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LICHENS AND AIR QUALITY IN INDIANA DUNES NATIONAL LAKESHORE

FINAL REPORT

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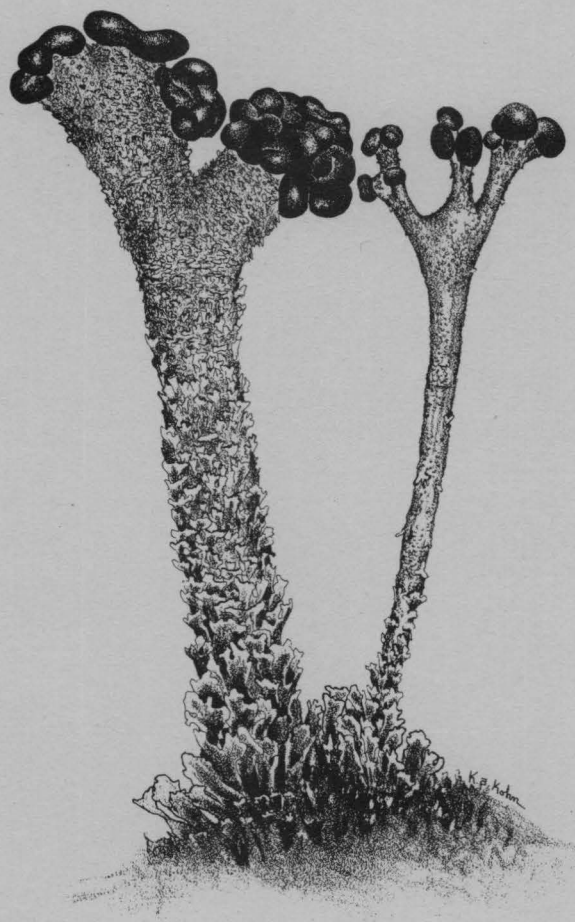

Cladonia cristatella

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IN
INDIANA DUNES NATIONAL LAKESHORE

Final Report

National Park Service
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TABLE OF CONTENTS

LICHENS OF INDIANA DUNES NAT. LAKESHORE

PREFACE

Under a grant from the National Park Service (USDI CX 0001-2-0034) a lichen study was to be performed in Indiana 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. Some are damaged or killed by levels of sulfur dioxide as low as 13 ug/cubic meter (annual average) or by nitrogen oxides at 3834-7668 ug/cubic meter or by other strongly oxidizing compounds such as ozone. Other lichens are less sensitive and a few can tolerate levels of sulfur dioxide over 300 ug/cubic meter. 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, which quickly leads to the death of the lichen. Lichens are more sensitive to air pollution when they are wet and physiologically active and are least sensitive when dry. The nature of the substrate is also important in determining the sensitivity to sulfur dioxide since substrates with high pH seem to buffer the fallout and permit the persistence of more sensitive species than one would expect. 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 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.

Indiana Dunes NL is located along the south shore of Lake Michigan between Gary, Indiana and Michigan City, Indiana and comprises several parcels of land with some non-park land inside some of them. The park is in the middle of the urban

and industrial area extending along southern Lake Michigan and many highways pass through and near the park. A steel plant is actually located between two parts of the park. The entire park is on sand dunes in various stages of stabilization from lakeshore with loose sand to mature oak forests at the south side of the park.

Along the lakeshore the typical foredune herbaceous vegetation dominates but in most places the forests begin just behind the top of the foredune. In some areas white pines (Pinus strobus) occur to the base of the foredune and oaks and cottonwoods (Populus deltoides) extend up the face. Black oak (Quercus velutina) dominates the drier sites and red oak (Quercus borealis) the wetter sites. In some of the pannes there are ponds or swamps while in others there is red maple (Acer rubrum) forest. Blowouts are present in many places where trails extend across stabilized dunes and fires are frequent in some areas.

No historical lichen collections are known from the park but Calkins listed 115 lichen species in a paper on the lichens of the Chicago area (Calkins, 1896) that included Cook, DuPage and northern Will Counties in Illinois and western Lake County in Indiana. The area covered in his paper included habitats very similar to those in the park and has been used for historical comparisons. Heiman and Apfelbaum (1984) did a preliminary vegetational study in the park and reported 11 lichens. They also stated that there was a gradient of species occurrence extending from west to east

with more species at the eastern end of the park.

METHODS

Field work was done during the summer of 1985. Two weeks in June were spent collecting in the park and 371 lichen collections were made at 24 localities. Two collections sites were also located in Warren Dunes State Park in Michigan. 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, third, to be in localities that should be rich in lichens. 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 are being entered into the computerized data base maintained

there. Lists of species found at each locality are included in Appendix III and are available from the computerized data base at any time on request.

LICHEN FLORA

The following list of lichens is based on my collections and those reported in the literature. This list includes 62 species collected in Indiana Dunes for this study and 92 additional species not found in this study but reported for the Chicago area by Calkins (1896). Eight species were collected only at Warren Dunes and are listed at the end. All of the species reported by Heiman and Apfelbaum were also collected by me in this study. There are three additional unidentified species. The species previously reported but not found in this study are indicated by an asterisk. The species found only once or twice are noted in the list by "Rare". Those also found at Warren Dunes are noted "Warren Dunes". 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 FOR INDIANA DUNES

154 Potential total species (historical and present)
111 species reported by Calkins
4 additional certain misidentifications and not counted in total
20 of these occur on rock only
92 (=*) species not collected by C. Wetmore, 1985 (=83%) [92/111]
62 species collected in 1985 in Indiana Dunes (+ 8 only in Warren Dunes)
19 of these were also reported by Calkins
43 new records since Calkins (4 of these were first by Heiman)
8 species in Warren Dunes not found in Indiana Dunes
"Warren Dunes" = also found in Warren Dunes, Mich.
"Rare" = found only 1 or 2 times in Indiana Dunes =27 species

*Acarospora fuscata (Nyl.) Arn.
Acarospora immersa Fink Rare
*Acrocordia gemmata (Ach.) Mass.
I Anisomeridium biforme (Borr.) R. Harris Rare
*Anzia colpodes (Ach.) Stizenb.
Arthonia caesia (Flot.) Körb. Warren Dunes
*Arthonia diffusa Nyl.
*Arthonia pyrrhuliza Nyl.
I *Arthonia radiata (Pers.) Ach. Warren Dunes
*Arthopyrenia punctiformis Mass.
*Arthothelium spectabile (Flot. ex Fr.) Mass.
*Arthothelium taediosum (Nyl.) Müll. Arg.
*Aspicilia calcarea (L.) Mudd
*Aspicilia contorta (Hoffm.) Kremp.
I Bacidia chlorococca (Stizenb.) Lett. Warren Dunes
*Bacidia inundata (Fr.) Körb.
*Bacidia polychroa (Th. Fr.) Körb.
I *Bacidia rubella (Hoffm.) Mass.
*Bacidia suffusa (Fr.) Schneid.
2 additional unidentified species of Bacidia
*Biatorella cyphalea (Tuck.) Zahlbr.
*Buellia disciformis (Fr.) Mudd
T Buellia punctata (Hoffm.) Mass.
*Buellia schaereri De Not.
S-I Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr. Rare, Warren Dunes
*Caloplaca cinnabarina (Ach.) Zahlbr.
Caloplaca feracissima Magn. Rare
*Caloplaca ferruginea (Huds.) Th. Fr.
S *Caloplaca flavorubescens (Huds.) Laund.
*Caloplaca microphylla (Tuck.) Hasse
S-I Candelaria concolor (Dicks.) B. Stein Warren Dunes
Candelariella efflorescens Harris & Buck Rare
*Candelariella vitellina (Hoffm.) Müll. Arg.
S-I Candelariella xanthostigma (Ach.) Lett. Warren Dunes

