl. (Armentano et al., 1985)
I Physconia detersa (Nyl.) Poelt (Armentano et al., 1985)
[Pysconia enteroxantha (Nyl.) Poelt (Armentano et al. 1985) Misidentification, probably does not occur in the Great Lakes Region]
Placynthiella icmalea (Ach.) Coppins & James
Placynthiella oligotropha (Laund.) Coppins & James
Platismatia tuckermanii (Oakes) W. & C. Culb.
Porpidia macrocarpa (DC. in Lam. & DC.) Hert. & Schwab
Pyrenula laevigata (Pers.) Arn. Rare
Pyrenula pseudobufonia (Rehm) R. Harris
S Ramalina americana Hale (Armentano et al., 1985)
I Ramalina dilacerata (Hoffm.) Hoffm. Rare
I Rinodina exigua (Ach.) Gray Rare
Rinodina milliaria Tuck. Rare
Rinodina populicola Magn. Rare
Sarcogyne regularis Körb.
I Scoliciosporum chlorococcum (Graewe ex Stenh.) Vezda
Sphinctrina anglica Nyl. Rare
Stereocaulon saxatile Magn.
Thrombium epigaeum (Pers.) Wallr. Rare
Trapelia involuta (Tayl.) Hert.
Trapeliopsis flexuosa (Fr.) Coppins & James
Trapeliopsis granulosa (Ehrh.) Lumbsch.
S-I Usnea hirta (L.) Weber ex Wigg.
S-I Usnea subfloridana Stirt.
Verrucaria glaucovirens Grumm. Rare
Verrucaria muralis Ach.
S-I Xanthoria fallax (Hepp in Arn.) Arn. (Armentano et al., 1985)
I Xanthoria polycarpa (Hoffm.) Rieber (Armentano et al., 1985)

DISCUSSION OF FLORA

This list includes 180 species collected for this study and an additional 4 species reported by Armentano et al. but not found by me. There are also and additional 4 unidentified species, some of which are undescribed. The most common species are Cladina mitis, Cladonia cristatella, Cladonia phyllophora, Evernia mesomorpha, Parmelia flaventior and

Parmelia sulcata. Some of the 4 species reported by Armentano et al. but not found by me are probable misidentifications or were rare and missed in the present study. These rare species may be rare because they require substrates that are rare in the park.

Many of the northern species only occur this far south in very moist habitats, such as in the bogs, where most of the northern species were found. The relatively undisturbed hardwood forests have too dense shade for good lichen growth except for those lichens that can tolerate the shade, can tolerate the drier habitats in the tree tops, or where there are canopy openings for increased light. The species requiring more light were often found in open farmyards or abandoned orchards and disturbed areas. Although the forests were mostly logged, most of the present forests are mature and it is unlikely that the logging influence still persists on the lichen flora.

The woodlands on stabilized dunes near shore with open jack pines were especially good for lichens. Many species were collected from the trees and on the ground in these habitats. Even the balsam poplar trees behind Sleeping Bear Dune were almost covered with lichens. In these localities the open aspect of the forest provided good lichen habitats. Similar open habitats were the farmyards and abandoned orchards.

There were few rocks in the park but several lichens were found on rocks and concrete around gravel pits and abandoned farms.

This list of species presents the first listing of lichens for the park and includes some species rare this far south in the Great Lakes Region.

An interesting tabulation indicates the uniqueness of different localities in the park. In the following list the numbers in the first column indicate the number of species that were only found once in the park at that particular locality (these are the species that are indicated by "Rare" in the species list). The second column is 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 #	
4	- 1	2 miles S of Empire at gravel pit
7	- 2	3 mi S of Empire at Esch Road
0	- 3	NE of Bass Lake at Trails End
6	- 4	NW of Little Platte L
2	- 5	Platte Point
3	- 6	1 mile S of Platte River Point
3	- 7	W end of Long L, N of Crystal L
4	- 8	N end of North Bar L, in bog
2	- 9	E of Sleeping Bear Dune
1	- 10	1.5 miles W of Burdickville, S shore of Glen L
0	- 11	1.5 miles S of Glen Lake Narrows
2	- 12	Sleeping Bear Point 1 mile NW of Glen Haven
1	- 13	1 mile S of Glen Haven, at farmsite
1	- 14	S edge of Glen Arbor, S of cemetery
1	- 15	W of Tucker L
1	- 16	3.5 miles NE of Glen Arbor
6	- 17	Northern tip of Pyramid Point
2	- 18	1 mile W of Shell L
1	- 19	4 miles NE of Glen Arbor, W of Bass L
2	- 20	S Manitou Isl., center
2	- 21	S Manitou Isl., NW of ranger station
2	- 22	S Manitou Isl., 1 mi SW of ranger station
2	- 23	Good Harbor Bay, SE of Shalda Creek
3	- 24	Good Harbor Bay, N of Little Traverse L
0	- 25	Good Harbor Bay, E of Good Harbor Creek
1	- 26	W of Empire Bluffs, S of Empire
0	- 27	2 miles NE of Empire at Voice Road

The locality with the highest number is 3 miles south of Empire at Esch Road closely followed by localities northwest of Little Platte Lake and at the northern tip of Pyramid Point. Localities with Thuja as at the Esch Road location are always rich in species. The other two localities have open jack pines with old logs and stumps that provide 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.

The lichen flora is reasonably diverse for this part of Michigan. 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.

Only some 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 these two most sensitive categories are as follows with the sensitivity category indicated in the first column.

S-I Anaptychia setifera Räs.
S-I Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr.
S Caloplaca flavorubescens (Huds.) Laund.
S-I Candelaria concolor (Dicks.) B. Stein
S-I Cladonia fimbriata (L.) Fr.
S Lobaria pulmonaria (L.) Hoffm.
S Parmelia squarrosa Hale
S-I Parmelia subaurifera Nyl.
S Ramalina americana Hale
S-I Usnea hirta (L.) Weber ex Wigg.
S-I Usnea subfloridana Stirt.
S-I Xanthoria fallax (Hepp in Arn.) Arn.

The distributions of these species are mapped Fig. 2-13. 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.

Three species of lichens were collected for elemental analysis at several localities in the park. At some localities all species were not present in quantities needed for the analysis.

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, and Hypogymnia physodes ~~and Evernia~~ mesomorpha on trees. These species were selected because they are locally present in abundance and relatively easy to clean.

Five localities were selected for elemental analysis and are indicated on the map of collection localities. These localities are: NW of Little Platte Lake, 4 miles NE of Glen Arbor west of Bass Lake, center of South Manitou Island, NW of ranger station on South Manitou Island, and Good Harbor Bay southeast of Shalda Creek. 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. Some replicates of each species were ground before being divided for analysis and are so marked 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 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

Table 1. Analysis of Sleeping Bear Dunes Lichens
Values in ppm of thallus

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
C. rangiferina	354	1528	557	307	151	140	22.9	20.6	18.1	1.6	5.4	2.3	#	0.2	0.2	530	N Little Platte L
C. rangiferina	370	1461	507	296	175	161	24.0	18.2	18.7	1.7	5.2	3.1	#	0.2	0.2	670	N Little Platte L
C. rangiferina	363	1516	556	315	153	148	19.2	24.7	18.8	1.7	5.4	3.4	#	0.3	0.2	750	N Little Platte L
C. rangiferina	399	1668	681	320	232	204	10.4	16.2	16.4	1.7	5.8	*0.8	#	0.2	0.2	660	E of Glen Arbor
C. rangiferina	373	1500	646	315	332	298	12.8	19.6	15.8	1.6	7.2	1.4	#	0.4	0.3	710	E of Glen Arbor
C. rangiferina	432	1736	723	344	248	227	12.0	17.9	17.0	1.7	7.0	1.8	#	0.2	0.3	550	E of Glen Arbor
C. rangiferina	364	1538	1470	485	266	263	31.2	14.9	16.3	2.3	5.8	4.1	0.6	0.3	0.2	840	Good Harbor Bay
C. rangiferina	356	1546	1489	497	241	237	30.6	15.0	16.1	2.3	4.6	3.5	0.8	0.4	0.1	740	Good Harbor Bay
C. rangiferina	340	1506	1460	483	257	253	27.6	15.4	16.6	2.3	5.9	3.7	0.3	0.3	0.1	810	Good Harbor Bay
C. rangiferina	370	1524	552	319	263	249	16.9	10.0	17.6	1.8	6.8	3.0	#	0.3	0.2	780	S. Manitou center
C. rangiferina	374	1531	556	326	278	261	16.9	12.9	17.8	1.8	5.7	3.5	#	0.3	0.2	820	S. Manitou center
C. rangiferina	339	1352	544	309	280	275	17.9	8.5	16.7	1.7	5.9	5.0	#	0.3	0.2	1020	S. Manitou center
C. rangiferina	424	1647	654	336	199	202	21.0	12.3	15.7	2.5	2.0	3.6	0.3	0.2	0.2	650	S. Manitou shore @
C. rangiferina	426	1639	642	346	195	185	24.9	11.8	16.4	2.5	2.3	5.5	0.8	0.5	0.3	675	S. Manitou shore @
C. rangiferina	418	1658	653	344	186	179	22.0	11.9	16.3	2.5	2.2	4.4	0.5	0.4	0.2	720	S. Manitou shore @
H. physodes	686	2879	13325	667	438	481	15.7	54.6	91.7	4.6	7.5	22.8	1.1	0.7	1.2	1690	N Little Platte L
H. physodes	665	2891	12960	643	432	490	14.4	51.1	89.2	4.8	7.4	23.4	1.0	0.8	1.1	1740	N Little Platte L
H. physodes	648	2754	11930	652	488	548	15.5	48.6	90.2	5.0	7.8	22.9	1.1	0.7	1.1	1630	N Little Platte L
H. physodes	707	3277	19213	778	277	312	18.9	59.3	70.3	3.7	5.2	23.5	0.8	0.6	1.1	980	S. Manitou shore @
H. physodes	694	3266	17971	766	288	342	19.4	57.2	71.0	3.5	7.0	23.3	1.1	2.1	1.0	1020	S. Manitou shore @
H. physodes	697	3270	18943	773	303	343	23.4	58.8	70.9	3.5	6.1	22.1	0.8	0.6	1.0	1070	S. Manitou shore @

