LICHENS AND AIR QUALITY

IN

BOUNDARY WATERS CANOE AREA

OF

SUPERIOR NATIONAL FOREST

Final Report

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LICHENS OF BWCA

PREFACE

Under a grant from the National Forest Service (43-63A9-5-867) a lichen study was to be performed in the Boundary Waters Canoe Area of Superior National Forest. This study was to survey the lichens of the wilderness area, 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 consultation with Robert Berrisford, Superior National Forest, Duluth and with personnel in the forest.

The USFS 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 Forest Service. I was assisted in collecting for the project by a former graduate student, Thomas D. Trana. 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.

The Boundary Waters Canoe Area is located along the northern border of Minnesota in an area of many lakes, swamps and streams. Because the area has been declared a Wilderness area, no roads extend into the BWCA and motorized boats are not permitted on most of the lakes. A few roads are located near the borders and some abandoned logging roads and presently maintained trails extend into the BWCA itself. This provides a wonderful wilderness setting but great difficulties for such a project as this where time is limited.

The vegetation is mixed boreal conifer forest and deciduous forest. The mature forest is balsam fir (Abies balsamea) and white spruce (Picea glauca) on more moist sites and jack pine (Pinus banksiana) or red pine (Pinus resinosa) or white pine (Pinus strobus) on drier upland sites. The swamps have either white cedar (Thuja occidentalis) or black ash (Fraxinus nigra). Most of the area has been logged and burned and the second-growth forest is white birch (Betula papyrifera) and aspen (Populus tremuloides and P. grandidentata). In some areas there are also red maple (Acer rubrum). There are many bogs, streams and rock outcrops throughout the BWCA but most of the substrate conditions are acidic.

METHODS

Field work was done during the late summer of 1986. Thomas Trana collected in the western and southern parts and C. Wetmore collected in the northern and eastern parts during August and September. A total of 35 localities were collected and about 2500 collections were made. 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 BWCA, second, to sample all vegetational types, third, to be in localities that should be rich in lichens. Because of problems of access most localities are near the borders of the BWCA or on lakes where motors are permitted. 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 these are being entered into the 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

In 1901 Bruce Fink collected lichens at many localities in northern Minnesota (Fink, 1903) and some of his localities may have been within the present BWCA. During the past 15 years Wetmore and some of his students have collected at a few localities within the BWCA. In 1978 and 1979 Wetmore collected in Voyageurs National Park for a lichen flora (Wetmore, 1981).

The following list of lichens is based only on the collections of Trana and Wetmore for this study. At the end of this list a comparison with the historical collections of Fink and the lichens of Voyageurs National Park will be made. Because there are few historical collections from this part of the state that might be within the BWCA references are not included in the species list to historical collections.

Species with `*' are reported from the BWCA but were not found in Voyageurs NP by Wetmore (1981). In the first columns the letters indicate the sensitivity to sulfur dioxide, if known, according to the categories proposed by Wetmore (1983).: S=Sensitive, I=Intermediate, T=Tolerant. S-I is intermediate between Sensitive and Intermediate and I-T is intermediate between Intermediate and Tolerant. Species in the Sensitive category are absent when annual average levels of sulfur dioxide are above 50ug per cubic meter. The Intermediate category includes those species present between 50 and 100ug and those in the Tolerant category are present at over 100ug per cubic meter.

Species List

Acarospora americana Magn.
Acarospora fuscata (Schrad.) Arn.
*Acrocordia cavata (Ach.) R. Harris in Vezda
Arthonia caesia (Flot.) K"orb.
Arthonia didyma K"orb.
Arthonia dispersa (Schrad.) Nyl.
Arthonia patellulata Nyl.
I Arthonia radiata (Pers.) Ach.
Arthothelium ruanum (Mass.) Zw.
Aspicilia caesiocinerea (Nyl. ex Malbr.) Arn.
Aspicilia cinerea (L.) K"orb.
*Aspicilia cinereorufescens (Ach.) Mass.
1 unidentified species of Aspicilia
Bacidia accedens (Arn.) Lett.
Bacidia epixanthoides (Nyl.) Lett.
*Bacidia incompta (Borr. ex Hook.) Anzi
Bacidia polychroa (Th. Fr.) K"orb.
*Bacidia populorum (Mass.) Trev.
Bacidia rubella (Hoffm.) Mass.
Bacidia sabuletorum (Schreb.) Lett.
Bacidia schweinitzii (Tuck.) Schneid.
Bacidia sphaeroides (Dicks.) Zahlbr.
1 unidentified species of Bacidia
Baeomyces rufus (Huds.) Rebent.
Biatorella moriformis (Ach.) Th. Fr.
Biatorella resinae (Fr.) Th. Fr.
I *Bryoria capillaris (Ach.) Brodo & Hawksw.
S Bryoria furcellata (Fr.) Brodo & Hawksw.
S Bryoria trichodes (Michx.) Brodo & Hawksw.
Buellia arnoldii Serv. & Nadv.
Buellia disciformis (Fr.) Mudd
T Buellia punctata (Hoffm.) Mass.
Buellia schaereri De Not.
I Buellia stillingiana J. Stein.
Calicium abietinum Pers.
Calicium parvum Tibell
Calicium salicinum Pers.
Calicium trabinellum (Ach.) Ach.
S-I Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr.
Caloplaca chrysophthalma Degel.
Caloplaca citrina (Hoffm.) Th. Fr.
*Caloplaca discolor (Will. ex Tuck.) Fink
Caloplaca flavovirescens (Wulf.) Dalla Torre & Sarnth.
I Caloplaca holocarpa (Hoffm.) Wade
Caloplaca pollinii (Mass.) Jatta