S-I *Cetraria ciliaris Ach.
Cladina mitis (Sandst.) Hale & W. Culb. Rare
Cladina rangiferina (L.) Harm. Rare
Cladonia bacillaris (Ach.) Nyl.
Cladonia bacilliformis (Nyl.) DTS Rare
Cladonia caespiticia (Pers.) Flörke Rare
Cladonia chlorophaea (Flörke ex Somm.) Spreng. Warren Dunes
I Cladonia coniocraea (Flörke) Spreng.
I Cladonia cristatella Tuck. Warren Dunes
Cladonia cryptochlorophaea Asah.
Cladonia cylindrica (Evans) Evans Rare
S-I Cladonia fimbriata (L.) Fr. Rare
*Cladonia furcata (Huds.) Schrad.
*Cladonia gracilis (L.) Willd.
Cladonia grayi Merr. ex Sandst.
*Cladonia macilenta Hoffm.
*Cladonia parasitica (Hoffm.) Hoffm.
Cladonia pleurota (Flörke) Schaer.
Cladonia peziziformis (With.) Laundon Warren Dunes
Cladonia polycarpoides Nyl.
Cladonia pyxidata (L.) Hoffm. Warren Dunes only
Cladonia ramulosa (With.) Laundon Rare
Cladonia rei Schaer. Warren Dunes
*Cladonia squamosa (Scop.) Hoffm.
Cladonia strepsilis(Ach.) Vain.
Cladonia verticillata (Hoffm.) Schaer.
*Collema auriforme (With.) Coppins & Laund.
*Collema conglomeratum Hoffm.
*Collema flaccidum (Ach.) Ach.
*Collema fragrans (Sm.) Ach.
*Collema limosum (Ach.) Ach.
*Collema tenax (Sw.) Ach.
*Conotrema urceolatum (Ach.) Tuck.
*Dermatocarpon lachneum (Ach.) A. L. Sm.
*Dermatocarpon miniatum (L.) Mann
Diploschistes scruposus (Schreb.) Norm. Rare Warren Dunes
Endocarpon pusillum Hedw. Rare
I Evernia mesomorpha Nyl. Rare
I *Graphis scripta (L.) Ach. Warren Dunes
*Heppia lutosa (Ach.) Nyl.
*Heterodermia granulifera (Ach.) W. Culb.
*Heterodermia speciosa (Wulf.) Trev.
I *Hyperphyscia adglutinata (Flörke) Mayrh. & Poelt
I *Hypogymnia physodes (L.) Nyl.
*Lecania erysibe (Ach.) Mudd
*Lecania perproxima (Nyl.) Zahlbr.
I *Lecanora allophana Nyl.
T Lecanora dispersa (Pers.) Somm. Rare
T Lecanora hagenii (Ach.) Ach. Rare
I *Lecanora pallida (Schreb.) Rabenh.
*Lecanora populicola (DC in Lam. & DC) Duby
I Lecanora saligna (Schrad.) Zahlbr.

*Lecanora sambuci (Pers.) Nyl.
I *Lecanora symmicta (Ach.) Ach. Warren Dunes
Lecanora thysanophora R. Harris ined. Rare
*Lecanora varia (Hoffm.) Ach.
Lecidea aeruginosa Borr. in Hook. & Sowerb.
*[Lecidea enteroleuca misident.]
*Lecidea varians Ach.
Lepraria finkii (B. de Lesd. in Hue) R. Harris
1 additional unidentified species of Lepraria
*Leptogium chloromelum (Sw. ex Ach.) Nyl.
*Leptogium corticola (Tayl.) Tuck.
*Leptogium lichenoides (L.) Zahlbr.
*Leptogium saturninum (Dicks.) Nyl.
*Leptorhaphis epidermidis (Ach.) Th. Fr.
Micarea prasina (Fr.) Körb. Rare
*Microthelia thelena (Ach.) Trev.
I *Opegrapha atra Pers.
I *Opegrapha varia Pers.
Parmelia bolliana Müll. Arg. Warren Dunes
*Parmelia borreri (Sm.) Turn.
I Parmelia caperata (L.) Ach.
*Parmelia cetrata Ach.
*Parmelia conspersa (Ehrh. ex Ach.) Ach.
*Parmelia crinita Ach.
Parmelia flaventior Stirt.
*Parmelia galbina Ach.
*Parmelia perforata (Jacq.) Ach.
*Parmelia perlata (Huds.) Vain.
I Parmelia rudecta Ach. Warren Dunes
S *Parmelia squarrosa Hale
S Parmelia subaurifera Nyl. Rare
I-T Parmelia sulcata Tayl. Warren Dunes
I *Parmeliopsis aleurites (Ach.) Nyl.
Peltigera rufescens (Weis.) Humb. Rare Warren Dunes
*Pertusaria leucostoma Mass.
*[Pertusaria multipuncta misident.]
*[Pertusaria pertusa misident.]
*Pertusaria pustulata (Ach.) Duby
*Pertusaria velata (Turn.) Nyl.
Phaeophyscia cernohorskyi (Nadv.) Essl. Rare
Phaeophyscia chloantha (Ach.) Moberg Warren Dunes
Phaeophyscia ciliata (Hoffm.) Essl. Rare
Phaeophyscia pusilloides (Zahlbr.) Essl.
Phaeophyscia rubropulchra (Degel.) Moberg Warren Dunes
I Physcia adscendens (Th. Fr.) Oliv. Warren Dunes
I *Physcia aipolia (Ehrh. ex Humb.) Furnrohr Warren Dunes
I Physcia millegrana Degel. Warren Dunes
I Physcia stellaris (L.) Nyl. Warren Dunes
I Physconia detersa (Nyl.) Poelt Rare Warren Dunes
Placynthiella icmalea (Ach.) Coppins & James
Placynthiella oligotropha (Laundon) Coppins & James
Rare
*Placynthium nigrum (Huds.) S. Gray
*Pyrenocollema prospersella (Nyl.) R. Harris

*Pyrenula laevigata (Pers.) Arn.
*Pyrenula nitida (Weig.) Ach.
S *Ramalina americana Hale
S *Ramalina calicaris (L.) Fr.
S *Ramalina fraxinea (L.) Ach.
*Rinodina bischoffi (Hepp) Mass.
*[Rinodina sophodes misident.]
*Sarcogyne privigna (Ach.) Mass.
*Sarcogyne regularis Körb.
*Teloschistes chrysophthalmus (L.) Th. Fr.
*Thelidium pyrenophorum (Ach.) Mudd
Thelocarpon laureri (Flot.) Nyl. Rare
*Trapelia coarctata (Sm.) Choisy in Wern.
Trapelia involuta (Tayl. in Mack.) Hert. Rare
*Verrucaria glaucina Ach.
*Verrucaria muralis Ach.
*Verrucaria nigrescens Pers.
Verrucaria rupestris Schrad.
*Verrucaria viridula (Schrad.) Ach.
S-I Xanthoria fallax (Hepp) Arn.
I *Xanthoria polycarpa (Hoffm.) Rieber Warren Dunes

Species found in Warren Dunes but not Indiana Dunes
Each species found only once

Arthonia dispersa (Schrad.) Nyl.
I Arthonia radiata (Pers.) Ach.
Catillaria nigroclavata (Nyl.) Schul.
I Graphis scripta (L.) Ach.
I Lecanora symmicta (Ach.) Ach.
Parmelia aurulenta Tuck.
I Physcia aipolia (Ehrh. ex Humb.) Furnrohr
I Xanthoria polycarpa (Hoffm.) Rieber

Cladonia pyxidata

DISCUSSION OF FLORA

Because of the relatively dry climate in the park the lichen flora is not particularly rich but there are some rare localities with microhabitats suitable for the lichens requiring more moisture. Examples are Cowles Bog where Thuja occidentalis occurs along with tamarack and ash and Pinhook Bog where several rare vascular plants and mosses have been found. There are always fewer lichens in northern hardwood forests, partly due to the dense shade. Even before widespread air pollution this region of the country had a relatively poor

lichen flora (Calkins, 1896). Now the lichen flora is only a fraction of what it was in the last century. I found 43 species not reported by Calkins. Adding these to those reported by Calkins provides a total potential lichen flora of 154 species. Comparing the number of lichens found in 1985 with the list reported by Calkins in 1896, 83 % of the lichens have been eliminated (92 species in the list by Calkins not found in 1985). Even if some of the species reported by him for the region are not counted because of the infrequent rock substrates in Indiana Dunes, there still has been a significant loss of species . However, there are a few places where rocks or concrete were found and so the substrate is not completely absent. All of the species most sensitive to sulfur dioxide are gone and also many in the S-I and I groups. The most common species are Physcia millegrana, Cladonia cristatella and Parmelia sulcata and these are relatively tolerant to sulfur dioxide. The only remaining species in the S category is Parmelia subaurifera, but the listing of this species in the most sensitive category is probably wrong. Lichens are not abundant at any locality and most species are represented by small thalli, often near the bases of the trees. Many of the species are in poor health with dying lobes and often with somewhat distorted growth. Some species, such as Arthonia caesia, that usually are fertile are frequent in Indiana Dunes but are almost always without apothecia. All of the 12 lichens with blue green algae reported by Calkins except one are now absent.