*= 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 Analysis ofSleeping Bear Dunes Lichens
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	362	1502	540	306	159	149	22.0	21.1	18.5	1.7	5.3	2.9	#	0.2	0.2	650	N Little Platte L
Std. dev.	8	36	29	9	13	10	2.5	3.3	0.4	0.1	0.1	0.5	#	<.1	<.1	111	N Little Platte L
Mean	401	1635	683	326	271	243	11.7	17.9	16.4	1.7	6.6	*1.3	#	0.3	0.3	640	E Glen Arbor
Std. dev.	29	121	39	16	54	49	1.2	1.7	0.6	0.1	0.7	0.5	#	0.1	<.1	82	E Glen Arbor
Mean	354	1530	1473	488	255	251	29.8	15.1	16.3	2.3	5.4	3.7	0.5	0.3	0.2	797	Good Harbor Bay
Std. dev.	12	21	15	8	13	13	1.9	0.3	0.3	0.0	0.7	0.3	0.2	0.0	0.1	51	Good Harbor Bay
Mean	361	1469	551	318	274	262	17.2	10.5	17.3	1.8	6.1	3.8	#	0.3	0.2	873	S. Manitou center
Std. dev.	19	101	6	8	9	13	0.6	2.3	0.6	0.1	0.6	1.1	#	<.1	<.1	129	S. Manitou center
Mean	423	1648	650	342	193	189	22.6	12.0	16.1	2.5	2.2	4.5	0.5	0.4	0.2	682	S. Manitou shore @
Std. dev.	5	9	7	5	7	12	2.0	0.3	0.4	<.1	0.2	1.0	0.3	0.1	0.1	35	S. Manitou shore @

Hypogymnia physodes

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	666	2841	12738	654	453	506	15.2	51.5	90.4	4.8	7.6	23.0	1.0	0.7	1.1	1687	N Little Platte L
Std. dev.	19	76	723	12	31	36	0.7	3.0	1.3	0.2	0.2	0.4	<.1	<.1	<.1	55	N Little Platte L
Mean	699	3271	18709	772	289	332	20.6	58.4	70.7	3.6	6.1	23.0	0.9	1.1	1.0	1023	S. Manitou shore @
Std. dev.	7	6	653	6	13	18	2.4	1.1	0.4	0.1	0.9	0.8	0.2	0.9	<.1	45	S. Manitou shore @

*= 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

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 Sleeping Bear lichens are within typical limits for similar lichens. From these tables it can be seen that there is no consistent correlation between element levels and location in the park. 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 530 to 1740 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 two species. Cladina rangiferina has lower levels than Hypogymnia physodes. Even when taking these differences into account there is no clear trend in accumulated levels of sulfur.

All of the other elements show normal levels with no trends of higher concentrations.

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 Sleeping Bear Dunes NL are being damaged by air quality. The lichen flora is reasonably diverse for such an area and there is no impoverishment of the lichen flora in any part of the the park. There are only a few species in the most sensitive category to sulfur dioxide in the park and these are quite rare. This rarity seems to be due more to ecological and climatic conditions than pollution since these species are quite healthy when present. The maps of the distributions of the more sensitive species do not show any significant voids that are not due to normal ecological conditions. There is no evidence of damaged or dead lichens in any area where healthy ones are not also present. The elemental analyses do not show abnormal accumulations of polluting elements at any locality.

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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.

loc #

Leenanau County

1 57864-57908 2 miles south of Empire. Around old gravel pit on west side of highway 22 with some maple and green ash around edges. Sec. 31, T28N, R14W. 29 June 1987. 44°47'08"N 86°02'59"W

Benzie County

2 57909-57968 At lakeshore 3 miles south of Empire at end of Esch Road. Behind foredune in mixed hardwood forest with hemlock, Thuja and pines. Sec. 1, T27N, R15W. 29 June 1987. 44°45'52"N 86°04'29"W

3 57969-57995 NE of Bass Lake at Trails End. Along shore and back from lake in mixed open forest with oaks, aspens and openings. Sec. 13, T27N, R15W. 29 June 1987. 44°44'03"N 86°03'40"W

4 57996-58035 NW of Little Platte Lake at end of Peterson Road. On dunes back from shore with jack pines, white pines and juniper. Sec. 22, TT27N, R15W. 30 June 1987. Chemical analysis. 44°43'44"N 86°06'10"W

5 58036-58085 Platte River Point. Behind first dune and along shore in hardwoods with some pines east of road. Sec. 20, T27N, R15W. 30 June 1987. 44°43'49"N 86°08'56"W

6 58086-58111 1 mile south of Platte River Point at end of Cooper Road. In hardwood forests between low wet areas with alder and Thuja. Sec. 29, T27N, R15W. 30 June 1987. 44°43'08"N 86°09'14"W

7 58112-58133 At west end of Long Lake north of Crystal Lake. In open field north of road with some maples and sumac. Sec. 36, T27N, R16W. 30 June 1987. 44°41'46"N 86°10'57"W

Leelanau County

8 58134-58161 At north end of North Bar Lake (2.5 miles N of Empire). Along edge and in bog with Thuja, black ash, some yellow birch and brush. Sec. 12, T28N, R15W. 1 July 1987.

9 58162-58193 Just east of Sleeping Bear Dune on dunes with juniper and scattered big tooth aspen. Sec. 31, T29N, R14W. 1 July 1987.

10 58194-58209 1.5 miles west of Burdickville on south shore of Glen Lake. On ridgetop in sugar maple and beech forest with some ash and white birch. Sec. 11, T28N, R14W. 1 July 1987.

11 58210-58229 1.5 miles south of Glen Lake narrows. On northwest facing open slope with scattered young sugar maple, juniper and brush. Sec. 15, T28N, R14W. 1 July 1987.

12 58230-58257 Sleeping Bear Point 1 mile northwest of Glen Haven. Near shore of Lake Michigan with jack pines on ridges and swamps in low areas. Sec. 17, T29N, R14W. 2 July 1987. 44°54'41"N 86°02'20"W

13 58258-58293 1 mile south of Glen Haven at former farmsite. In open fields and around open yard trees. Sec. 29, T29N, R14W. 2 July 1987. 44°53'13"N 86°01'26"W

14 58294-58308 At south edge of Glen Arbor south of cemetery. In dense beech-sugar maple forest with a few pines. Sec. 27, T29N, R14W. 2 July 1987. 44°53'09"N 85°59'33"W

15 58309-58328 Just west of Tucker Lake 1 mile east of Glen Arbor. In abandoned field with some sumac. Sec. 24, T29N, R14W. 2 July 1987. 44°54'12"N 85°57'26"W

16 58329-58348 3.5 miles northeast of Glen Arbor. At old gravel pit and around roadside trees. Sec. 12, T29N, R14W. 3 July 1987. 44°56'02"N 85°56'40"W

17 58349-58377 At northern tip of Pyramid Point. On sand cliffs near lake in hardwood forest with beech, maple and some Thuja. Sec. 31, T30N, R13W. 3 July 1987.

18 58378-58403 1 mile west of Shell Lake on Pyramid Point. In old field with some pines, sugar maples and sumac. Sec. 6, T29N, R13W. 3 July 1987. 44°57'13"N 85°54'49"W

19 58404-58433 4 miles northeast of Glen Arbor at boundary of park west of Bass Lake. In apple orchard and abandoned fields. Sec. 7, T29N, R13W. 3 July 1987. Chemical analysis. 44°55'22"N 85°54'52"W

20 58434-58483 South Manitou Island. Near center of island in old orchard and open fields with scattered maples and sumac and juniper. Sec. 4, T30N, R15W. 4 July 1987. Chemical analysis.