I-T Caloplaca vitellinula (Nyl.) Oliv.
2 unidentified species of Caloplaca
S-I Candelaria concolor (Dicks.) B. Stein
Candelaria fibrosa (Fr.) M"ull. Arg.
Candelariella efflorescens Harris & Buck
I Candelariella vitellina (Hoffm.) M"ull. Arg.
S-I Candelariella xanthostigma (Ach.) Lett.
Catillaria atropurpurea (Schaer) Th. Fr.
*Catillaria lenticularis (Ach.) Th. Fr.
*Catillaria nigroclavata (Nyl.) Schul.
Cetraria aurescens Tuck.
Cetraria halei W. & C. Culb.
I Cetraria pinastri (Scop.) S. Gray
I Cetraria sepincola (Ehrh.) Ach.
Cetrelia chicitae (W. Culb.) W. & C. Culb.
Cetrelia olivetorum (Nyl.) W. & C. Culb.
Chaenotheca brunneola (Ach.) M"ull. Arg.
Chaenotheca chrysocephala (Turn.) Th. Fr.
I Chaenotheca ferruginea (Turn. ex Sm.) Mig.
Chaenotheca furfuracea (L.) Tibell
Chaenotheca stemonea (Ach.) Zw.
Chaenotheca trichialis (Ach.) Th. Fr.
Chaenotheca xyloxena Nadv.
Chaenothecopsis debilis (Turn. & Borr. ex Sm.) Tibell
Chaenothecopsis lignicola (Nadv.) A. Schmidt
Chaenothecopsis savonica (R"as.) Tibell
Chaenothecopsis subpusilla (Kremp.) A. Schmidt
1 unidentified species of Chaenothecopsis
*Chrysothrix candelaris (L.) Laund.
*Cladina arbuscula (Wallr.) Hale & W. Culb.
Cladina mitis (Sandst.) Hale & W. Culb.
Cladina rangiferina (L.) Harm.
Cladina stellaris (Opiz) Brodo
*Cladina stygia (Fr.) Ahti
Cladonia acuminata (Ach.) Norrl.
Cladonia amaurocraea (Fl"orke) Schaer.
Cladonia bacillaris (Ach.) Nyl.
Cladonia botrytes (Hag.) Willd.
Cladonia caespiticia (Pers.) Fl"orke
Cladonia cariosa (Ach.) Spreng.
Cladonia cenotea (Ach.) Schaer.
Cladonia chlorophaea (Fl"orke ex Somm.) Spreng.
Cladonia coccifera (L.) Willd.
I Cladonia coniocraea (Fl"orke) Spreng.
Cladonia cornuta (L.) Hoffm.
Cladonia crispata (Ach.) Flot.
I Cladonia cristatella Tuck.
Cladonia decorticata (Fl"orke) Spreng.
Cladonia deformis (L.) Hoffm.
Cladonia digitata (L.) Hoffm.
S-I Cladonia fimbriata (L.) Fr.
Cladonia floerkeana (Fr.) Fl"orke
Cladonia furcata (Huds.) Schrad.

Cladonia gracilis (L.) Willd.
Cladonia grayi Merr. ex Sandst.
Cladonia humilis (With.) Laundon
Cladonia merochlorophaea Asah.
Cladonia multiformis Merr.
Cladonia parasitica (Hoffm.) Hoffm.
Cladonia phyllophora Hoffm.
Cladonia pleurota (Fl"orke) Schaer.
Cladonia pseudorangiformis Asah.
Cladonia pyxidata (L.) Hoffm.
Cladonia rei Schaer.
Cladonia scabriuscula (Del.) Leight.
Cladonia squamosa (Scop.) Hoffm.
Cladonia subulata (L.) Wigg.
Cladonia sulphurina (Michx.) Fr.
Cladonia turgida (Ehrh.) Hoffm.
Cladonia uncialis (L.) Wigg.
Cladonia verticillata (Hoffm.) Schaer.
Collema conglomeratum Hoffm.
Collema flaccidum (Ach.) Ach.
Collema fuscovirens (With.) Laund.
*Collema limosum (Ach.) Ach.
Collema nigrescens (Huds.) DC.
Collema pulcellum Ach.
Collema subflaccidum Degel.
Coniocybe pallida (Pers.) Fr.
Cyphelium lucidum (Th. Fr.) Th. Fr.
Cyphelium tigillare (Ach.) Ach.
Dermatocarpon luridum (With.) Laundon
Dermatocarpon miniatum (L.) Mann
Dimelaena oreina (Ach.) Norm.
SDimerella lutea (Dicks.) Trev.
Diploschistes scruposus (Schreb.) Norm.
Eopyrenula leucoplaca (Wallr.) R. C. Harris
Ephebe lanata (L.) Vain.
Ephebe ocellata Henss.
IEvernia mesomorpha Nyl.
IGraphis scripta (L.) Ach.
Gyalecta truncigena (Ach.) Hepp
Haematomma elatinum (Ach.) Mass.
*Haematomma pustulatum Brodo
*Heterodermia galactophylla (Tuck.) W. Culb.
Heterodermia speciosa (Wulf.) Trev.
IHypogymnia physodes (L.) Nyl.
S*Hypogymnia tubulosa (Schaer.) Hav.
Icmadophila ericetorum (L.) Zahlbr.
Lasallia papulosa (Ach.) Llano
Lecanactis chloroconia Tuck.
Lecania dubitans (Nyl.) A. L. Sm.
ILecanora allophana Nyl.
Lecanora caesiorubella Ach. var. saximontana Imsh. & Brodo
Lecanora cenisia Ach.
ILecanora circumborealis Brodo & Vitik.

*Lecanora crenulata (Dicks.) Hook.
*Lecanora fuliginosa Brodo
Lecanora impudens Degel.
Lecanora meridionalis Magn.
TLecanora muralis (Schreb.) Rabenh.
Lecanora mutabilis Somm.
Lecanora opiniconensis Brodo
I Lecanora pallida (Schreb.) Rabenh. var. rubescens Imsh. & Brodo
Lecanora piniperda K"orb.
Lecanora polytropa (Hoffm.) Rabenh.
ILecanora pulicaris (Pers.) Ach.
Lecanora rugosella Zahlbr.
ILecanora symmicta (Ach.) Ach.
Lecanora thysanophora Harris ined.
Lecanora wisconsinensis Magn.
2 unidentified species of Lecanora
Lecidea aeruginosa Borr. in Hook & Sowerb.
Lecidea anthracophila Nyl.
*Lecidea auriculata Th. Fr.
Lecidea berengeriana (Mass.) Nyl.
Lecidea caeca Lowe
Lecidea elabens Fr.
Lecidea epixanthoidiza Nyl.
Lecidea erratica K"orb.
Lecidea erythrophaea Lowe
Lecidea friesii Ach.
Lecidea granulosa (Ehrh.) Ach.
Lecidea helvola (K"orb.) Oliv.
Lecidea hypnorum Libert
Lecidea plana (Lahm) Nyl.
*Lecidea plebeja Nyl.
I Lecidea scalaris (Ach.) Ach.
*Lecidea tornoensis Nyl.
S Lecidea vernalis (L.) Ach.
Lecidea viridescens (Schrad.) Ach.
3 unidentified species of Lecidea
I Lecidella elaeochroma (Ach.) Choisy
Lecidella euphorea (Fl"orke) Hert.
Lecidella stigmatea (Ach.) Hert. & Leuck.
Lepraria finkii (B. de Lesd. in Hue) R. Harris
Lepraria lobificans (Hue) ined.
Lepraria neglecta (Nyl.) Lett.
2 unidentified species of Lepraria
Leptogium cyanescens (Rabenh.) K"orb.
Leptogium saturninum (Dicks.) Nyl.
Leptogium tenuissimum (Dicks.) K"orb.
*Leptorhaphis contorta Degel.
Leptorhaphis epidermidis (Ach.) Th. Fr.
S Lobaria pulmonaria (L.) Hoffm.
Lobaria quercizans Michx.
Micarea melaena (Nyl.) Hedl.
*Micarea misella (Nyl.) Hedl.
*Micarea peliocarpa (Anzi) Coppins & R. Sant.