These observations indicate that there has been significant air quality degradation in the park that has caused observable damage to the lichen flora over the past one hundred years. Many species have been eliminated, the species remaining are tolerant to sulfur dioxide, are small and often with distorted growth and not fertile. This air quality degradation extends all the way to Warren Dunes in Michigan because only a few additional species were found there but nowhere near the number to be expected in a clean area.

Heiman & Apfelbaum (1894) reported a species density gradient from east to west in the park with more species in the east. Appendix III lists the species found by localities and it is apparent that there is no gradient in species numbers. Miller Woods at the west end of the park has 10 species and Mt. Baldy at the east end has 12 species. This difference is not significant. Miller woods has fewer lichens because it is very frequently burned and this radically reduces lichen abundance (Wetmore, 1981). In contrast, Mt. Baldy is very shady with much underbrush and this contributes to lichen scarcity. The best area for lichens was Howes Prairie with 23 species. This area is open woods with many openings and different kinds of trees which all contribute to better lichen habitat. The numbers of species in the different sulfur dioxide categories is not significantly different at the different localities (Appendix III). If there were a strong air pollution gradient from west to east one would expect to see a difference in these numbers also. This seems

to indicate that the air pollution is over a broad area and any concentration gradient extends much further east than is included in Indiana Dunes or even as far as Warren Dunes.

Since lichens are not known to be sensitive to acid precipitation, no conclusions can be drawn about this environmental contaminant. However, preliminary reports indicate that some species of Umbilicaria do show damage from acid precipitation by dying at the margins. No specimens of this genus were seen in the park.

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 only a few lichens in the park both common and with known sensitivity to sulfur dioxide according to the list presented in Wetmore (1983). The common species are the more tolerant ones. Species in the most sensitive category are usually absent when sulfur dioxide levels are above 50ug per cubic meter average annual concentrations. The only species in this category that occurs in the park is Parmelia subaurifera however, this species probably belongs in the S-I category which is between Sensitive and Intermediate.

S *Parmelia subaurifera* (2 collections)
S-I *Caloplaca cerina* (1 collection)
S-I *Candelaria concolor*
S-I *Candelariella xanthostigma*
S-I *Cladonia fimbriata* (2 collections)
S-I *Xanthoria fallax*

The distributions of these species are mapped (Fig. 2-7). All of these species are too infrequent to be of much use with this technique but there is no apparent restriction of these to one part of the park or another.

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 one species was collected in spunbound olefin sample bags at three localities in different parts of the park for laboratory analysis. *Cladonia cristatella* was the only species abundant enough and suitable for cleaning. This species grows on soil and is not especially good to use but was the only one available. Three localities were selected to represent the geographical extremes of the park and are indicated on the map of collection localities. These localities are: West Beach at the western end of the park, north of Furnessville Road near the center of the park, and south of Beverly Shores near the eastern end of the park. Ten

to 20 grams of each species were collected at each locality.

Lichens were air dried and cleaned of all sand under a dissecting microscope but thalli were not washed. Three samples of each collection were submitted for analysis. Analysis was done for sulfur and multi-element analysis by the Research Analytical Laboratory at the University of Minnesota. In the sulfur analysis a ground and pelleted 100-150 mg sample was prepared for total sulfur by dry combustion and measurement of evolved sulfur dioxide on a LECO Sulfur Determinator, model no. SC-132, by infra red absorption. Multi-element determination for Ca, Mg, Na, K, P, Fe, Mn, Al, Cu, Zn, Cd, Cr, Ni, Pb, and B were determined simultaneously by Inductively Coupled Plasma (ICP) Atomic Emission Spectrometry. For the ICP one gram of dried plant material was dry ashed in a 20 ml high form silica crucible at 485 degrees Celsius for 10-12 hrs. Crucibles were covered during the ashing as a precaution against contamination. The dry ash was boiled in 2N HCl to improve the recovery of Fe, Al and Cr and followed by transfer of the supernatant to 7 ml plastic disposable tubes for direct determination by ICP.

RESULTS AND DISCUSSION

Table 1 gives the results of the analyses for all replicates and the means and standard deviations for each set of replicates and data for Cladonia cristatella from Cedar Creek, Minnesota (a clean area) for comparison. All reported values are above the lower detection limits of the instruments. All of the levels found in the Indiana Dunes

Table 1. Analysis of *Cladonia cristatella* from Indiana Dunes
Values in ppm of thallus

P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
599	2160	710	466	551	1498	55.9	60.9	52.6	10.0	2.9	20.4	1.2	3.1	0.3	1550	West Beach
607	2260	657	474	578	1598	56.7	61.1	53.9	9.7	3.3	20.7	1.6	3.3	0.3	1400	West Beach
638	2314	702	510	588	1531	62.2	62.3	54.4	11.2	3.3	21.3	1.5	3.4	0.2	1510	West Beach
855	2266	487	331	509	899	42.2	41.6	37.6	8.1	2.7	16.6	1.1	2.2	0.2	930	Furnessville Rd.
948	2538	484	323	503	847	37.4	39.2	34.4	8.3	2.6	13.7	1.2	1.9	0.2	1020	Furnessville Rd.
945	2548	503	330	493	795	36.4	39.3	35.5	8.1	2.6	16.3	1.4	1.9	0.2	1000	Furnessville Rd.
878	2640	443	314	470	630	34.4	27.0	34.0	9.2	2.5	10.8	1.2	1.3	0.2	1000	Beverly Shores
870	2593	456	307	486	650	33.0	26.8	32.5	8.4	2.6	10.0	1.2	1.4	0.2	1050	Beverly Shores
946	2808	467	332	453	616	38.1	26.8	33.5	9.3	3.0	9.9	1.0	1.3	0.2	1040	Beverly Shores

Summary of analysis of *Cladonia cristatella* from Indiana Dunes
Values in ppm of thallus

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	615	2245	690	483	572	1542	58.2	61.4	53.6	10.3	3.2	20.8	1.4	3.3	0.3	1487	West Beach
Std. dev.	21	78	29	24	19	51	3.4	0.8	1.0	0.8	0.2	0.4	0.2	0.1	<.1	78	West Beach
Mean	916	2451	492	328	501	847	38.7	40.0	35.9	8.1	2.6	15.5	1.2	2.0	0.2	983	Furnessville Rd.
Std. dev.	53	160	10	5	8	52	3.1	1.4	1.6	0.1	0.1	1.6	0.1	0.2	<.1	47	Furnessville Rd.
Mean	898	2681	455	318	470	632	35.2	26.9	33.3	9.0	2.7	10.2	1.1	1.3	0.2	1030	Beverly Shores
Std. dev.	42	113	12	13	16	17	2.6	0.1	0.8	0.5	0.2	0.5	0.1	0.1	<.1	26	Beverly Shores
Mean	885	2511	657	372	629	586	39.7	21.1	20.3	4.2	1.5	9.3	1.4	1.0	0.2	792	Cedar Creek, MN

lichens are within typical limits for similar lichens although there are no literature reports for sulfur analyses of this species. The sulfur levels in this species range from 930 to 1550 ppm for all samples. Sulfur levels in the same species from Cedar Creek in Minnesota (a clean area) are somewhat lower than in Indiana Dunes. The collections from West Beach (on the western side of the park) are significantly higher than the other two localities in Indiana Dunes. Some of the other elements are also higher at Western Beach (Fe, Na, Mn, Zn, Cu and Pb). These are all pollutants from the industrial areas within and to the west of the park. Copper and lead also show a gradient within the localities toward the east in the park.