21 58484-58526 South Manitou Island. Northwest of ranger station at lighthouse in jack pines back from beach with some Thuja and balsam fir. Sec. 3, T30N, R15W. 5 July 1987. Chemical analysis.

22 58527-58558 South Manitou Island. 1 mile southwest of ranger station and lighthouse near shore in maple-aspen forest with some Thuja. Sec. 10, T30N, R15W. 5 July 1987.

23 58559-58596 Good Harbor Bay southeast of Shalda Creek. Near shore in open jack pines and juniper between road and lake. Sec. 4, T29N, R13W. 7 July 1987. Chemical analysis. 44° 56' 25"N 85° 52' 38"W

24 58597-58637 Good Harbor Bay north of Little Traverse Lake. Back from shore in woods with oaks, pines and openings and some quaking aspens. Sec. 3 & 10, T29N, R13W. 7 July 1987. 44° 56' 11"N 85° 51' 12"W

25 58638-58661 Good Harbor Bay at northeast end of park east of Good Harbor Creek. Near shore in grove of balsam poplar on sand dunes. Sec. 6, T29N, R12W. 7 July 1987. 44° 56' 54"N 85° 48' 32"W

26 58662-58686 West of Empire Bluffs just south of Empire. In openings and along ridge with ash, maple and oak. Sec. 25, T28N, R15W. 8 July 1987. 44° 48' 05"N 86° 03' 55"W

27 58687-58710 2 miles northeast of Empire just north of Voice Road. In old field on hillside with sumac. Sec. 18, T28N, R14W. 8 July 1987. 44° 49' 58"N 86° 02' 16"W

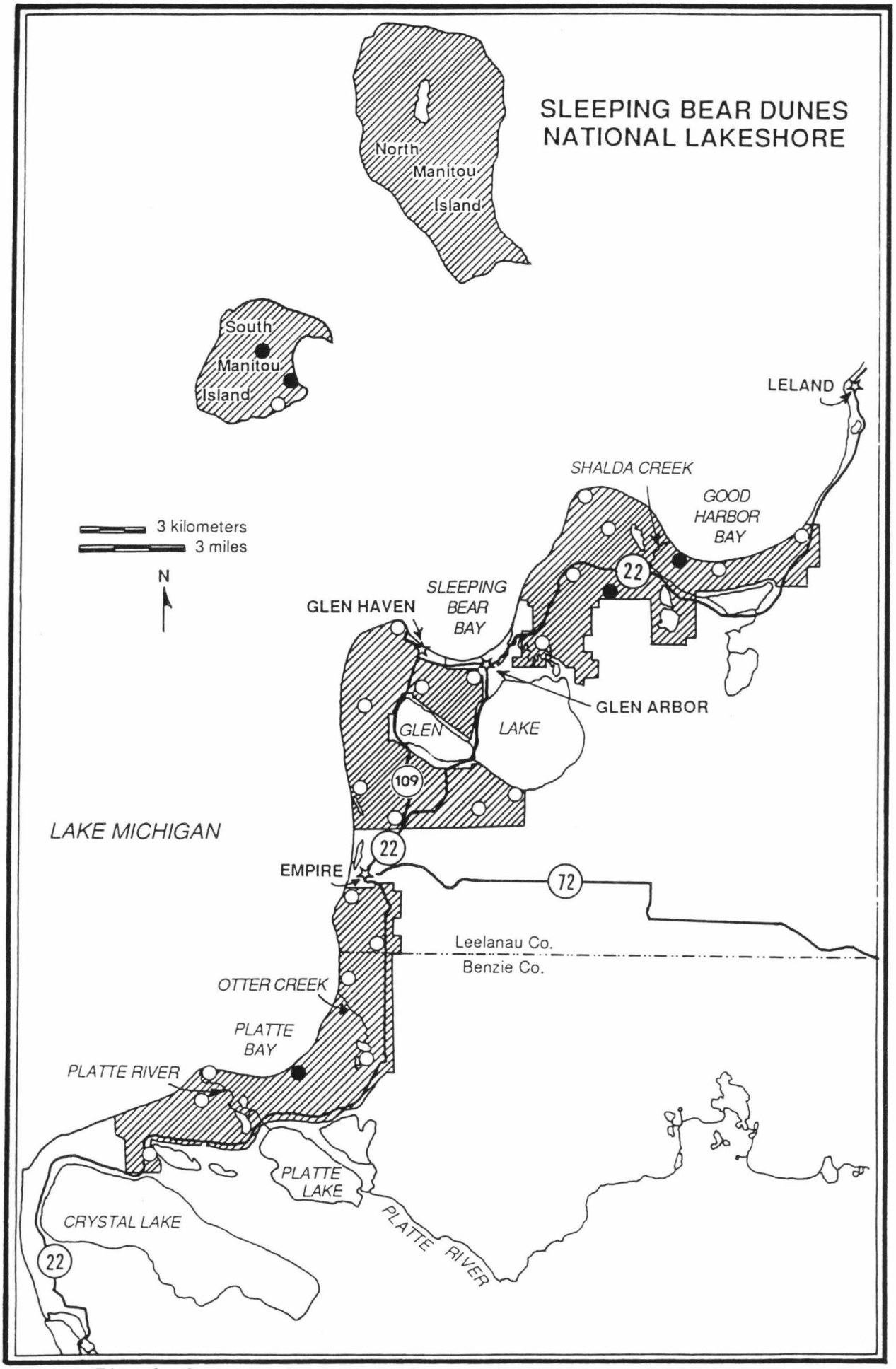

Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities.

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 Sleeping Bear Dunes NL fall within the Sensitive and Sensitive/Intermediate categories 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. The species in both of these categories are mapped.

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

Fig. 2 S-I Anaptychia setifera Räs.
Fig. 3 S-I Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr.
Fig. 4 S Caloplaca flavorubescens (Huds.) Laund.
Fig. 5 S-I Candelaria concolor (Dicks.) B. Stein
Fig. 6 S-I Cladonia fimbriata (L.) Fr.
Fig. 7 S Lobaria pulmonaria (L.) Hoffm.
Fig. 8 S Parmelia squarrosa Hale
Fig. 9 S-I Parmelia subaurifera Nyl.
Fig. 10 S Ramalina americana Hale
Fig. 11 S-I Usnea hirta (L.) Weber ex Wigg.
Fig. 12 S-I Usnea subfloridana Stirt.
Fig. 13 S-I Xanthoria fallax (Hepp in Arn.) Arn.