Micarea prasina (Fr.) K"orb.
1 unidentified species of Micarea
I Mycoblastus sanguinarius (L.) Norm.
Mycocalicium subtile (Pers.) Szat.
Nephroma bellum (Spreng.) Tuck.
Nephroma helveticum Ach.
Nephroma parile (Ach.) Ach.
Nephroma resupinatum (L.) Ach.
S *Ochrolechia androgyna (Hoffm.) Arn.
Ochrolechia arborea (Ljubitz.) Almb.
*Ochrolechia pseudopallescens Brodo
Ochrolechia rosella (M"ull. Arg.) Vers.
I Opegrapha varia Pers.
Pachyospora verrucosa (Ach.) Mass.
Pachyphiale fagicola (Hepp) Zw.
Pannaria leucophaea (Vahl) J"org. ined.
Pannaria praetermissa Nyl. in Chyd. & Furuh.
*Pannaria tavaresii P. J"org.
Parmelia aurulenta Tuck.
I Parmelia caperata (L.) Ach.
Parmelia conspersa (Ach.) Ach.
Parmelia cumberlandia (Gyeln.) Hale
Parmelia disjuncta Erichs.
I Parmelia exasperatula Nyl.
Parmelia flaventior Stirt.
Parmelia fraudans Nyl.
Parmelia galbina Ach.
I Parmelia glabratula Lamy
Parmelia hypopsila M"ull. Arg.
Parmelia infumata Nyl.
Parmelia obsessa Ach.
Parmelia olivacea (L.) Ach.
Parmelia plittii Gyeln.
I Parmelia rudecta Ach.
I Parmelia septentrionalis (Lynge) Ahti
Parmelia soredica Nyl.
*Parmelia sorediosa Almb.
S Parmelia squarrosa Hale
I-T Parmelia subargentifera Nyl.
S Parmelia subaurifera Nyl.
*Parmelia subcentrifuga Oxn.
I Parmelia subrudecta Nyl.
Parmelia substygia R"as.
I-TParmelia sulcata Tayl.
Parmelia taractica Kremp.
IParmelia trabeculata Ahti
IParmeliopsis aleurites (Ach.) Nyl.
I Parmeliopsis ambigua (Wulf.) Nyl.
IParmeliopsis hyperopta (Ach.) Arn.
Parmeliopsis placorodia (Ach.) Nyl.
Peltigera aphthosa (L.) Willd.
Peltigera canina (L.) Willd.
Peltigera didactyla (With.) Laundon

Peltigera elisabethae Gyeln.
Peltigera evansiana Gyeln.
IPeltigera horizontalis (Huds.) Baumg.
Peltigera lepidophora (Nyl.ex Vain.) Bitter
Peltigera leucophlebia (Nyl.) Gyeln.
Peltigera malacea (Ach.) Funck
*Peltigera membranacea (Ach.) Nyl.
Peltigera neckeri M"ull. Arg.
Peltigera polydactyla (Neck.) Hoffm.
Peltigera rufescens (Weis.) Humb.
Peltigera scabrosa Th. Fr.
IPertusaria amara (Ach.) Nyl.
Pertusaria consocians Dibb.
IPertusaria multipunctoides Dibb.
Pertusaria ophthalmiza (Nyl.) Nyl.
Pertusaria stenhammari Hellb.
Pertusaria velata (Turn.) Nyl.
2 unidentified species of Pertusaria
Phaeocalicium polyporaeum (Nyl.) Tibell
Phaeophyscia adiastola (Essl.) Essl.
Phaeophyscia chloantha (Ach.) Moberg
Phaeophyscia ciliata (Hoffm.) Essl.
Phaeophyscia endococcina (K"orb.) Essl.
*Phaeophyscia hirsuta (Meresch.) Moberg
*Phaeophyscia hirtella Essl.
Phaeophyscia hispidula (Ach.) Moberg
Phaeophyscia imbricata (Vain.) Essl.
I*Phaeophyscia orbicularis (Neck.) Moberg
Phaeophyscia pusilloides (Zahlbr.) Essl.
Phaeophyscia rubropulchra (Degel.) Moberg
Phaeophyscia sciastra (Ach.) Moberg
IPhlyctis argena (Spreng.) Flot.
IPhyscia adscendens (Th. Fr.) Oliv.
IPhyscia aipolia (Ehrh. ex Humb.) Furnrohr
Physcia americana Merr. in Evans & Meyrow.
TPhyscia dubia (Hoffm.) Lett.
*Physcia intermedia Vain.
Physcia phaea (Tuck.) Thoms.
IPhyscia stellaris (L.) Nyl.
Physcia subtilis Degel.
IPhysconia detersa (Nyl.) Poelt
Placynthiella icmalea (Ach.) Coppins & James
Placynthiella oligotropha (Laundon) Coppins & James
Placynthium nigrum (Huds.) S. Gray
*Plagiocarpa phaeospora R. Harris
Platismatia tuckermanii (Oakes) W. & C. Culb.
Polyblastiopsis fallaciosa (Stizenb.) Zahlbr.
*Porpidia albocaerulescens (Wulf.) Hert. & Knoph
Porpidia macrocarpa (DC.) Hert. & Schwab
Pseudevernia consocians (Vain.) Hale & W. Culb.
1 unidentified species of Pyrenopsis
Pyxine sorediata (Ach.) Mont.
SRamalina americana Hale

