C Wetmore

LICHENS AND AIR QUALITY IN

DELAWARE WATER GAP RECREATION AREA

FINAL REPORT

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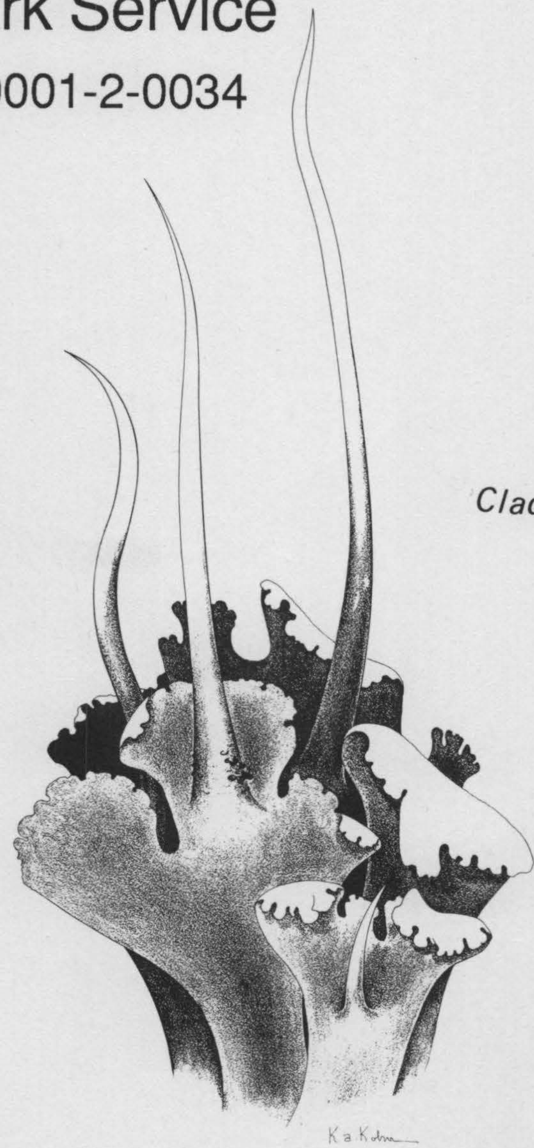

Cladonia coniocraea

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IN
DELAWARE WATER GAP NATIONAL RECREATION AREA

Final Report

National Park Service
Contract CX 0001-2-0034

National Park Service Contracting Officer
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LICHENS OF DELAWARE WATER GAP NRA

PREFACE

Under a grant from the National Park Service (USDI CX 0001-2-0034) a lichen study was to be performed in Delaware Water Gap National Recreation Area. 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. Assistance in identification of some of the problem species was provided by Dr. John Thomson. 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.

Delaware Water Gap NRA extends along the Delaware River in eastern Pennsylvania from Stroudsburg, Pa. north to near the New York state line and includes territory along the river in New Jersey and Pennsylvania. The park includes low hills and river bottoms with elevations from 300 to 1500 feet. The vegetation is eastern deciduous forest with some areas of conifers.

In some of the moist valleys there are stands of eastern hemlock (*Tsuga canadensis*) with white pine (*Pinus strobus*) on the drier slopes. Most of the ridges and slopes are mixed oak-maple forests with red oak (*Quercus borealis*), black oak (*Quercus velutina*), chestnut oak (*Quercus montana*), shagbark hickory (*Carya ovata*), sugar maple (*Acer saccharum*) and birch (*Betula populifolia* and *B. lenta*). In the lowlands there are occasional stands of red maple (*Acer rubrum*), white spruce (*Picea glauca*), basswood (*Tilia americana*) and white ash (*Fraxinus americana*). There are numerous steep shale banks where gravel has been removed leaving some steep cliffs. The ridgetops in a few locations in the southern part of the park are capped with limestone but these areas are quite limited.

METHODS

Field work was done during July and August, 1986 and 1029 collections were made at 33 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, 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 the label data 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

Although there are no very early records of lichens from the park, Darlington (1853) published a list of lichens from Chester County, near Philadelphia and Britton (1889) included lichens in his list of plants of New Jersey. Wood (1914) published a list of lichens occurring within 100 miles of New York City and his area includes the present park. The lichens reported by Britton and Wood from the counties in which the present park is located are included here as literature records but those reported by Darlington are not, although most of the species in the latter list probably did occur also within the present park boundaries. Niering (1953) studied the ecology of High Point State Park in Sussex County, N. J. and reported some lichens. Nash (1972, 1975) studied the disappearance of lichens in the Lehigh Water Gap and used one locality at Delaware Water Gap as his control locality. It is apparent from his list for Delaware Water Gap that even in his control locality many of the lichens were gone.