Inman & Parker (1978) studied metals in the soils of several localities in northwesten Indiana and found higher levels of Zn, Cd, Pb and Cu in the northern urban soils than in more southern localities. They found slower decomposition rates on polluted soils than on clean soils. No soil was analysed from Indiana Dunes localities in the present study but it may be assumed that pollutant levels in these soils are elevated also. Seaward & Bylinska (1980) did not show a correlation between levels of Pb, Cr, Ni, Cu, Mn and Zn in the soils and in lichens growing on them. However, LeRoy & Koksoy (1962) found a correlation between lichen levels and substrate levels of some elements in Colorado. The higher levels of some elements in the lichens from Indiana Dunes found in this study and the higer levels found in the soils from Inman &

Parker (1978) probably both came from atmospheric fallout and the levels in the lichens analysed probably reflect this airborn input rather than the indirect pathway through the soil.

CONCLUSIONS

The present lichen flora of Indiana Dunes is severely damaged by air pollution. Only about 17% of the original flora is still present. There are no species left that are very sensitive to sulfur dioxide and the ones present are often in poor health or small or frequently without apothecia. There is no detectable species density gradient from west to east and there are only 8 species in Warren Dunes that are not in Indiana Dunes. There are 62 species in Indiana Dunes including 43 new records for the region.

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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.

1 53684- Porter Co., Howes Prairie just S of E end of Dune
53707 Acres. In open oak woodland with scattered small openings and around campsite near road. 20 June 1985.

2 53708- La Porte Co., Around Mt. Baldy, just W of Michigan
53722 City. In oak woods on stabilized dunes. 20 June 1985.

3 53723- Lake Co., West Tolleston Dunes near eastern edge of
53741 county. Oak savanna and open sand and low wet areas. 21 June 1985.

4 53742- Lake Co., East Tolleston Dunes near eastern edge of
53757 county. Oak savanna and open sand areas and low wet areas. 21 June 1985.

5 53758- Porter Co., At end of Central Ave. E of Beverly
53772 Shores. Dunes with oak forest W of parking lot. 22 June 1985.

6 53773- Porter Co., At Lakeshore Ave. and highway 12 S of
53778 Beverly Shores. North of railroad and power lines in wet red maple forest. 22 June 1985.

7 53779- Porter Co., Behind visitor center on Kemil Road. In
53800 open oak woods with areas of young oak and open areas. 22 June 1985.

Warren Dunes, Michigan

8 53801- Berrien Co., Mich. Warren Dunes State Park. Above
53820 picnic area in basswood and sassafras woods with some oak. 23 June 1985.

9 53821- Berrien Co., Mich. Warren Dunes State Park. On
53844 stabilized dunes E of beach parking lot. Along ridges with oaks, basswood and some cottonwood and pines. 23 June 1985.

Indiana Dunes, Indiana

10 53845- Porter Co., N of Furnessville Road along horse trail
53866 SW of visitor center. In open sand prairie with oaks and sand blowouts. 24 June 1985.

11 53867- Porter Co., S of Furnessville Road along horse trail
53872 SW of visitor center. In brushy second growth and in old

shady oak woods with wet areas. 24 June 1985.

53873- Porter Co., Near highway 20 and trailhead of horse
53890 trail (SW of visitor center). In dense old woods with open area near parking lot. 24 June 1985.

53891- Porter Co., North of Bethlehem Steel plant NW of
53901 Porter. Along dunes by lakeshore and inland in oak woods. 25 June 1985.

53902- Porter Co., Cowles Bog S of Dune Acres. On rise in bog
53912 with white pine, red maple, Thuja and yellow birch. 25 June 1985.

53913- Porter Co., Indiana Dunes State Park, at eastern end
53932 of park near Kemil Road. In oak woodland with basswood and sassafras and jack pines near shore. 26 June 1985.

53933- Porter Co., Kemil Beach parking lot N of visitor
53950 center. In open fields with scattered cottonwoods and aspen. 26 June 1985.

53951- Porter Co., Heron Rookery Unit (7 miles SSW of Michigan
53952 City). In beech - maple forest with cottonwood and sycamore. 26 June 1985.

53953- La Porte Co., Pinhook Bog Unit (8 miles SSE of
53959 Michigan City). Tamarack bog with Sphagnum, blueberries and poison sumac. 26 June 1985.

53960- Porter Co., Eastern edge of Ogden Dunes near steel
53980 mills. In open areas with cottonwood and in oak woods with some basswood. 27 June 1985.

53981- Porter Co., Inland Marsh area S of Ogden Dunes. On
53995 ridges with oaks and some open sandy areas. 27 June 1985.

53996- Lake Co., Miller Woods W of Miller visitor center. On
54008 open frequently burned oak woods. 28 June 1985.

54009- Porter Co., West Beach W of Ogden Dunes. In oak forest
54025 with some basswood, sassafras and white pine. 28 June 1985.

54026- Porter Co., One mile W of visitor center on highway
54027 12. Concrete foundation of former house. 28 June 1985.

54028- Porter Co., Tremont Road S of Indiana Dunes State
54038 Park. Beech - maple forest with oaks and ponds and some sandy areas. 29 June 1985.

54039- Porter Co., Around Chellberg Farm S of headquarters.
54043 Along stream on old beech - maple forest with some oak.

29 June 1985.

54044- Porter Co., S of Beverly Shores between highway 12 and
54054 20. In open oak woods and sandy areas. 30 June 1985.

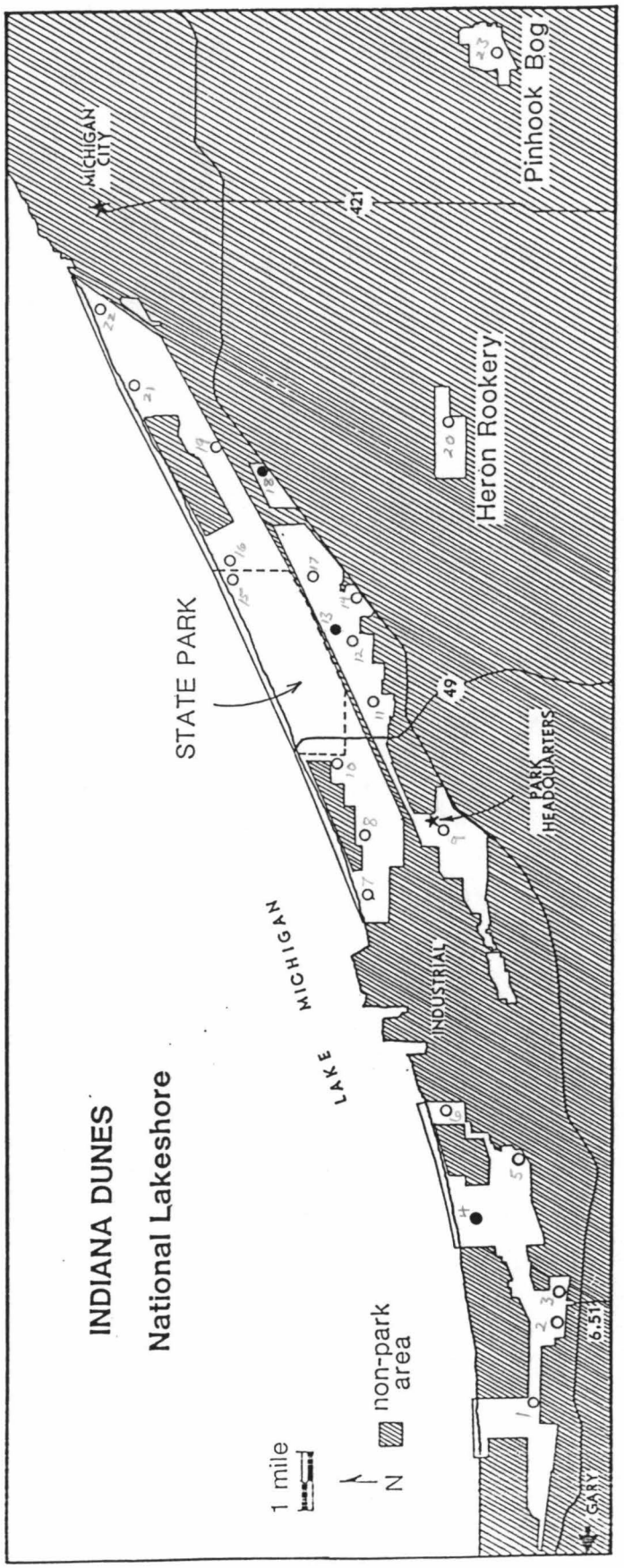

Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities.