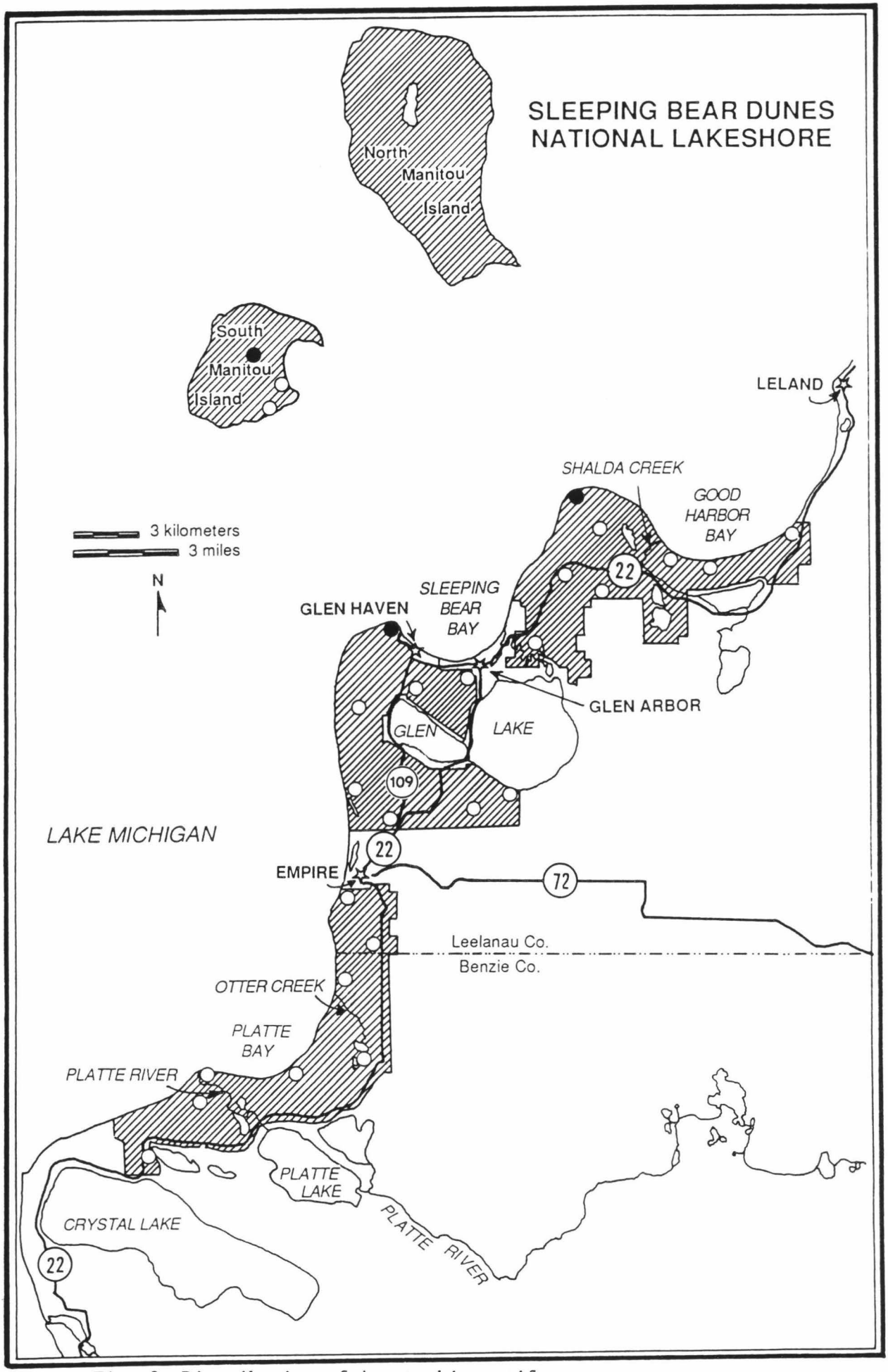

Fig. 2. Distribution of Anaptychia setifera

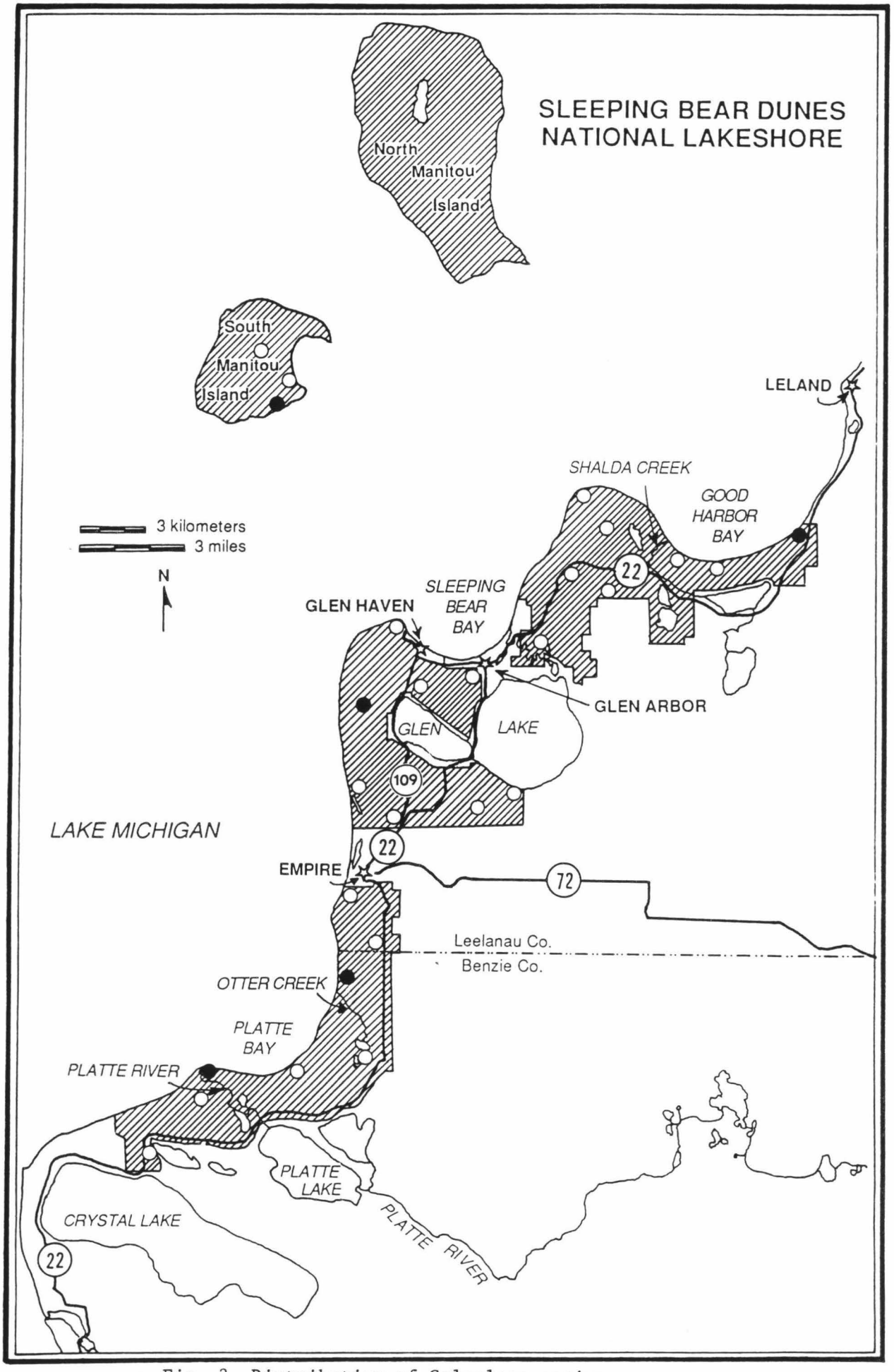

Fig. 3. Distribution of Caloplaca cerina

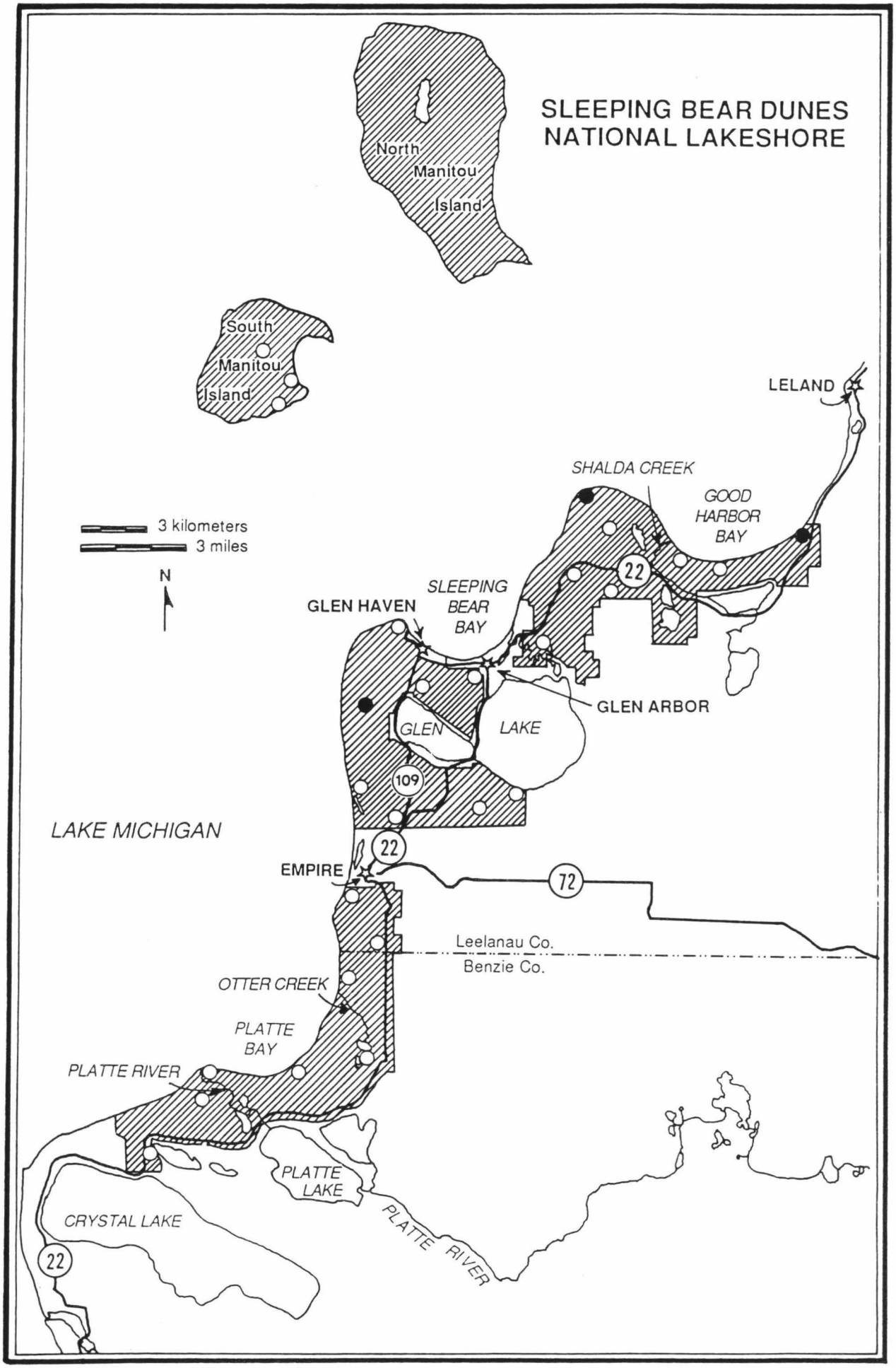