The following list of lichens is based on my collections, historical specimens in the University of Minnesota herbarium and those reported in the literature. The species previously reported but not found in this study are preceded by an asterisk and those in brackets are probable misidentifications. 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 OF DELAWARE LICHENS

*Acarospora chlorophana (Wahlenb. in Ach.) Mass. Wood, 1914
*Acarospora discreta (Ach.) Th. Fr. Wood, 1914
Acarospora fuscata (Nyl.) Arn. Nash, 1972
*Acarospora schleicheri(Ach.) Mass. Wood, 1914
1 additional unidentified species of Acarospora
*Alectoria ochroleuca (Hoffm.) Mass. Britton, 1889
Anaptychia palmulata (Michx.) Vain. Wood, 1914
Anisomeridium juistense(Erichs.) R. Harris

Arthonia byssacea (Weig.) Almq.
Arthonia caesia (Flot.) Körb. Wood, 1914
*Arthonia glaucescens Nyl. Wood, 1914
*Arthonia glebosa Tuck. Wood, 1914
I *Arthonia radiata (Pers.) Ach. Wood, 1914
*Arthopyrenia punctiformis Mass. Wood, 1914
*Arthothelium spectabile (Flot. ex Fr.) Mass. Wood, 1914
Aspicilia caesiocinerea (Nyl. ex Malbr.) Arn.
Aspicilia cinerea (L.) Körb. Wood, 1914, Nash, 1972, 1975
*Aspicilia gibbosa (L.) Körb. Wood, 1914
*Aspicilia limitata (Magn.) ined. Nash, 1972
1 additional unidentified species of Aspicilia
*Bacidia bagliettoana (Mass.) Jatta Wood, 1914
*Bacidia chlorosticta (Tuck.) Schneid. Wood, 1914
*Bacidia cupreoresella (Nyl.) Schneid. Britton, 1889
*Bacidia granosa (Tuck.) Zahlbr. Wood, 1914
Bacidia inundata (Fr.) Körb. Wood, 1914
*Bacidia polychroa (Th. Fr.) Körb. Wood, 1914
I *Bacidia rubella (Hoffm.) Mass. Wood, 1914
*Bacidia sabuletorum (Schreb.) Lett. Wood, 1914
Bacidia schweinitzii (Tuck.) Schneid. Wood, 1914
*Bacidia suffusa (Fr.) Schneid. Wood, 1914
2 additional unidentified species of Bacidia
Baeomyces fungoides (Sm.) Ach. Wood, 1914, Nash, 1972
*Biatorella campestris (Fr.) Almq. Wood, 1914
*Biatorella fossarum (Duf. ex Fr.) Th. Fr. Wood, 1914
*Biatorella resinae (Fr.) Th. Fr. Wood, 1914
*Bryoria bicolor (Ehrh.) Brodo & Hawksw. Britton, 1889,
*Bryoria chalybeiformis (L.) Brodo & Hawksw. Wood, 1914
S *Bryoria furcellata (Fr.) Brodo & Hawksw. Brodo & Hawksworth, 1977
S *Bryoria implexa (Hoffm.) Brodo & Hawksw. Wood, 1914
S *Bryoria trichodes (Michx.) Brodo & Hawksw. Wood, 1914
Buellia dialyta (Nyl.) Tuck. Wood, 1914, Nash, 1972, 1975
*Buellia disciformis (Fr.) Mudd Wood, 1914
Buellia polyspora (Will.) Vain.
T Buellia punctata (Hoffm.) Mass. Wood, 1914
*Buellia schaereri DeNot. Wood, 1914
*Buellia spuria (Schaer.) Anzi Wood, 1914
*Buellia stellulata (Tayl.) Mudd Wood, 1914
*Buellia stigmaea Tuck. Nash, 1972
I Buellia stillingiana J. Stein.
*Buellia vernicoma (Tuck.) Tuck. Wood, 1914
*Calicium abietinum Pers. Wood, 1914
*Calicium trabinellum (Ach.) Ach. Wood, 1914
S-I *Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr. Wood, 1914
*Caloplaca cinnabarina (Ach.) Zahlbr. Wood, 1914
Caloplaca cirrochroa (Ach.) Th. Fr.
Caloplaca citrina (Hoffm.) Th. Fr.
*Caloplaca ferruginea (Huds.) Th. Fr. Wood, 1914
S Caloplaca flavorubescens (Huds.) Laund. Wood, 1914
Caloplaca flavovirescens (Wulf.) DT & S Wood, 1914, Nash, 1972