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 Indiana Dunes 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 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 S *Parmelia subaurifera*
Fif. 3 S-I *Caloplaca cerina*
Fig. 4 S-I *Candelaria concolor*
Fig. 5 S-I *Candelariella xanthostigma*
Fig. 6 S-I *Cladonia fimbriata*
Fig. 7 S-I *Xanthoria fallax*

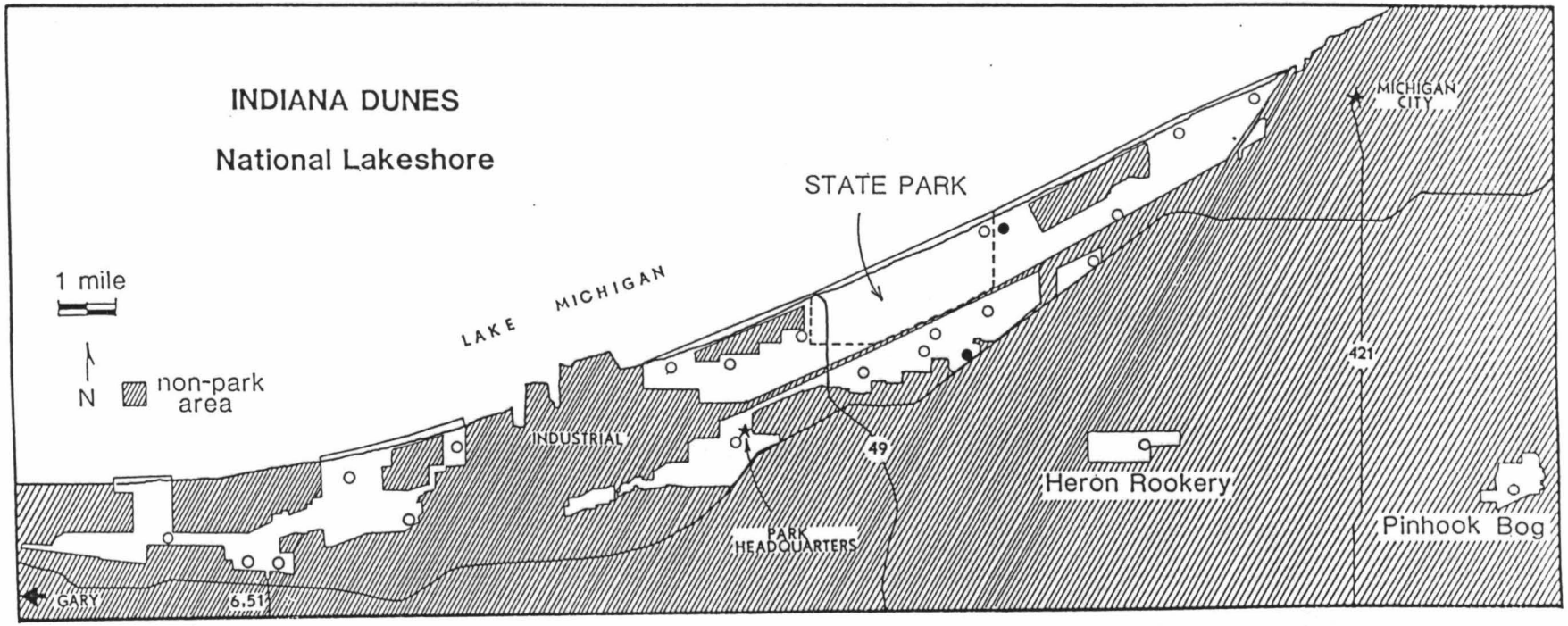

Fig. 2. Parmelia subaurifera

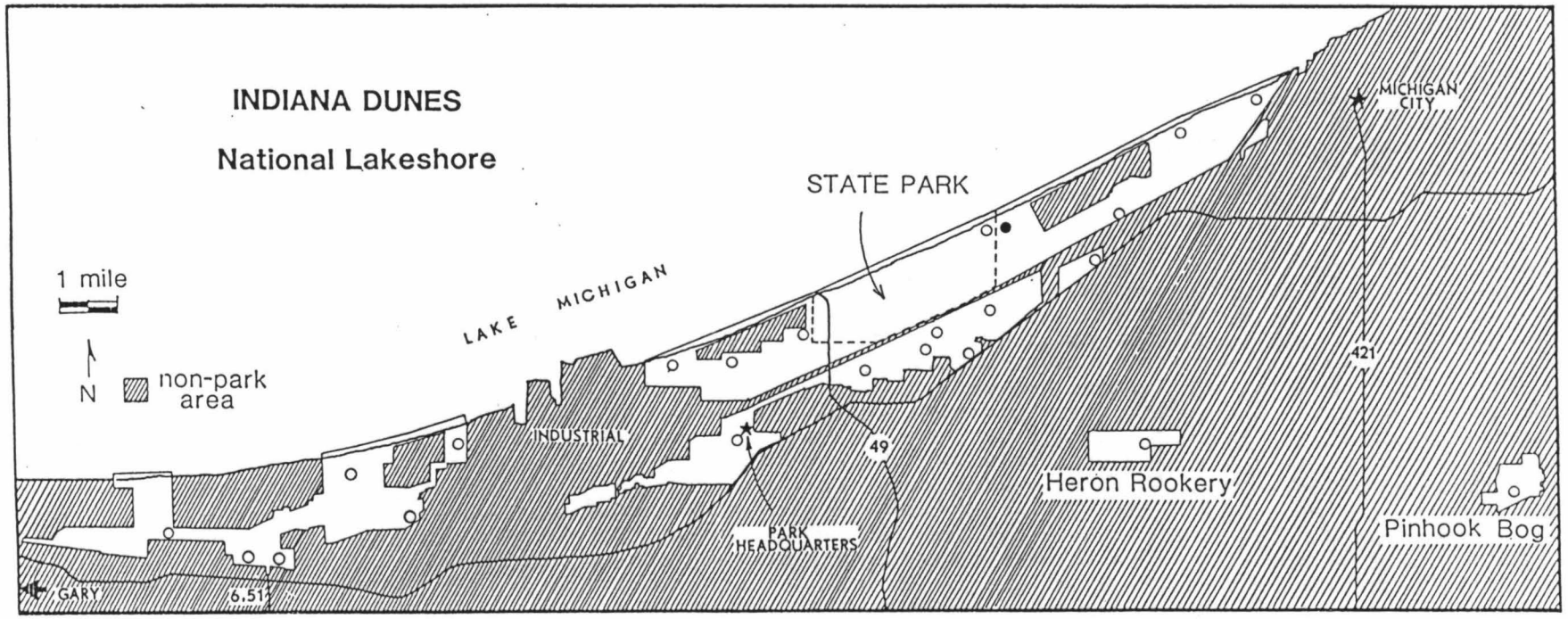

Fig. 3. Caloplaca cerina

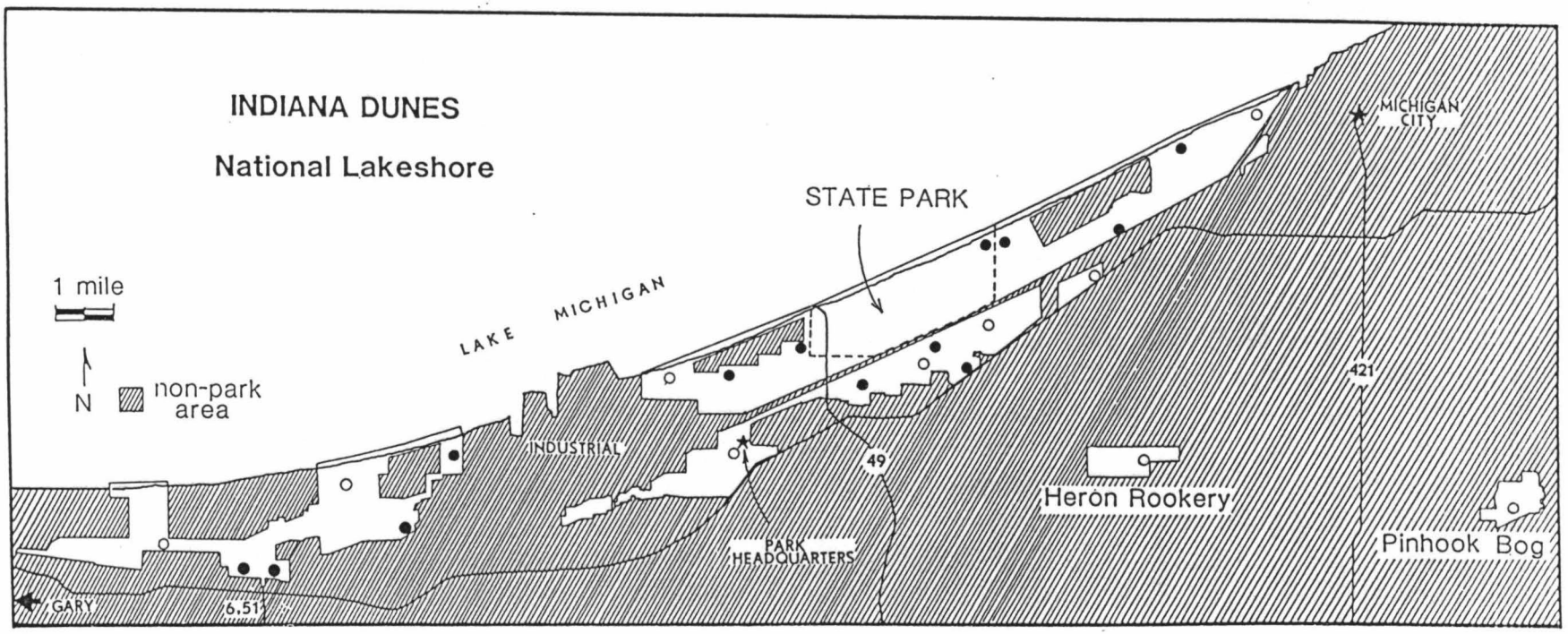

Fig. 4. Candelaria concolor

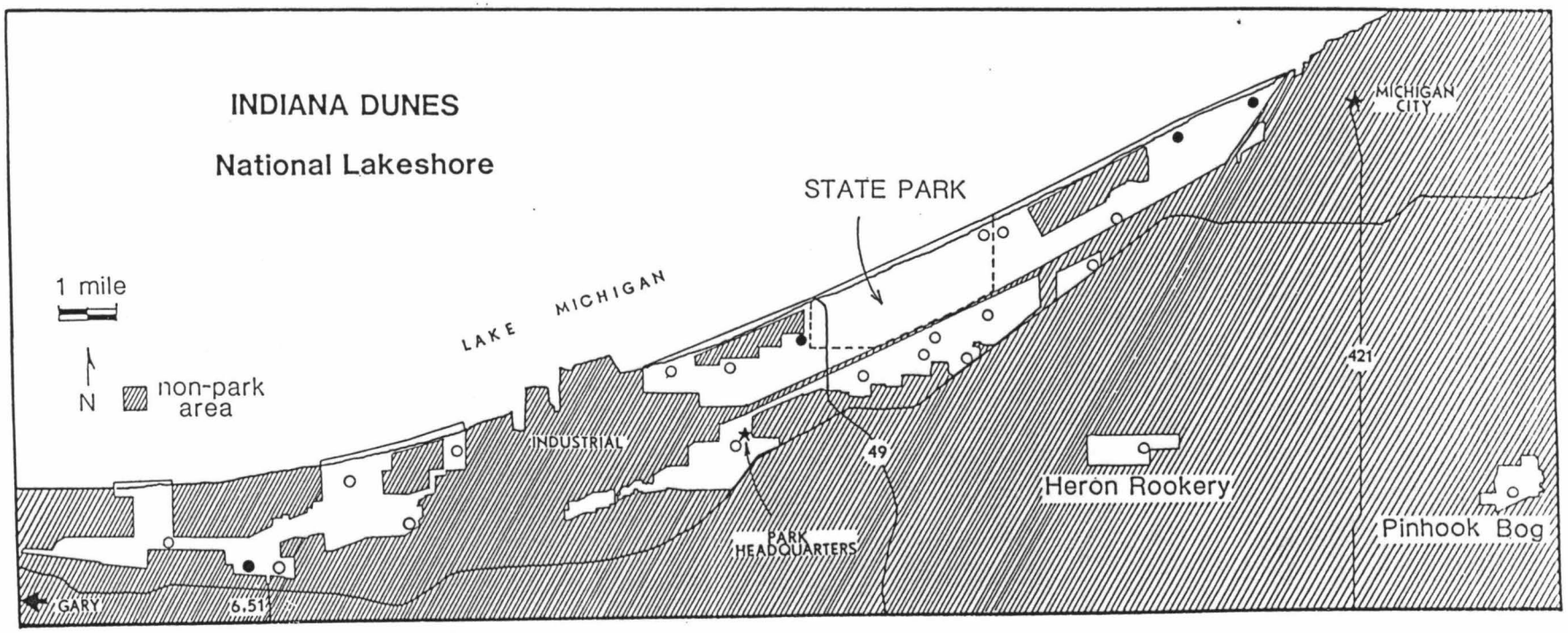

Fig. 5. Candelariella xanthostigma

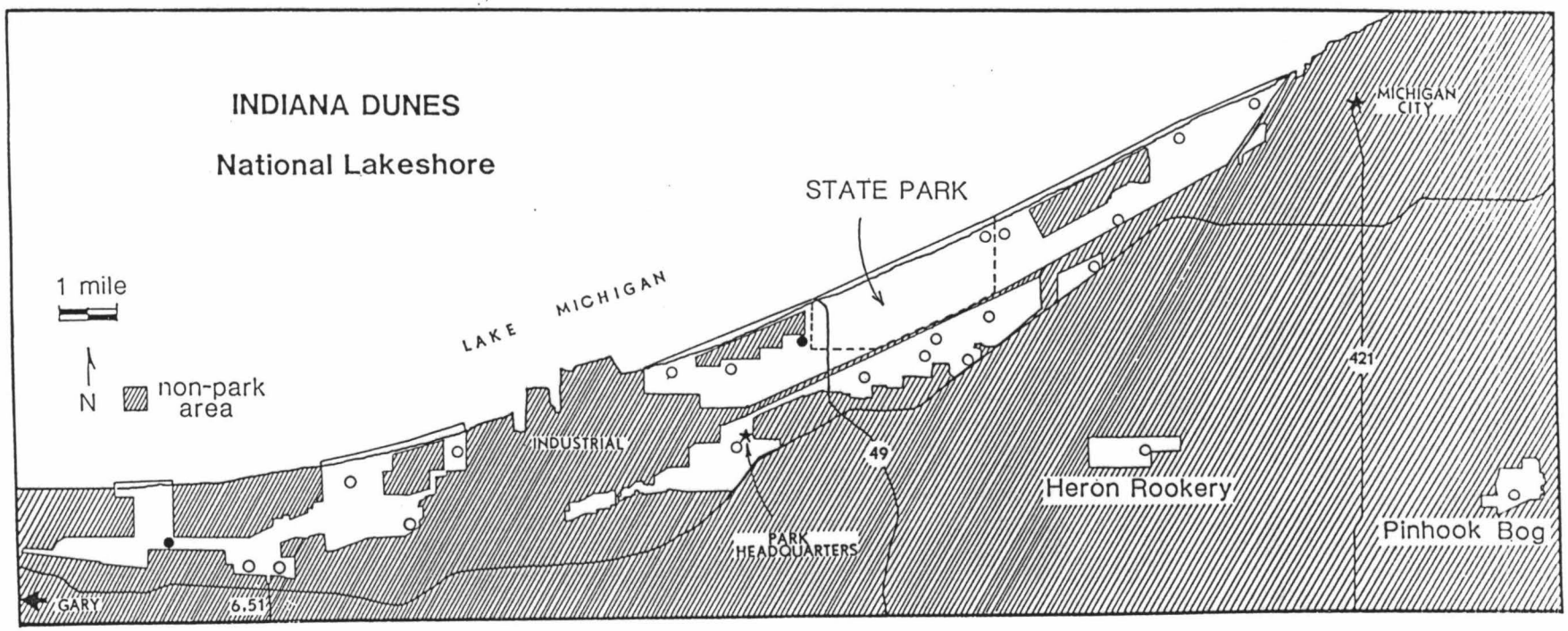

Fig. 6. Cladonia fimbriata

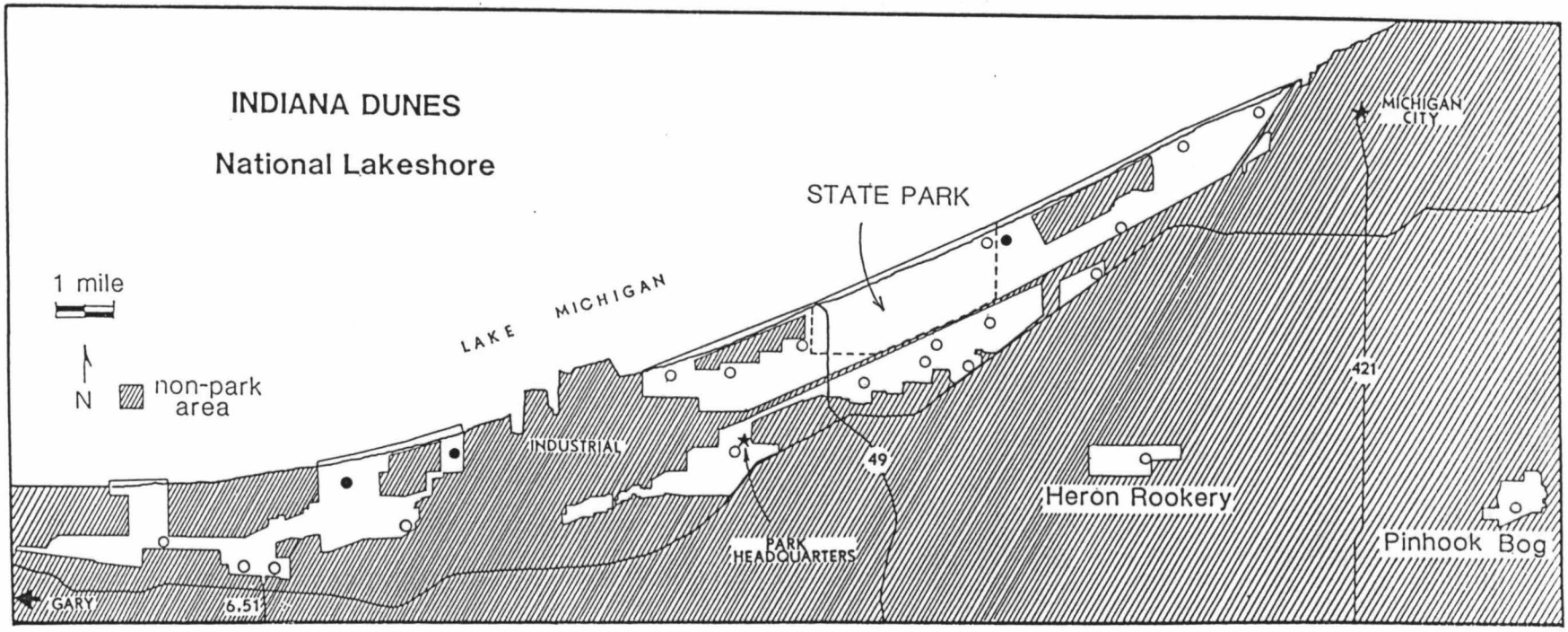

Fig. 7. Xanthoria fallax

APPENDIX III

Species lists for individual localities in Indiana Dunes and Warren Dunes. Localities are arranged from west to east with those found only once or twice marked with *.

Summary of species by localities with numbers of species in each sensitivity category for each locality.

E-W	Indiana Dunes	Species	S	S-I	I	I-T	T
1	Miller Woods	10		1	2	1	
2	West Tolleston Dunes	16		2	5	1	1