I<u>Ramalina</u> <u>dilacerata</u> (Hoffm.) Hoffm.
<u>Ramalina</u> <u>intermedia</u> (Del. ex Nyl.) Nyl.
<u>Ramalina</u> <u>sinensis</u> Jatta
<u>Rhizocarpon</u> <u>badioatrum</u> (Fl"orke ex Spreng.) Th. Fr.
<u>Rhizocarpon</u> <u>disporum</u> (Naeg. ex Hepp) M"ull. Arg.
*<u>Rhizocarpon</u> <u>distinctum</u> Th. Fr.
<u>Rhizocarpon</u> <u>grande</u> (Fl"orke ex Flot.) Arn.
<u>Rhizocarpon</u> <u>hochstetteri</u> (K"orb.) Vain.
<u>Rhizocarpon</u> <u>obscuratum</u> (Ach.) Mass.
<u>Rhizocarpon</u> <u>plicatile</u> (Leight.) Sm.
<u>Rhizoplaca</u> <u>chrysoleuca</u> (Smith) Poelt
1 unidentified species of <u>Rhizocarpon</u>
<u>Rinodina</u> <u>archaea</u> (Ach.) Arn.
*<u>Rinodina</u> <u>colobina</u> (Ach.) Th. Fr.
<u>Rinodina</u> <u>dakotensis</u> Magn.
I<u>Rinodina</u> <u>exigua</u> (Ach.) S. Gray
*<u>Rinodina</u> <u>polyspora</u> Th. Fr.
<u>Rinodina</u> <u>subminuta</u> Magn.
*<u>Rinodina</u> <u>thujae</u> (Magn.) Sheard
*<u>Rinodina</u> <u>verrucosa</u> Sheard
2 unidentified species of <u>Rinodina</u>
I<u>Scoliciosporum</u> <u>chlorococcum</u> (Graew. ex Stenham.) Vezda
<u>Scoliciosporum</u> <u>umbrinum</u> (Ach.) Arn.
<u>Sphinctrina</u> <u>anglica</u> Nyl.
<u>Sphinctrina</u> <u>turbinata</u> (Pers.) De Not.
<u>Spilonema</u> <u>revertens</u> Nyl.
<u>Staurothele</u> <u>fissa</u> (Tayl.) Zw.
<u>Staurothele</u> <u>fuscocuprea</u> (Nyl.) Zsch.
I <u>Stenocybe</u> <u>major</u> Nyl. ex K"orb.
<u>Stenocybe</u> <u>pullatula</u> (Ach. ex Somm.) B. Stein.
<u>Stereocaulon</u> <u>paschale</u> (L.) Hoffm.
<u>Stereocaulon</u> <u>saxatile</u> Magn.
<u>Stereocaulon</u> <u>tomentosum</u> Fr.
<u>Strigula</u> <u>stigmatella</u> (Ach.) R. Harris
1 unidentified species of <u>Thelidium</u>
*<u>Trapelia</u> <u>involuta</u> (Tayl. in Mack.) Hert.
*<u>Trapelia</u> <u>obtegens</u> (Th. Fr.) Hert.
*<u>Trapelia</u> <u>placodioides</u> Coppins & James
<u>Umbilicaria</u> <u>deusta</u> (L.) Baumg.
<u>Umbilicaria</u> <u>mammulata</u> (Ach.) Tuck.
<u>Umbilicaria</u> <u>muehlenbergii</u> (Ach.) Tuck.
<u>Umbilicaria</u> <u>vellea</u> (L.) Ach.
<u>Usnea</u> <u>cavernosa</u> Tuck.
S <u>Usnea</u> <u>filipendula</u> Stirt.
S-I <u>Usnea</u> <u>hirta</u> (L.) Wigg.
<u>Usnea</u> <u>lapponica</u> Vain.
S-I <u>Usnea</u> <u>subfloridana</u> Stirt.
<u>Verrucaria</u> <u>margacea</u> (Wahlenb.) Wahlenb.
<u>Xanthoria</u> <u>elegans</u> (Link) Th. Fr.
S-I <u>Xanthoria</u> <u>fallax</u> (Hepp) Arn.
I <u>Xanthoria</u> <u>polycarpa</u> (Hoffm.) Rieber
<u>Xanthoria</u> <u>sorediata</u> (Vain.) Poelt
<u>Xylographa</u> <u>abietina</u> (Pers.) Zahlbr.

DISCUSSION OF FLORA

This list includes 350 species collected for this study. There are an additional 19 unidentified species and some of these may be undescribed. The most common species are Bryoria furcellata, Cladina rangiferina, Cladonia gracilis, Evernia mesomorpha, Hypogymnia physodes, Parmelia sulcata, Peltigera polydactyla, Physconia detersa and Usnea subfloridana. The lichen flora is very diverse and there were no cases where lichens sensitive to sulfur dioxide were observed to be damaged or killed. Numerous species most sensitive to sulfur dioxide are present, including many with blue green algae, and all species normally found fertile were also fertile in all parts of the BWCA. Fink (1903) reported 312 species from the area between Lake of the Woods and Tower and earlier (Fink, 1899) had reported 258 species from Grand Portage to Ely, including localities along Lake Superior (where there are more lichen species).

Wetmore (1981) reported 405 species in Voyageurs National Park but this study was based on over 8000 collections at 128 different localities most of which were along the lakeshores and this may account for the larger number of species. There were 86 species in Voyageurs not found in the BWCA and none of these was in the categories more sensitive to sulfur dioxide (S or S-I) so their absence in the BWCA is probably not related to air quality. In the present study there were 43 species found in the BWCA but not found in Voyageurs (indicated by `*' in the list above).

These observations indicate that there is no air quality degradation in the BWCA due to sulfur dioxide that causes observable damage to the lichen flora.

Since lichens are not known to be sensitive to acid precipitation, no conclusions can be drawn about this environmental contaminant. However, preliminary reports (Sigal & Johnston, 1986) indicate that some species of Umbilicaria do show damage from acid precipitation by dying at the margins. A few specimens of these lichens were seen with dead margins that might be due to acid rain.