Fig. 4. Distribution of Caloplaca flavorubescens

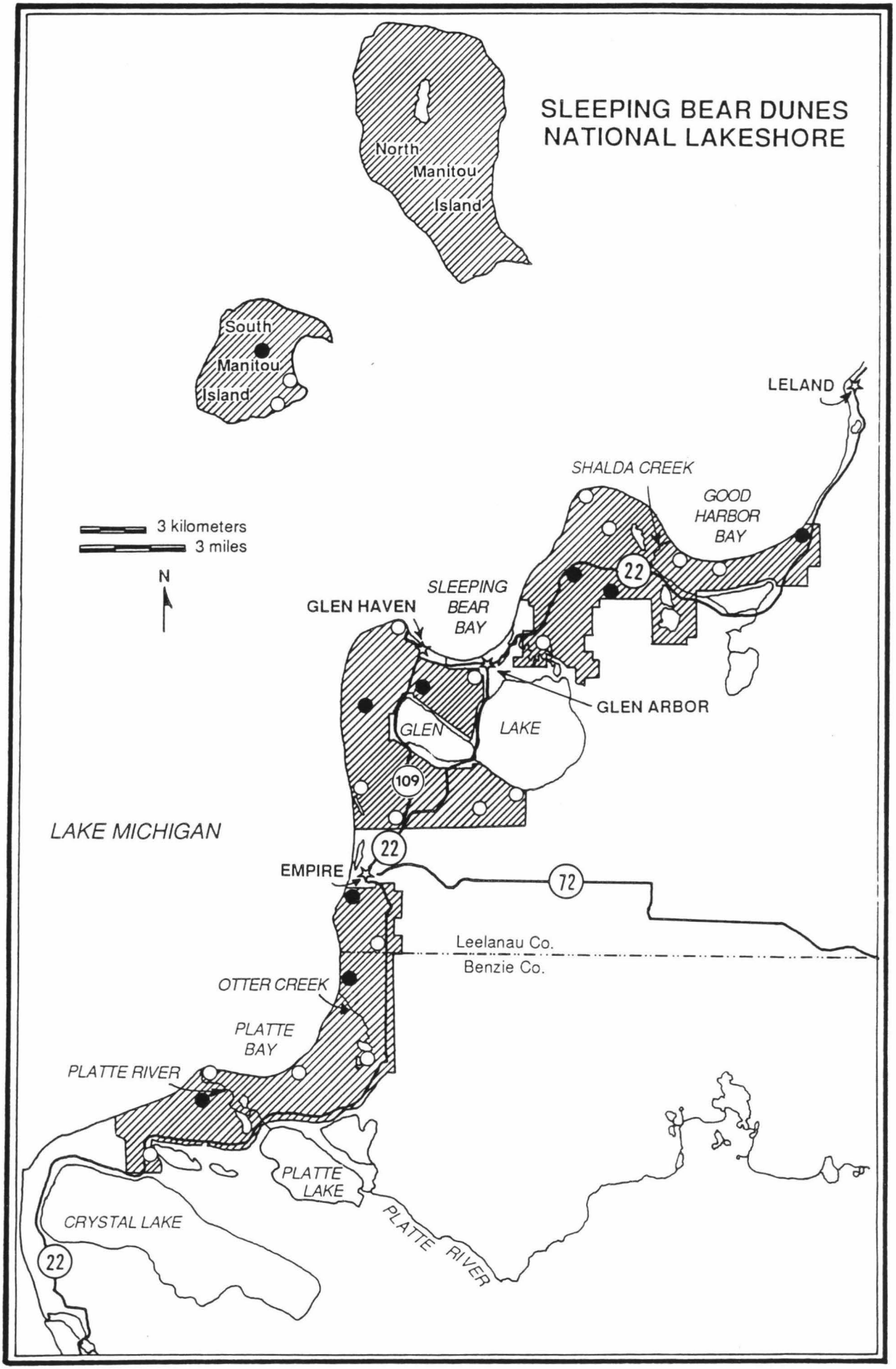

Fig. 5. Distrbution of Candelaria concolor

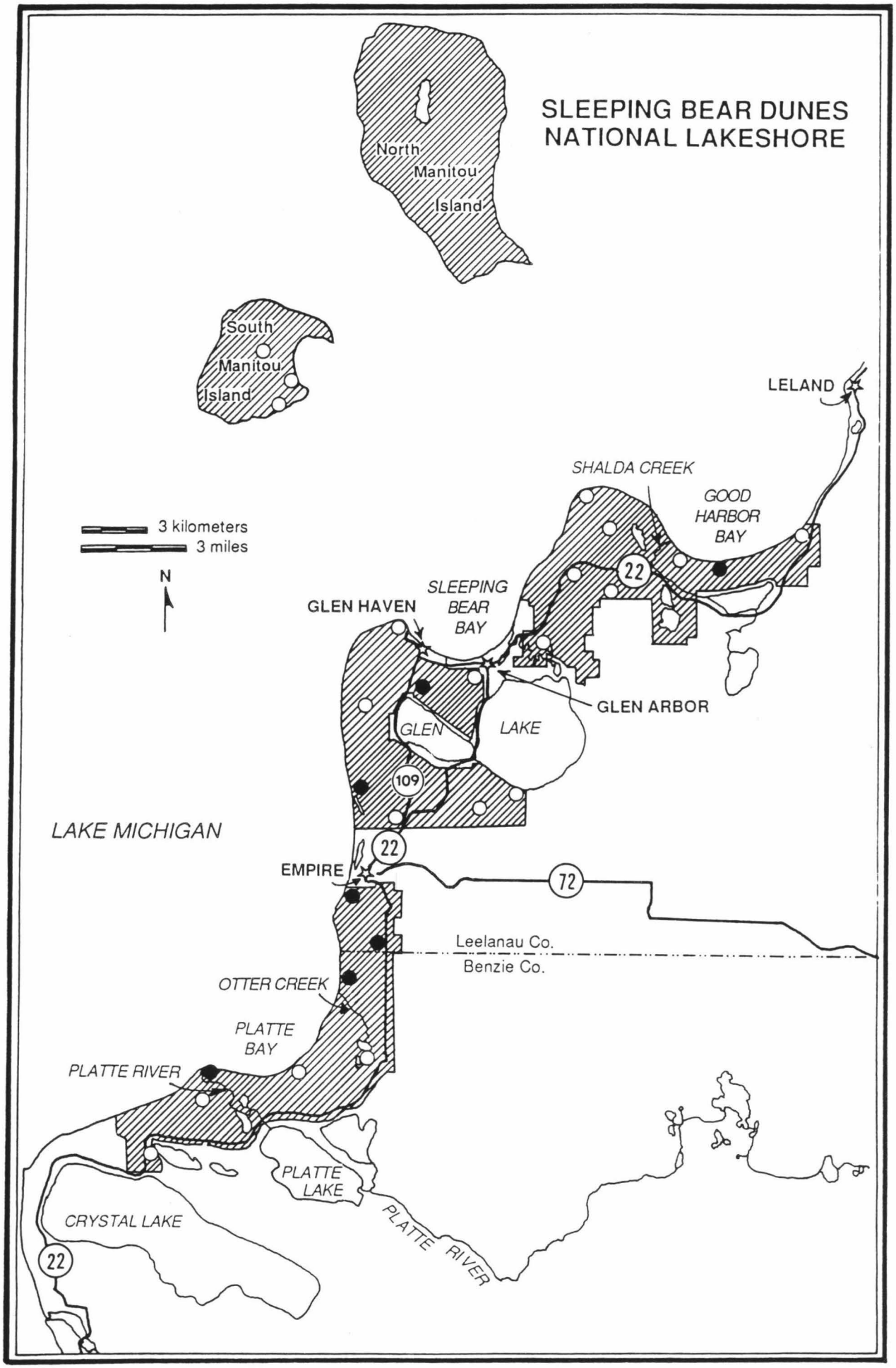