3	East Tolleston Dunes	15		1	6	1	
4	West Beach	12		1	3		1
5	Inland Marsh	13		1	3	1	1
6	East edge of Ogden Dunes	19		2	6	1	
7	Steel plant NW of Porter	10			4		
8	Cowles Bog	9		1	3	1	
9	Chellberg Farm	5			1		
10	Howes Prairie	23		3	4		2
11	Tremont Road S of state park	10		1	4	1	
12	South of Furnessville Road	5			3		
13	North of Furnessville Road	19		1	3	1	1
14	Highway 20 and horse trail	16	1	1	5	1	
15	E end of St. Prk. near Kemil Rd.	18		1	4	1	
16	Kemil Beach parking lot	17	1	3	5	1	
17	Kemil Road Visitor Center	19			4	1	
18	South of Beverly shores	9			2		
19	Beverly Shores at Lakeshore Ave.	4		1	1		
20	Heron Rookery Unit	2			2		
21	East of Beverly Shores	13		2	3	1	
22	Mt. Baldy	12		1	4		
23	Pinhook Bog Unit	7			4		
	Warren Dunes, picnic area	18		2	7	1	
	Warren Dunes, beach	20		3	8	1	
	Total possible		1	5	16	1	3

Indiana Dunes complete species lists by localities

1 Miller Woods 10 species

Arthonia caesia
Candelaria concolor
S-I* *Cladonia fimbriata*
Cladonia rei
I *Lecanora saligna*
I-T *Parmelia sulcata*
Phaeophyscia chloantha
Phaeophyscia pusilloides
I *Physcia millegrana*

Placynthiella icmalea

2 West Tolleston Dunes 16 species
Arthonia caesia
S-I Candelaria concolor
S-I Candelariella xanthostigma