Another way of analyzing the lichen flora of an area is to study the distributions of the sensitive species within the study area 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 eleven species in the BWCA in the most sensitive category 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 species that occur in the park in this category are as follows.

Bryoria furcellata
Bryoria trichodes
Dimerella lutea
Hypogymnia tubulosa
Lecidea vernalis
Lobaria pulmonaria
Ochrolechia androgyna
Parmelia squarrosa
Parmelia subaurifera
Ramalina americana
Usnea filipendula

The distributions of these species are mapped (Fig. 2-12). Although these species are not found at all localities and many 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 for some of these species.

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 six localities in different parts of the BWCA for laboratory analysis. Species collected and the substrates were Cladina rangiferina (on soil), Evernia mesomorpha (on trees) and Hypogymnia physodes (trees).

These species were selected because they are usually present in abundance and relatively easy to clean.

Six localities were selected to represent the geographical extremes of the BWCA and are indicated on the map of collection localities. These localities are: Saganaga Lake, E of Clark Isl.; S of Trap Lake; N end of Jackfish Bay of Basswood Lake; NE of Sandbar Isl. in Lac La Croix; SE corner of Trout Lake; and half mile W of Isabella Lake (this sample collected by Trana). A bag of ten to 20 grams of each species were collected at each locality from each of two places about 50 feet apart.

Lichens were air dried and cleaned of all bark under a dissecting microscope but thalli were not washed. Two samples of each collection bag were submitted for analysis except where inadequate material was available. 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 hours. 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 arranged by species. Table 2 gives the means and standard deviations for each set of replicates. All reported values are above the lower detection limits of the instruments.

All of the levels of sulfur found in the BWCA lichens are within typical limits for similar species. There is no significant difference between localities within one species. The sulfur levels are

Table 1: Analysis of BWCA Lichens

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
C. rangiferina	315	1477	487	240	219	167	23.9	21.8	12.7	1.6	1.5	2.1	0.4	0.4	0.2	495	Saganaga
C. rangiferina	469	1534	502	249	232	177	27	33.5	14.6	1.5	1.7	2.2	0.7	0.4	0.2	425	Saganaga
C. rangiferina	682	2069	845	345	198	146	46	60.1	20.8	2.2	1.4	1.5	0.6	0.4	0.2	445	Trap Lake
C. rangiferina	859	2587	634	347	221	166	26.8	44.7	19.5	2	1.9	0.9	0.6	0.4	0.1	580	Trap Lake
C. rangiferina	342	1387	449	218	244	201	24.6	29.1	13.2	1.4	1.3	1.7	0.7	0.4	0.1	418	Basswood L
C. rangiferina	392	1606	462	241	269	220	24.4	89.9	15.2	1.3	1.3	1.4	0.6	0.4	0.1	453	Basswood L
C. rangiferina	415	1637	472	284	288	239	29	18	12	1.4	1.9	1.3	0.7	0.5	0.2	470	Lac La Croix
C. rangiferina	579	2007	587	346	224	187	26.1	35.3	13.1	1.4	1.9	0.9	0.5	0.4	0.1	453	Lac La Croix
C. rangiferina	713	2420	683	349	179	200	33.8	81.7	18.3	1.8	1.8	0.9	0.5	0.4	0.1	493	Trout L
C. rangiferina	565	2235	532	313	284	325	29.3	34	15.2	1.5	2.2	1	0.7	0.5	0.2	488	Trout L
C. rangiferina	319	1494	597	239	231	192	31.8	48.4	15.5	1.5	1.8	1.1	0.3	0.4	0.2	440	Isabella L
C. rangiferina	351	1643	604	270	291	235	24.2	46.5	17.7	1.7	1.8	2	0.8	0.4	0.2	500	Isabella L
E. mesomorpha	462	2116	662	290	520	461	38.3	41.5	27.3	2.2	5.3	4.8	1.2	1	0.2	1078	Saganaga
E. mesomorpha	580	2532	692	331	466	397	52.3	93.1	27.6	2.6	5.5	5.2	1	1	0.5	1005	Saganaga
E. mesomorpha	534	2562	1006	277	371	296	26.1	29.7	34.1	2.5	5	4.4	0.7	0.7	0.2	948	Trap Lake
E. mesomorpha	435	2227	516	344	717	808	40.2	24.2	31.1	3.1	6	5.4	1	1.2	0.3	1310	Basswood L
E. mesomorpha	528	2532	1044	342	603	645	37.4	26.6	29.2	2.9	6.1	4.4	0.9	1	0.2	1133	Basswood L
E. mesomorpha	603	2746	1159	479	966	1037	50.4	23.8	29	3.3	6.6	5.3	1.2	1.5	0.3	1373	Lac La Croix
E. mesomorpha	447	2112	658	335	636	703	42.3	34.8	27	2.5	5.2	7.5	1	1.1	0.2	1148	Trout L
E. mesomorpha	319	1540	656	246	519	632	34.4	28.3	21.5	1.8	4.6	5.5	1	0.9	0.2	910	Trout L
E. mesomorpha	365	1912	1097	314	569	502	22.7	61.5	30.6	2.4	4.7	4.9	0.7	0.9	0.1	940	Isabella L
E. mesomorpha	431	2202	1952	396	720	667	28.1	76.6	34.7	3.1	5.1	7.2	0.9	1	0.2	1070	Isabella L
H. physodes	709	3223	18585	616	443	418	41.7	213.5	65.3	2.8	3.8	19.3	1.6	0.8	0.7	1025	Saganaga
H. physodes	740	3157	22165	618	480	444	39.5	329	60.8	2.8	3.5	16.7	1.5	1	0.7	1003	Saganaga
H. physodes	593	3337	17190	592	306	257	24.3	76.5	71.1	3.7	3.2	16	1.3	0.6	0.8	878	Trap Lake
H. physodes	849	3573	32955	553	336	333	30.7	117.7	105.7	4.2	5	20.9	1.2	0.6	0.8	930	Trap Lake
H. physodes	681	3326	15432	663	530	508	32.6	146.2	64.2	3.2	4.1	16.1	1.6	0.9	0.8	915	Basswood L
H. physodes	929	3775	22004	905	582	588	32.9	134.5	47.3	3.5	4.8	20.8	1.6	1	0.7	1033	Lac La Croix
H. physodes	790	3694	21045	752	491	605	35.5	180.3	59.2	3.3	4.9	13.8	1.8	1.1	0.6	1118	Trout L
H. physodes	633	3304	18332	639	481	571	29.5	194.8	54.8	2.7	3.3	17.8	1.5	0.9	0.6	1005	Trout L
H. physodes	656	3044	32543	880	640	607	24.7	340.3	75.3	3.8	4.9	24	1.6	1	1.5	835	Isabella L
H. physodes	447	2575	35893	733	515	566	20.7	319.9	61.2	3.8	4.1	29.9	1.7	0.8	1.2	770	Isabella L