Fig. 6. Distribution of Cladonia fimbriata

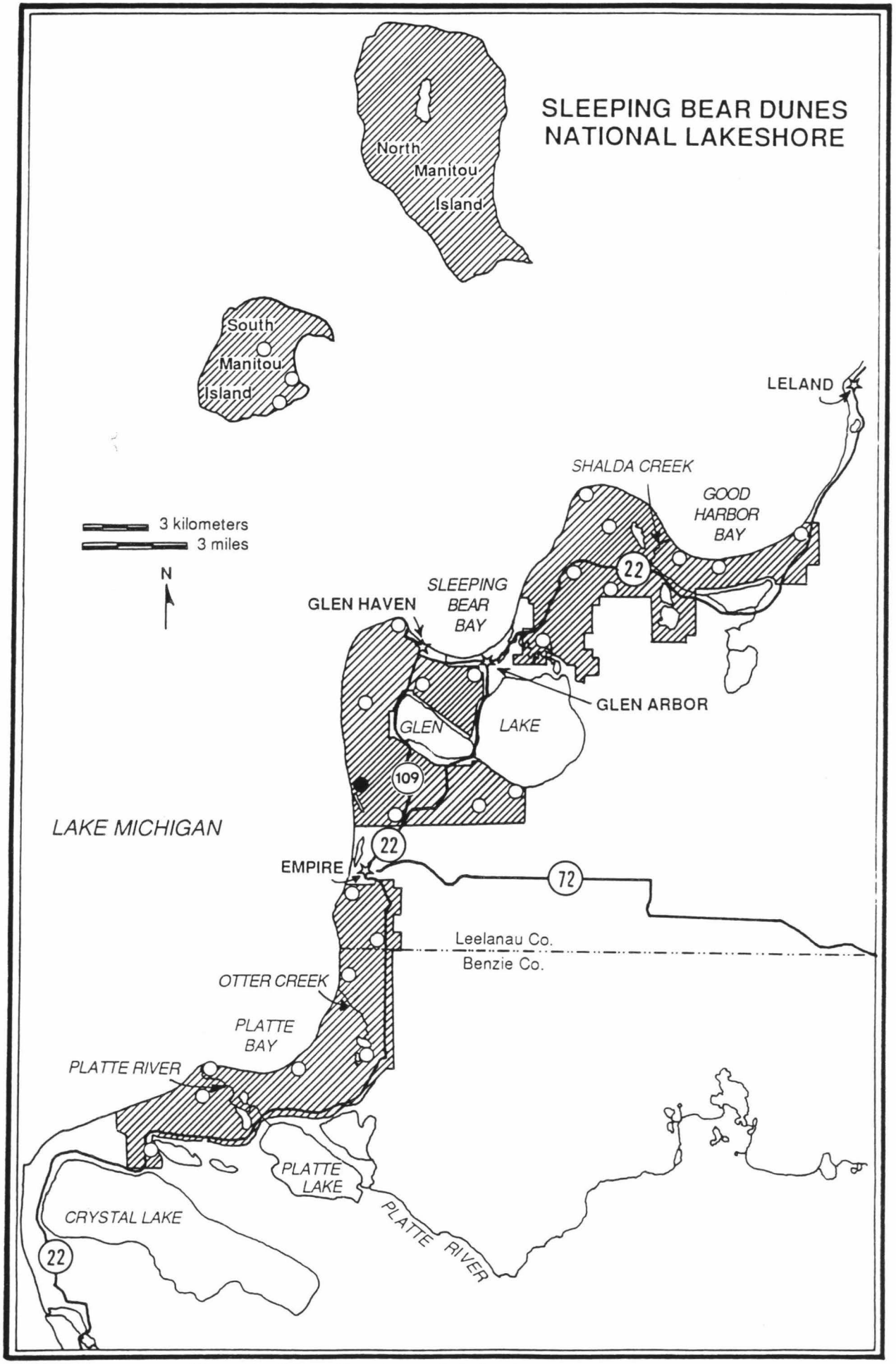

Fig. 7. Distribution of Lobaria pulmonaria

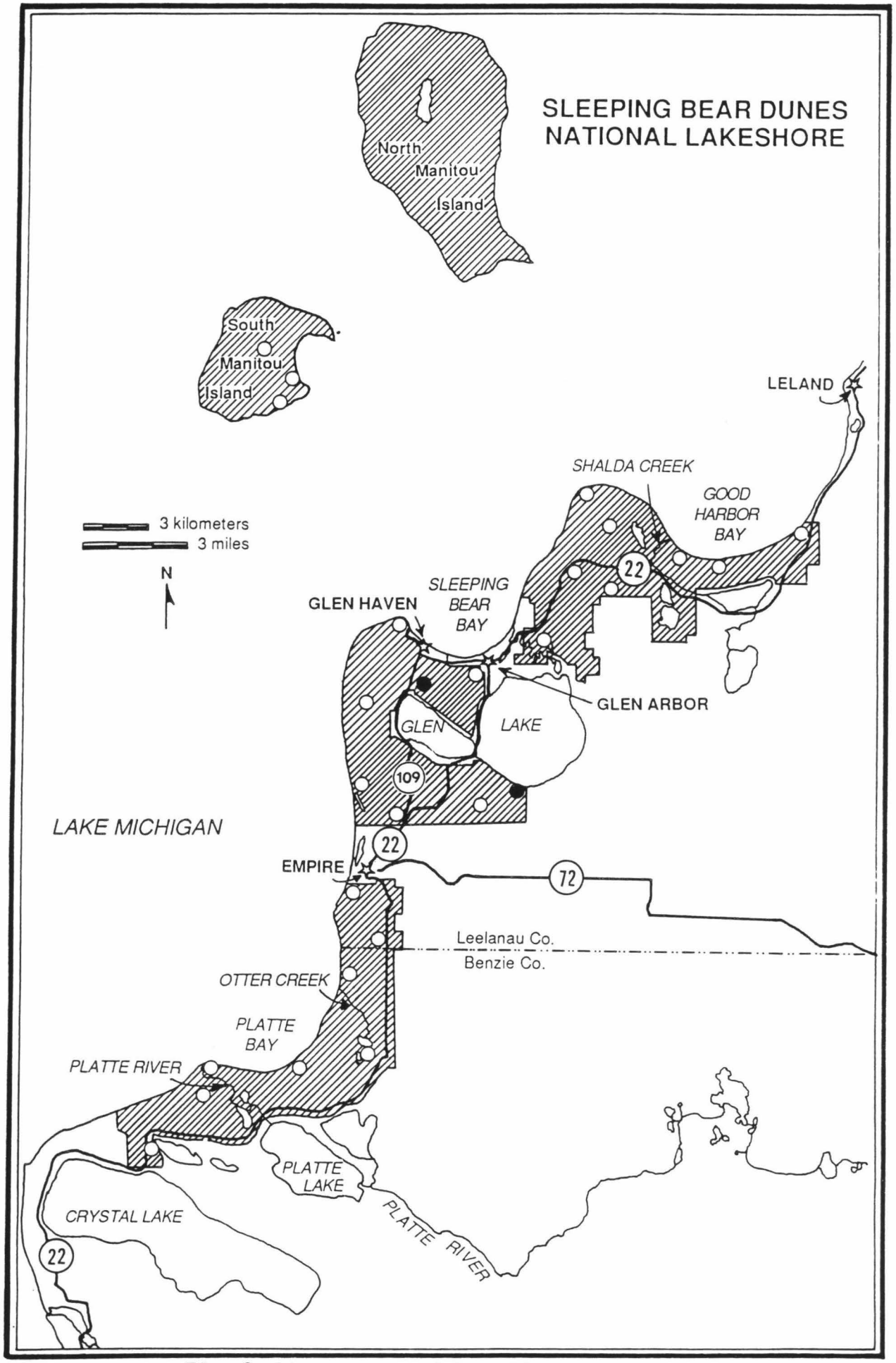

Fig. 8. Distribution of Parmelia squarrosa