I Cladonia cristatella
Cladonia peziziformis
Cladonia polycarpoides
Cladonia rei
T *Lecanora hagenii
I Lecanora saligna
Lecidea aeruginosa
Parmelia flaventior
I Parmelia rudecta
I-T Parmelia sulcata
Phaeophyscia rubropulchra
I Physcia millegrana
I Physcia stellaris

3 East Tolleston Dunes 15 species
Arthonia caesia
S-I Candelaria concolor
I Cladonia cristatella
Cladonia peziziformis
Cladonia rei
*Endocarpon pusillum
I Lecanora saligna
Lecidea aeruginosa
I Parmelia caperata
I-T Parmelia sulcata
Phaeophyscia chloantha
Phaeophyscia rubropulchra
I Physcia millegrana
I Physcia stellaris
Placynthiella icmalea

4 West Beach 12 species
T Buellia punctata
*Candelariella efflorescens
Cladonia polycarpoides
Cladonia rei
*Diploschistes scruposus
Lepraria finkii
*Phaeophyscia ciliata
Phaeophyscia rubropulchra
I Physcia adscendens
I Physcia millegrana
I Physcia stellaris
S-I Xanthoria fallax

5 Inland Marsh 13 species
Arthonia caesia
T Buellia punctata

S-I Candelaria concolor
Cladonia cryptochlorophaea
Cladonia polycarpoides
Cladonia rei
Lecidea aeruginosa
I Parmelia caperata
I-T Parmelia sulcata
*Peltigera rufescens
*Phaeophyscia cernohorskyi
I Physcia millegrana
I Physcia stellaris