Table 2: Summary of BWCA Analysis

Cladina rangiferina

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	392	1505	495	245	225	172	25.5	27.6	13.7	1.5	1.6	2.2	0.6	0.4	0.2	460	Saganaga
Std. dev.	109	41	10	7	9	7	2.2	8.3	1.4	0.1	0.1	0.1	0.2	<.1	<.1	49	
Mean	770	2328	740	346	210	156	36.4	52.4	20.2	2.1	1.7	1.2	0.6	0.4	0.2	513	Trap Lake
Std. dev.	125	366	149	1	16	14	13.6	10.9	0.9	0.1	0.4	0.4	0.1	<.1	<.1	95	
Mean	367	1496	455	230	256	210	24.5	59.5	14.2	1.4	1.3	1.5	0.7	0.4	0.1	435	Basswood L
Std. dev.	35	155	9	16	18	14	0.2	43	1.3	0.1	<.1	0.3	<.1	<.1	<.1	25	
Mean	497	1822	529	315	256	213	27.5	26.7	12.5	1.4	1.9	1.1	0.6	0.4	0.1	462	Lac La Croix
Std. dev.	116	262	81	43	46	37	2.1	12.2	0.8	<.1	<.1	0.2	0.1	<.1	<.1	12	
Mean	639	2328	607	331	231	263	31.5	57.9	16.7	1.6	2	1	0.6	0.4	0.1	490	Trout L
Std. dev.	104	131	107	26	74	88	3.2	33.7	2.2	0.2	0.3	<.1	0.1	0.1	<.1	4	
Mean	335	1568	601	254	261	214	28	47.5	16.6	1.6	1.8	1.6	0.6	0.4	0.2	470	Isabella L
Std. dev.	22	105	5	22	42	30	5.4	1.3	1.5	0.1	<.1	0.6	0.4	<.1	<.1	42	

Evernia mesomorpha

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	521	2324	677	311	493	429	45.3	67.3	27.4	2.4	5.4	5	1.1	1	0.3	1041	Saganaga
Std. dev.	83	294	21	30	38	45	9.9	36.5	0.3	0.3	0.1	0.3	0.1	<.1	0.2	51	
	534	2562	1006	277	371	296	26.1	29.7	34.1	2.5	5	4.4	0.7	0.7	0.2	948	Trap Lake
Mean	482	2380	780	343	660	726	38.8	25.4	30.1	3	6	4.9	0.9	1.1	0.2	1221	Basswood L
Std. dev.	66	215	373	1	81	116	1.9	1.7	1.4	0.1	0.1	0.7	0.1	0.2	0.1	126	
	603	2746	1159	479	966	1037	50.4	23.8	29	3.3	6.6	5.3	1.2	1.5	0.3	1373	Lac La Croix
Mean	383	1826	657	290	578	668	38.3	31.6	24.3	2.1	4.9	6.5	1	1	0.2	1029	Trout L
Std. dev.	90	405	1	63	83	50	5.6	4.6	3.9	0.5	0.4	1.4	<.1	0.1	<.1	168	
Mean	398	2057	1524	355	645	585	25.4	69	32.6	2.8	4.9	6.1	0.8	1	0.2	1005	Isabella L
Std. dev.	46	205	605	58	107	117	3.8	10.6	2.9	0.5	0.3	1.7	0.1	0.1	0.1	92	

Table 2, Continued: Summary of BWCA Analysis

Hypogymnia physodes

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	
Mean	724	3190	20375	617	461	431	40.6	271.3	63	2.8	3.6	18	1.6	0.9	0.7	1014	Saganaga
Std. dev.	22	47	2532	2	26	19	1.6	81.7	3.1	<.1	0.2	1.9	0.1	0.1	<.1	16	
Mean	721	3455	25072	572	321	295	27.5	97.1	88.4	3.9	4.1	18.4	1.3	0.6	0.8	904	Trap Lake
Std. dev.	181	167	11148	27	21	54	4.5	29.1	24.4	0.3	1.2	3.4	0.1	<.1	<.1	37	
	681	3326	15432	663	530	508	32.6	146.2	64.2	3.2	4.1	16.1	1.6	0.9	0.8	915	Basswood L
	929	3775	22004	905	582	588	32.9	134.5	47.3	3.5	4.8	20.8	1.6	1	0.7	1033	Lac La Croix
Mean	712	3499	19688	695	486	588	32.5	187.5	57	3	4.1	15.8	1.7	1	0.6	1061	Trout L
Std. dev.	111	276	1918	80	7	24	4.3	10.3	3.2	0.4	1.1	2.8	0.2	0.1	<.1	80	
Mean	552	2809	34218	807	577	586	22.7	330.1	68.3	3.8	4.5	26.9	1.7	0.9	1.4	803	Isabella L
Std. dev.	147	332	2369	104	88	29	2.8	14.4	10	<.1	0.6	4.2	0.1	0.1	0.2	46	

comparable to those found for these species in Voyageurs NP and Isle Royale NP. The sulfur levels in lichens tested range from 418 to 1387 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, for example, when comparing sulfur levels of different species at the same locality. Cladina rangiferina has lower levels than Evernia mesomorpha and Hypogymnia physodes. The differences in calcium levels between species is even more dramatic. Even when taking these differences into account there is no clear trend in accumulated levels of sulfur.

Of the other elements, iron shows somewhat higher levels at Lac La Croix in Evernia mesomorpha but not in the other species. Manganese and zinc are also higher for some species at some localities but this may reflect local rock or soil conditions.

CONCLUSIONS

There is no indication that the lichens of the BWCA are being damaged by air quality. The lichen flora is quite diverse and comparable to Voyageurs NP and there is no impoverishment of the lichen flora in any part of the BWCA. Those species most sensitive to sulfur dioxide are common throughout the area and their distributions reflect suitable ecological conditions and habitats. Most of the species reported from the region by Fink (1903) and from Voyageurs (Wetmore, 1981) are also present in the BWCA. The maps of the distributions of the most 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.