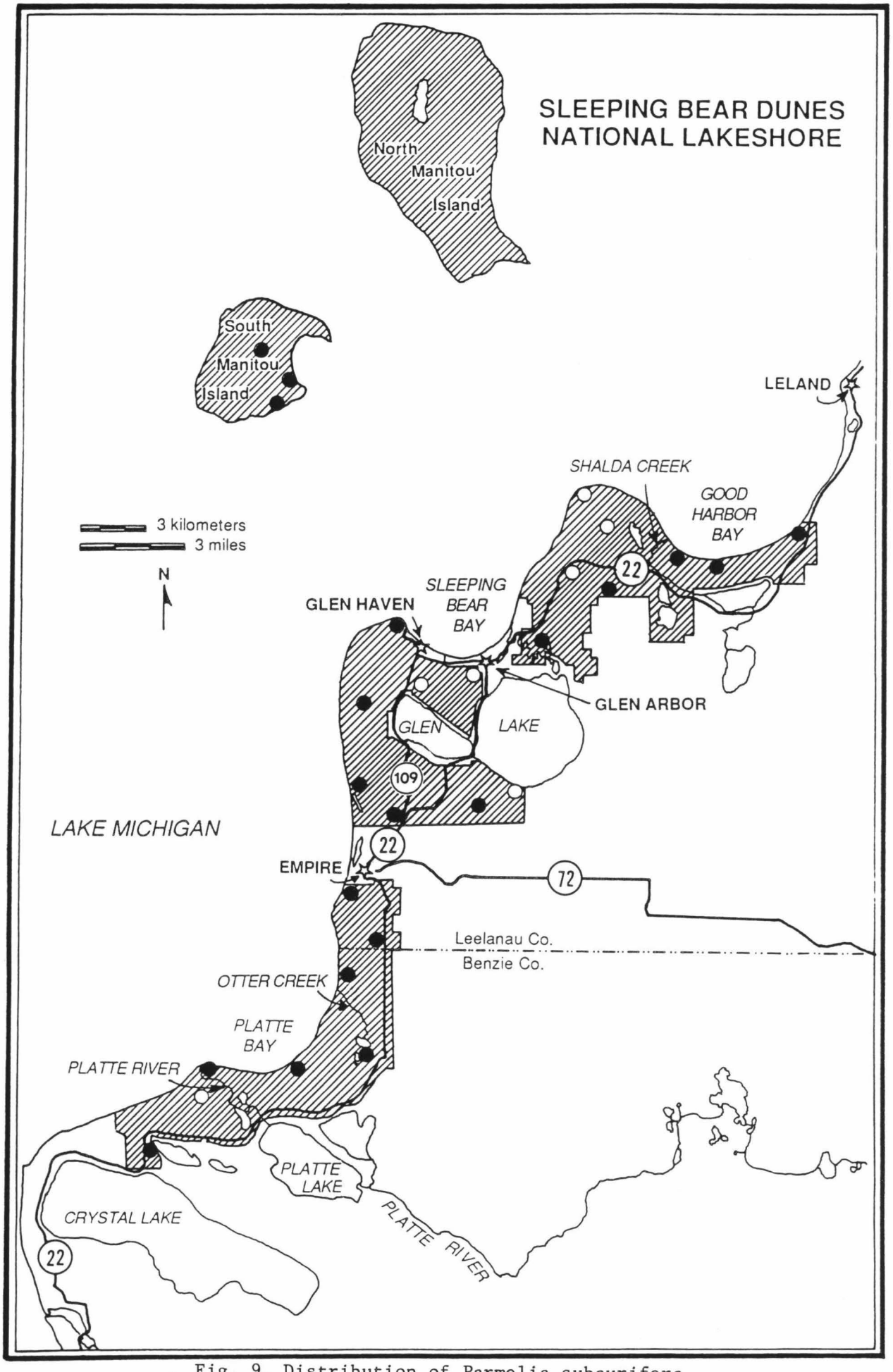

Fig. 9. Distribution of Parmelia subaurifera

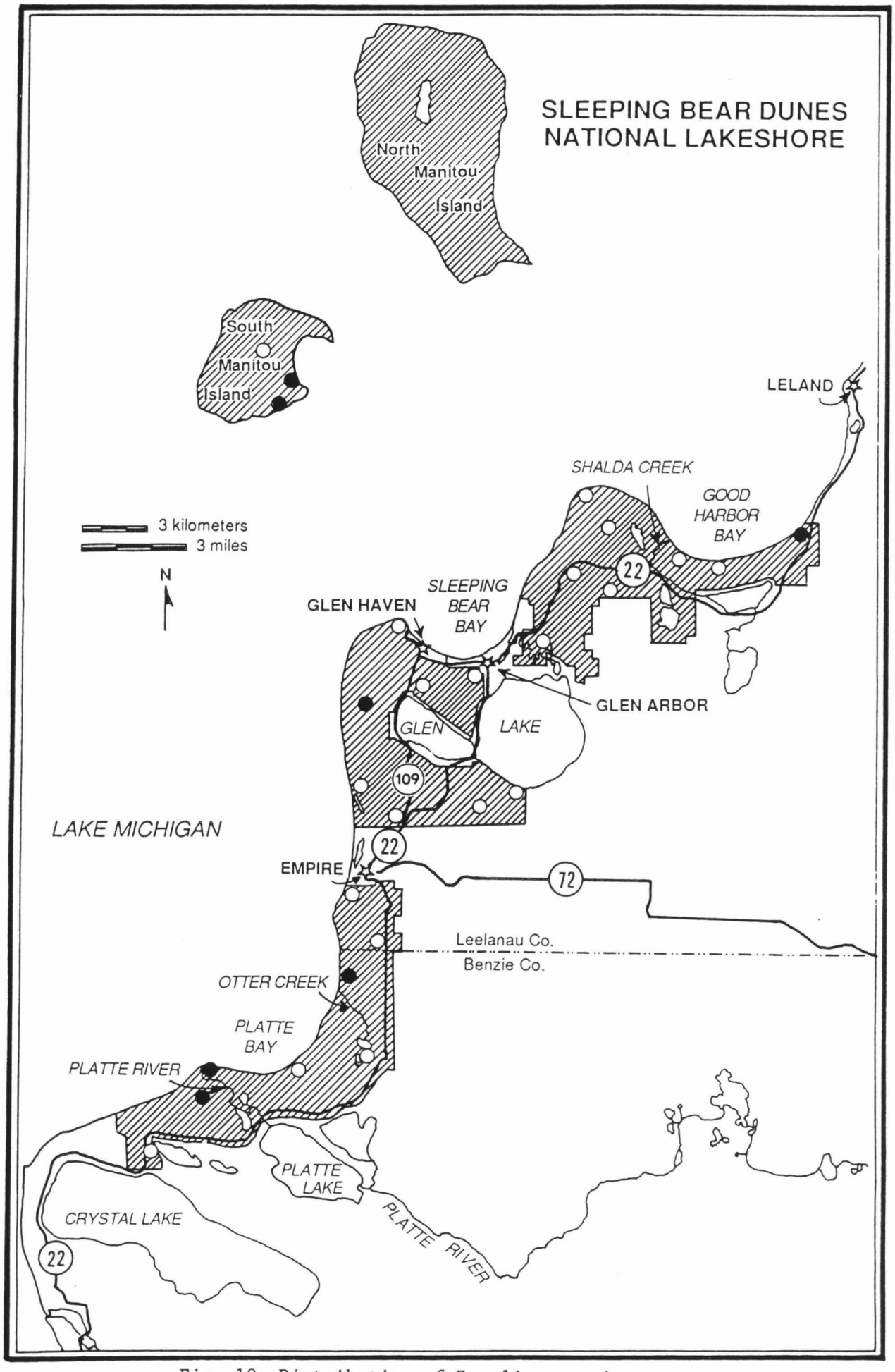

Fig. 10. Distribution of Ramalina americana

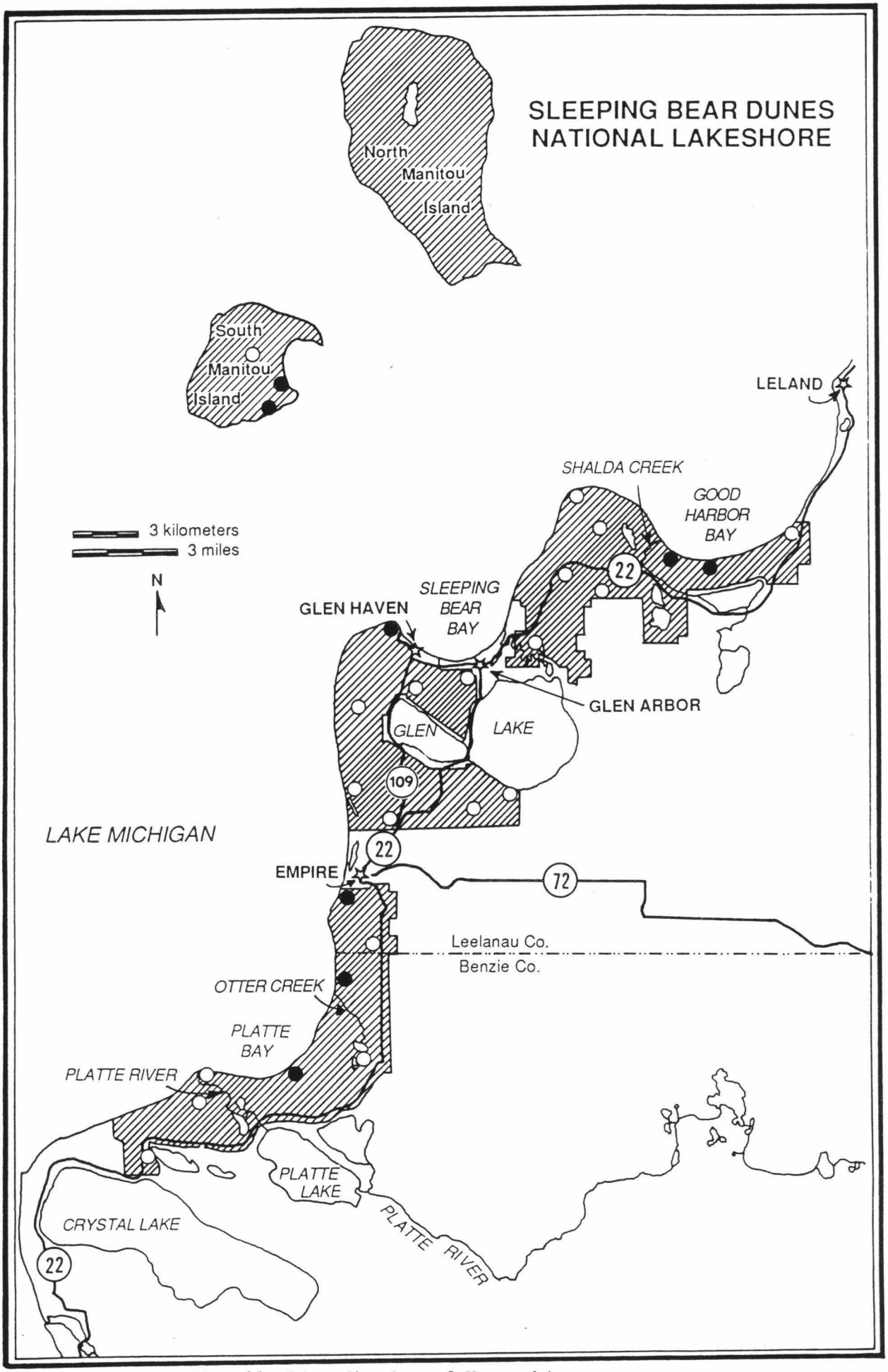