6 East edge of Ogden Dunes 19 species
I Bacidia chlorococca
S-I Candelaria concolor
*Candelariella efflorescens
Cladonia chlorophaea
I Cladonia coniocraea
I Cladonia cristatella
Cladonia polycarpoides
Cladonia rei
Lepraria finkii
Parmelia bolliana
I-T Parmelia sulcata
Phaeophyscia pusilloides
Phaeophyscia rubropulchra
I Physcia adscendens
I Physcia millegrana
I Physcia stellaris
Placynthiella icmalea
*Thelocarpon laureri
S-I Xanthoria fallax

7 Steel plant NW of Porter 10 species
Arthonia caesia
Cladonia bacillaris
I Cladonia cristatella
Cladonia peziziformis
Cladonia polycarpoides
Cladonia rei
I Lecanora saligna
I Physcia adscendens
I Physcia millegrana
Placynthiella icmalea

8 Cowles Bog 9 species
Arthonia caesia
I Bacidia chlorococca
S-I Candelaria concolor
I Cladonia coniocraea
*Cladonia cylindrica
*Lecanora thysanophora
I-T Parmelia sulcata
Phaeophyscia rubropulchra

I Physcia millegrana

9 Chellberg Farm 5 species
Arthonia caesia
*Cladonia ramulosa
*Phaeophyscia cernohorskyi
I Physcia millegrana
Verrucaria rupestris

10 Howes Prairie 23 species
*Acarospora immersa
Arthonia caesia
*Caloplaca feracissima
S-I Candelaria concolor
S-I Candelariella xanthostigma
Cladonia bacillaris
I Cladonia cristatella
S-I*Cladonia fimbriata
Cladonia polycarpoides
*Endocarpon pusillum
T *Lecanora dispersa
T *Lecanora hagenii
Lecidea aeruginosa
Lepraria finkii
*Micarea prasina
Parmelia bolliana
Parmelia rudecta
Phaeophyscia rubropulchra
I Physcia adscendens
I Physcia millegrana
I *Physconia detersa
Placynthiella icmalea
Verrucaria rupestris

11 Tremont Road south of state park 10 species
I *Anisomeridium biforme
Arthonia caesia
S-I Candelaria concolor
I Cladonia cristatella
Cladonia rei
Cladonia verticillata
I-T Parmelia sulcata
Phaeophyscia rubropulchra
I Physcia millegrana
I Physcia stellaris

12 South of Furnessville Road 5 species
Arthonia caesia
I Bacidia chlorococca
I Cladonia coniocraea
I Cladonia cristatella
Placynthiella icmalea

13 North of Furnessville Road 19 species

Arthonia caesia
T Buellia punctata
S-I Candelaria concolor
*Cladina mitis
Cladonia bacillaris
*Cladonia caespiticia
I Cladonia cristatella
Cladonia grayi
Cladonia pleurota
Cladonia polycarpoides
Cladonia rei
Cladonia strepsilis
Cladonia verticillata
Parmelia caperata
I-T Parmelia sulcata
I Physcia millegrana
I Physcia stellaris
Placynthiella icmalea
*Placynthiella oligotropha

14 Highway 20 and horse trail 16 species

I *Anisomeridium biforme
Arthonia caesia
S-I Candelaria concolor
I Cladonia cristatella
Cladonia grayi
Cladonia polycarpoides
Cladonia rei
Parmelia flaventior
S *Parmelia subaurifera
I-T Parmelia sulcata
Phaeophyscia chloantha
Phaeophyscia rubropulchra
I Physcia adscendens
I Physcia millegrana
I Physcia stellaris
Placynthiella icmalea

15 East end of State Park near Kemil Road 18 species

Arthonia caesia
I Bacidia chlorococca
S-I Candelaria concolor
Cladonia chlorophaea
I Cladonia cristatella
Cladonia peziziformis
Cladonia polycarpoides
Cladonia pyxidata
Cladonia rei
Cladonia verticillata
Lecidea aeruginosa
Lepraria finkii
Parmelia bolliana
I-T Parmelia sulcata

Phaeophyscia rubropulchra
I Physcia millegrana
I Physcia stellaris
Placynthiella icmalea

16 Kemil Beach parking lot 17 species
S-I*Caloplaca cerina
S-I Candelaria concolor
I Cladonia cristatella
Cladonia polycarpoides
Cladonia rei
I *Evernia mesomorpha
Parmelia flaventior
S *Parmelia subaurifera
I-T Parmelia sulcata
*Phaeophyscia ciliata
Phaeophyscia pusilloides
Phaeophyscia rubropulchra
I Physcia adscendens
I Physcia millegrana
I Physcia stellaris
*Trapelia involuta
S-I Xanthoria fallax

17 Kemil Road Visitor Center 19 species
Arthonia caesia
I Bacidia chlorococca
*Cladina rangiferina
Cladonia bacillaris
*Cladonia bacilliformis
I Cladonia cristatella
Cladonia cryptochlorophaea
Cladonia grayi
Cladonia pleurota
Cladonia rei
Cladonia strepsilis
Cladonia verticillata
Lepraria finkii
Parmelia flaventior
I Parmelia rudecta
I-T Parmelia sulcata
Phaeophyscia rubropulchra
I Physcia millegrana
Placynthiella icmalea

18 South of Beverly shores 9 species
I Cladonia cristatella
Cladonia grayi
Cladonia pleurota
Cladonia polycarpoides
Cladonia rei
Cladonia strepsilis
Cladonia verticillata
Lecidea aeruginosa

Physcia millegrana

19 Beverly Shores at Lakeshore Ave. 4 species
S-I Candelaria concolor
*Cladonia cylindrica
Phaeophyscia rubropulchra
I Physcia millegrana

20 Heron Rookery Unit 2 species
I Physcia millegrana
I Physcia stellaris

21 East of Beverly Shores 13 species
Arthonia caesia
I Bacidia chlorococca
S-I Candelaria concolor
S-I Candelariella xanthostigma
Cladonia bacillaris
I Cladonia coniocraea
*Lecanora thysanophora
*Micarea prasina
Parmelia bolliana
I-T Parmelia sulcata
Phaeophyscia rubropulchra
I Physcia millegrana
Placynthiella icmalea

22 Mt. Baldy 12 species
Arthonia caesia
I Bacidia chlorococca
S-I Candelariella xanthostigma
I Cladonia cristatella
Cladonia rei
Lecidea aeruginosa
Lepraria finkii
Parmelia bolliana
I Parmelia rudecta
Phaeophyscia rubropulchra
I Physcia millegrana
Verrucaria rupestris

23 Pinhook Bog Unit 7 species
I Bacidia chlorococca
Cladonia bacillaris
I Cladonia coniocraea
I Cladonia cristatella
Cladonia cryptochlorophaea
Phaeophyscia rubropulchra
I Physcia adscendens

1 mile W of visitor center 2 species
*Caloplaca feracissima
T Lecanora dispersa

Warren Dunes, Michigan
+ = not found in Indiana Dunes

Picnic area 18 species

+*Arthonia dispersa*
I +*Arthonia radiata*
S-I *Candelaria concolor*
S-I *Candelariella xanthostigma*
+*Catillaria nigroclavata*
Cladonia peziziformis
Cladonia rei
I +*Lecanora symmicta*
+*Parmelia aurulenta*
Parmelia bolliana
I-T *Parmelia sulcata*
Peltigera rufescens
Phaeophyscia rubropulchra
I *Physcia adscendens*
I +*Physcia aipolia*
I *Physcia millegrana*
I *Physcia stellaris*
I *Physconia detersa*

East of beach parking lot 20 species

Arthonia caesia
I *Bacidia chlorococca*
S-I *Caloplaca cerina*
S-I *Candelaria concolor*
S-I *Candelariella xanthostigma*
Cladonia chlorophaea
I *Cladonia cristatella*
Cladonia pyxidata
Cladonia rei
Diploschistes scruposus
I +*Graphis scripta*
I *Parmelia rudecta*
I-T *Parmelia sulcata*
Peltigera rufescens
Phaeophyscia chloantha
Phaeophyscia rubropulchra
I *Physcia adscendens*
I *Physcia millegrana*
I *Physcia stellaris*
I +*Xanthoria polycarpa*