RECOMMENDATIONS

Although no air quality problems were detected in this study, the proximity of the BWCA to potential sources of air pollution indicates that periodic checks should be made. The most sensitive biological indicator of increasing air pollution is by elemental analysis of the lichens. This method will detect increased pollution long before the lichen flora is damaged (Wetmore, 1985). It is recommended that periodic checks (3-5 years) be run on several species of lichens for accumulation of pollutants. If increased levels of pollutants are detected then permanent plots should be established to monitor the lichen flora for loss of vigor or species, or monitoring instruments can be installed.

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APPENDIX I

Collection Localities

Below are listed the collections localities of Clifford Wetmore and Thomas Trana for this survey. The first list is that of C. Wetmore and the localities of T. Trana follow. All collections within each list are in ascending order by collection number and date of collection.

Collections of C. Wetmore

Cook Co.
56740- Saganaga Lake, E of Clark Isl. On ridge up from shore 56840 with balsam fir, black spruce and some pines, Sec. 8, T66N, R4W. 18 Sept. 1986. Chemical analysis.

56841- Saganaga Lake, W of Gold Isl. near Lone Creek. Along 56928 shore with Thuja, balsam fir, spruce and rocks, Sec. 15, T66N, R5W. 18 Sept. 1986.

56929- Sea Gull Lake at southern end of Fishook Isl. With 57022 jack pine, spruce, rocks and some Thuja, Sec. 1, T65N, R5W. 19 Sept. 1986.

57023- Southern end of Sea Gull Lake between Rog and Sea Gull 57126 Lakes. Along shores and stream in ash, quaking aspen and some pine and Thuja, Sec. 16, T65N, R5W. 19 Sept. 1986.

57127- NE of Sea Gull Ranger Station along Gunflint Trail. On 57216 ridge with jack pines, quaking aspen and rock ledges, Sec. 10, T65N, R4W. 20 Sept. 1986.

57217- South of west end of Loon Lake, NE of Dawkins Lake. 57293 Lowland with mixed balsam fir, old quaking aspen and some black spruce, Sec. 6, T64N, R3W. 20 Sept. 1986.

57294- South side of Topper Lake, S of South Lake. Along 57357 shore with white pine, mountain maple, balsam fir and black spruce, Sec. 27, T65N, R2W. 20 Sept. 1986.

57358- Above Poplar Creek SE of Poplar Lake. On small hill 57429 with quaking aspen, balsam fir and spruce, Sec. 22, T64N, R1W. 21 Sept. 1986.

57430- South of Trap Lake south of Crocodile Lake just 57486 outside of BWCA. On hillside with white pine, quaking aspen and brush, Sec. 19, T64N, R1E. 21 Sept. 1986. Chemical analysis.

Lake Co.
57487- North end of Jackfish Bay of Basswood Lake. On rocky 57567 point on N side above a cliff with jack pine, some quaking aspen and spruce, Sec. 36, T65N, R11W. 22 Sept. 1986. Chemical analysis.

St. Louis Co.
57568- Newton Lake just S of Pipestone Falls. In bog with 57645 black ash and Thuja, Sec. 27, T64N, R11W. 22 Sept. 1986.

57646- Lac La Croix near Snow Bay, on piont NE of Sandbar 57713 Isl. On low ridge with pines, birch and some quaking aspen, Sec. 32, T68N, R15W. 23 Sept. 1986. Chemical analysis.

57714- Trout Lake, NW side near Orniniack Lake Portage. On 57794 hillside with red pine and white pine and few quaking aspen, Sec. 26, T64N, R16W. 24 Sept. 1986.

57795- Trout Lake at SE corner E of Steamboat Isl. On north 57858 facing hillside with Thuja, balsam fir and black spruce, Sec. 19, T63N, R15W. 24 Sept. 1986. Chemical analysis.

Collections of T. Trana

[Note: USFS used for U. S. Forest Service; * used for degree symbol.]

St. Louis Co.
13103- N of USFS Trail #92 on the E shore of Slim Lake, 9 13207 miles NW of Ely (SW 1/4 NW 1/4 Sec. 26, T64N, R13W). 48* N, 91* 58' W. Elev. ca. 1600 ft. Rock outcroppings on summit of hill with occasional maple, oak, and red pine. 4 Sept. 1986.

13208- Along USFS Trail #159, half mile WSW of the S end of 13317 Angleworm Lake; 13 miles NNW of Ely (NW 1/4 NW 1/4 Sec. 32, T65N, R12W). 48* 05' N, 91* 53' W. Elev. ca. 1450 ft. Open mixed coniferous-deciduous woods on rock out crops. 5 Sept. 1986.

13318- W of Little Indian Sioux River, half mile N of USFS 13404 Route 116; 24 miles NW of Ely (NW 1/4 NW 1/4 Sec. 1, T65N, R15W). 48* 08' N, 92* 13' W. Elev. 1300 ft. Dry black ash-balsam fir swamp along stream, with stands of balsam fir and balsam poplar around the upland periphery. 6 Sept. 1986.

13405- Just E of Bezhik Creek, SE of Seranade Lake; 17 miles 13482 NW of Ely (SE 1/4 SE 1/4 Sec. 5, T64N, R14W). 48* 03' N, 92* 08' W. Elev. ca. 1400 ft. Black spruce-Ledum- Sphagnum bog, with a few tamarack, balsam fir, and paper birch along the bog's border with a Carex marsh. 7 Sept. 1986.

13483- Half mile E of Range Line Creek, half mile S of 13563 County Route 116; 21 miles NW of Ely (E 1/2 NE 1/4 Sec. 18, T65N, R14W). 48* 07' N, 92* 12' W. Elev. ca. 1450 ft. White spruce and balsam fir stands on a moderate W & SW slope, with interspersed paper birch and balsam poplar. 8 Sept. 1986.

13564- At the end of the Moose River Portage, 1.5 miles N 13634 of County Route 116; 20 miles NW of Ely (SE 1/4 NW 1/4 Sec. 11, T65N, R14W). 48* 08' N, 92* 06' W. Elev. 1300 ft. Balsam fir-paper birch woods on moderate N-facing slope, with scattered red and white pine and balsam poplar. 8 Sept. 1986.