Fig. 11. Distribution of Usnea hirta

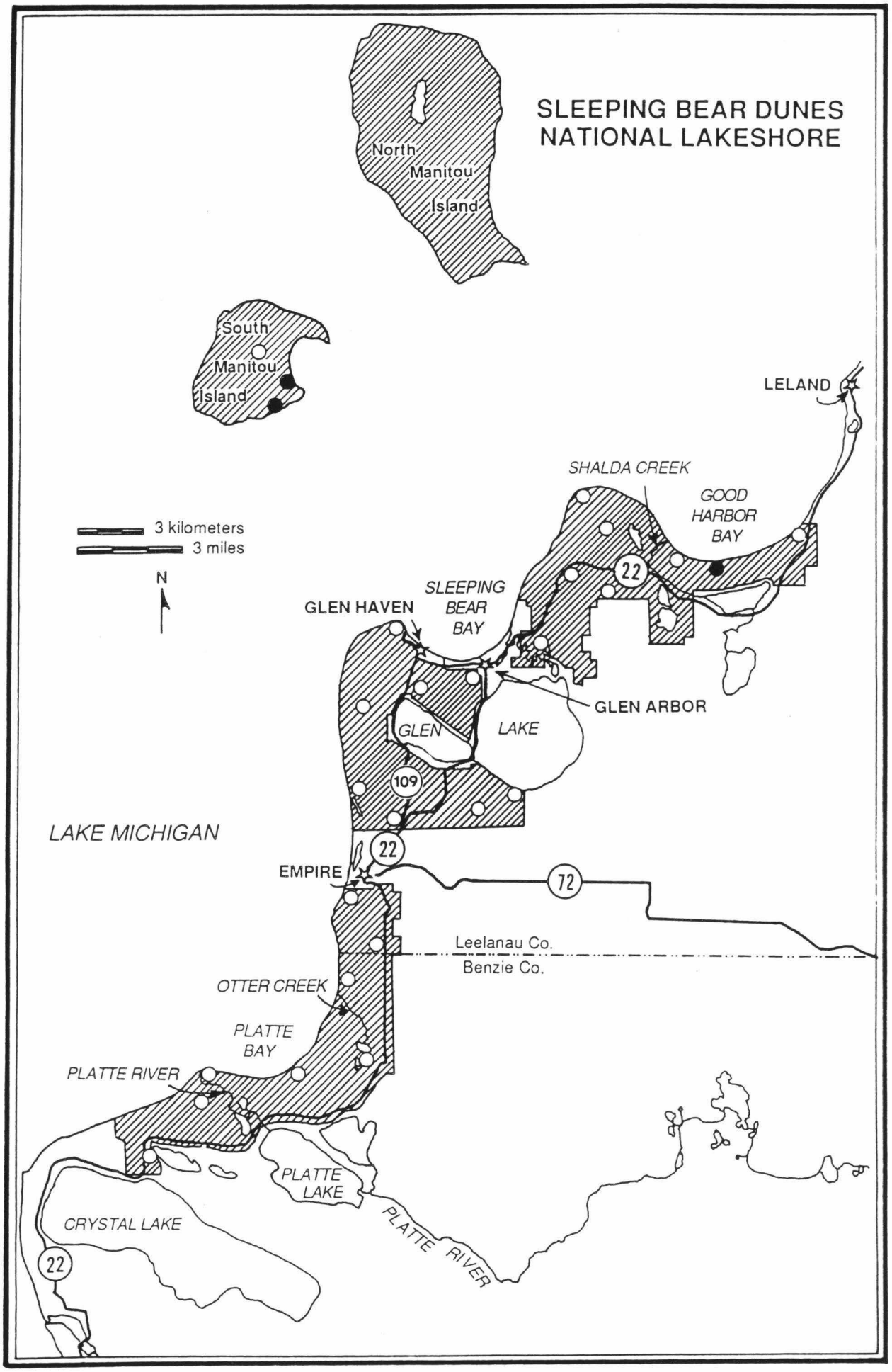

Fig. 12. Distribution of Usnea subfloridana

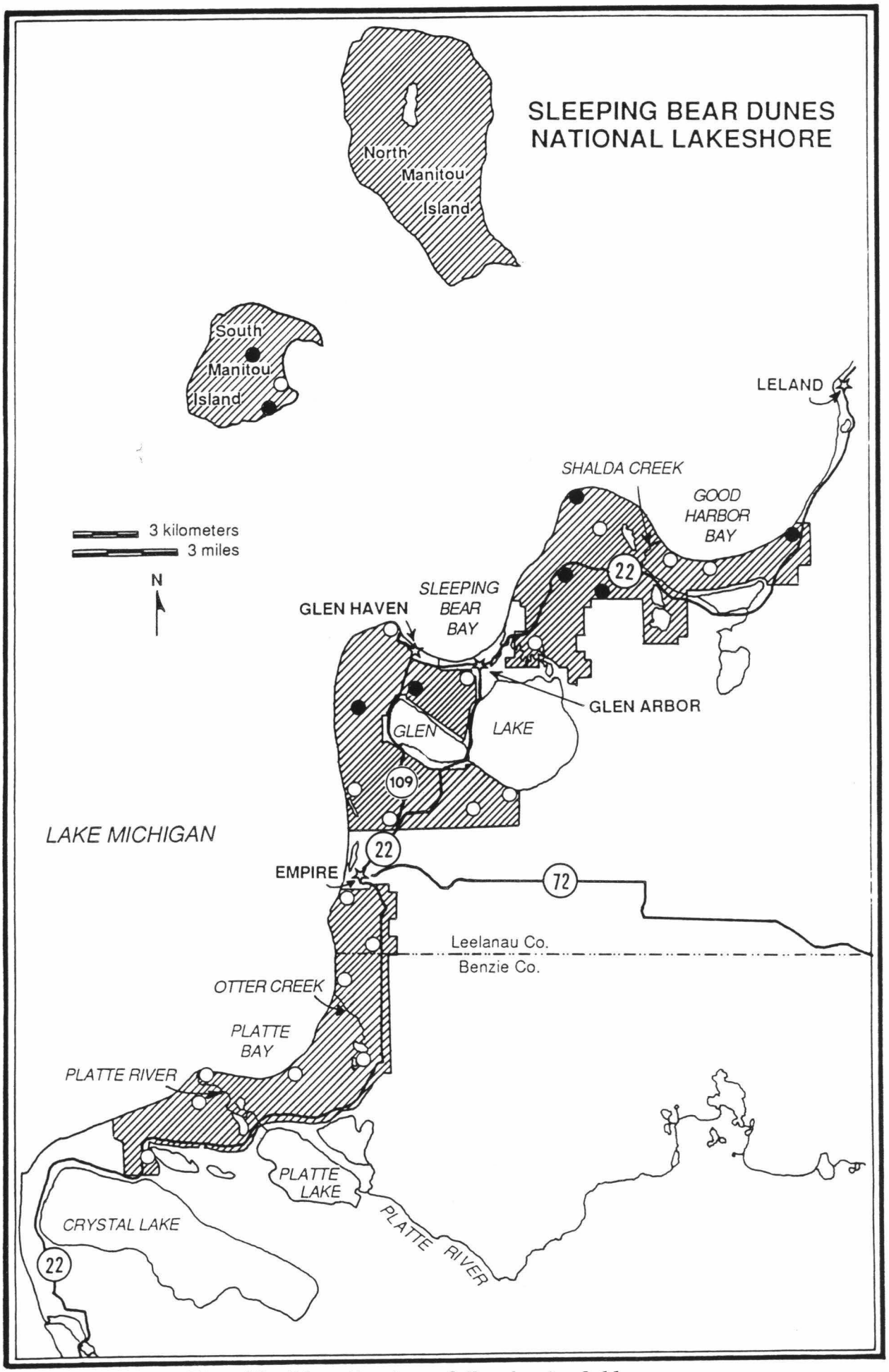

Fig. 13. Distribution of Xanthoria fallax