Lake Co.
13635- Near S shore of South Farm Lake, 0.75 mile E of 13735 County Route 16; 8 miles ESE of Ely (SE 1/4 Sec. 2, T62N, R11W). 47* 53' N, 91* 41' W. Elev. 1400 ft. Black ash swamp along stream plus rocky area in woods. 11 Sept. 1986.

13736- 0.75 mile SW of Sourdough Lake, 10 miles ENE of Ely 13859 (SE 1/4 NE 1/4 Sec. 7, T63N, R10W). 47* 57' N, 91* 39' W. Elev. 1500 ft. Sunny outcrop area, with surrounding forest of paper birch, balsam poplar, trembling aspen, and conifers. 12 Sept.1986.

13860- Just N of the Kawishiwi River, 1/8 mile SE of the S 13956 end of USFS Road #439; 17 miles E of Ely (SE 1/4 SW 1/4
Sec. 17, T63N, R9W). 47* 56' N, 91* 30' W. Elev. ca. 1500 ft. Jack pine stand on outcrop near shore of river. 13 Sept. 1986.

13957- 1/8 mile E of Boy Scout Camp on E shore of Moose 14101 Lake, 19 miles ENE of Ely (SE 1/4 NW 1/4 Sec. 28,
T64N, R9W). 48* N, 91* 30' W. Elev. ca. 1400 ft. Thuja- black ash swamp in valley between 20-ft. N- and S- facing cliffs. 14 Sept. 1986.

14102- Snake River, 1 mile SSW of S tip of Bald Eagle Lake; 14136 18 miles SE of Ely (SE 1/4 SE 1/4 Sec. 12, T61N, R10W).
47* 47' N, 91* 32' W. Elev. 1500 ft. Open, sunny clear ing (a former homestead) just W of the river. 15 Sept. 1986.

14137- Snake River, 1 mile S of S tip of Bald Eagle Lake; 18 14200 miles SE of Ely (SE 1/4 SE 1/4 Sec. 12, T61N, R10W +
1NW 1/4 SW 1/4 Sec. 7, T61N, R9W). 47* 47' N, 91* 32' EW. Elev. 1490 ft. Black ash, balsam fir, paper birch, sand pruce along the E bank of the river. 15 Sept. 1986.

14202- SW corner of Little Gabbro Lake, 11 miles ESE of Ely 14325 (SE 1/4 SW 1/4 Sec. 17, T62N, R10W). 47* 52' N, 91* 37'
W. Elev. 1480 ft. Jack pine-black spruce stand on rocky outcrop on shore of lake. 16 Sept. 1986.

Cook Co.

14326- Along the trail from the Eagle Mountain Trail (USFS 14433 #131) to the Brule Lake Lookout Tower, 18 miles NW of
Grand Marais (NE 1/4 NE 1/4 Sec. 25, T63N, R3W). 47* 55' N, 90* 39' W. Elev. 2000-2100 ft. Paper birch- trembling aspen woods with scattered spruce and balsam fir. 19 Sept. 1986.

14434- W shore of Whale Lake & the SE base of Eagle 14560 Mountain, 14 miles NW of Grand Marais (SW 1/4 SW 1/4
Sec. 35, T63N, R2W). 47* 52' N, 90* 33' W. Elev. ca. 2000 ft. Thuja, paper birch, and balsam fir near the lakeshore. 20 Sept. 1986.

14561- Along the S shore of Baker Lake, NW of Baker Lake 14649 Campground, 19 miles N of Tofte (SE 1/4 SW 1/4 Sec. 15,
T62N, R4W). 47* 50' N, 90* 49' W. Elev. ca. 1750 ft. Red and white pine stand with understory of balsam fir, spruce, birch, and Thuja. 22 Sept. 1986.

14650- 0.75 mile E of Sawbill Lake Campground, 21 miles N of 14772 Tofte (SW 1/4 NW 1/4 Sec. 8, T62N, R4W). 47* 53' N, 90*
52' W. Elev. ca. 1850 ft. Black ash and black spruce bogs, plus groves of aspen and a willow-alder marsh. 23 Sept. 1986.

Lake Co.

14773- 1/2 mile NE of Kawishiwi Lake Campground, 22 miles 14877 NNW of Tofte (SW 1/4 NE 1/4 Sec. 21, T62N, R6W). 47*
51' N, 91* 06' W. Elev. ca. 1650 ft. Trembling aspen- paper birch stand with scattered pines, spruce, and fir. 24 Sept. 1986.

Cook Co.

14878- 1.5 miles SSE of Phoebe Lake, 19 miles NNW of 14942 Tofte (SE 1/4 SW 1/4 Sec. 20, T62N, R5W). 47* 50' N,

90* 59' W. Elev. ca. 1920 ft. Grove of large trembling aspen with a few paper birch and a dense understory of alder and mountain maple. 24 Sept. 1986.

14943- Just outside BWCA 1.5 miles SSE of Phoebe Lake, 19 14988 miles NNW of Tofte (NE 1/4 NW 1/4 Sec. 29, T62N, R5W).

47* 50' N, 90* 59' W. Elev. 1900 ft. Open, sunny area with widely spaced maples, pines,spruce, aspen, and birch. 24 Sept. 1986.

Lake Co.

14989- Half mile W of Isabella Lake, next to USFS Route 151, 15055 25 miles ESE of Ely (SW 1/4 SW 1/4 Sec. 26, T62N, R8W). 47* 48' N, 91* 19' W. Elev. ca. 1580 ft. Black ash-Ledum-Sphagnum bog. 26 Sept. 1986. Chemical analysis.

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 the BWCA fall within the Sensitive category as listed by Wetmore, 1983. Sensitive species (S) are those present only under 50ug sulfur dioxide per cubic meter (average annual). Open circles 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 BWCA.

Fig. 2 *Bryoria furcellata*
Fig. 3 *Bryoria trichodes*
Fig. 4 *Dimerella lutea*
Fig. 5 *Hypogymnia tubulosa*
Fig. 6 *Lecidea vernalis*
Fig. 7 *Lobaria pulmonaria*
Fig. 8 *Ochrolechia androgyna*
Fig. 9 *Parmelia squarrosa*
Fig. 10 *Parmelia subaurifera*
Fig. 11 *Ramalina americana*
Fig. 12 *Usnea filipendula*