Caloplaca vitellinula (Nyl.) Oliv.
2 additional unidentified species of Caloplaca
S-I Candelaria concolor (Dicks.) B. Stein. Wood, 1914, Nash, 1972
Candelariella efflorescens Harris & Buck
I Candelariella vitellina (Hoffm.) Müll. Arg. Nash, 1972
S-I Candelariella xanthostigma (Ach.) Lett.
S *Catillaria griffithii (Sm.) Malme Wood, 1914
Catillaria lenticularis (Ach.) Th. Fr.
Cetraria arenaria Karnef. Kärnefelt, 1979
Cetraria aurescens Tuck. Wood, 1914
S-I Cetraria ciliaris Ach. Wood, 1914
*Cetraria commixta (Nyl.) Th. Fr. Britton, 1889, Wood, 1914
Cetraria culbersonii Hale
*Cetraria fendleri (Nyl.) Tuck. Wood, 1914
[*Cetraria islandica (L.) Ach. Britton, 1889, Wood, 1914, Torrey, 1937: misident. = arenaria]
*Cetraria juniperina (L.) Ach. Wood, 1914
Cetraria oakesiana Tuck. Nash, 1972
Cetrelia chicitae (W. Culb.) W. & C. Culb.
Cetrelia olivetorum (Nyl.) W. & C. Culb.
*Chaenotheca phaeocephala (Turn.) Th. Fr. Wood, 1914
Chaenothecopsis rubescens Vain.
Cladina arbuscula (Wallr.) Hale & W. Culb. Wood, 1914
Cladina rangiferina (L.) Nyl. Niering, 1953, Nash, 1972
*Cladina stellaris (Opiz) Brodo Wood, 1914
Cladonia apodocarpa Robb. Nash, 1972
Cladonia atlantica Evans
Cladonia bacillaris Nyl. Nash, 1972
Cladonia caespiticia (Pers.) Flörke
*Cladonia cariosa (Ach.) Spreng. Wood, 1914 Nash, 1972
Cladonia caroliniana Schwein. ex Tuck. Niering, 1953
*Cladonia chlorophaea (Flörke ex Somm.) Spreng. Nash, 1972
Cladonia coccifera (L.) Willd. Britton, 1889, Wood, 1914
I Cladonia coniocraea (Flörke) Spreng. Nash, 1972, 1975
Cladonia cornuta (L.) Hoffm. Wood, 1914
*Cladonia crispata (Ach.) Flot. Wood, 1914
I Cladonia cristatella Tuck. Nash, 1972, 1975
Cladonia cylindrica (Evans) Evans
Cladonia deformis (L.) Hoffm.
S-I *Cladonia fimbriata (L.) Fr. Wood, 1914, Nash, 1972
Cladonia floerkeana (Fr.) Flörke
Cladonia furcata (Huds.) Schrad. Wood, 1914 Nash, 1972
*Cladonia gracilis (L.) Willd. Wood, 1914
Cladonia grayi Merr. ex Sandst.
Cladonia macilenta Hoffm. Wood, 1914 Nash, 1972
Cladonia mateocyatha Robb.
Cladonia parasitica (Hoffm.) Hoffm. Wood, 1914
Cladonia peziziformis (With.) Laund. Britton, 1889, Wood, 1914
Cladonia phyllophora Ehrh. ex Hoffm. Britton, 1889, Wood, 1914

Cladonia pleurota (Flörke) Schaer. Nash, 1972
Cladonia polycarpoides Nyl.
Cladonia pyxidata(L.) Hoffm. Wood, 1914 Nash, 1972
Cladonia rei Schaer.
Cladonia robbinsii Evans
*Cladonia scabriuscula (Del. in Duby) Nyl. Wood, 1914
*Cladonia sobolescens (Nyl.) Vain. Nash, 1972
Cladonia squamosa (Scop.) Hoffm. Wood, 1914, Nash, 1972, 1975
Cladonia strepsilis (Ach.) Vain.
*Cladonia stricta (Nyl.) Nyl. Wood, 1914
*Cladonia subulata (L.) Webb. in Wigg. Wood, 1914
*Cladonia symphycarpa (Ach.) Fr. Wood, 1914
*Cladonia turgida Hoffm. Britton, 1889, Wood, 1914
Cladonia uncialis (L.) Wigg. Wood, 1914, Niering, 1953, Nash, 1972, 1975
Cladonia verticillata (Hoffm.) Schaer. Wood, 1914
1 additional unidentified species of Cladonia
*Coccocarpia erythroxyli (Spreng.) Swinsc. & Krog Wood, 1914
Coccocarpia palmicola (Spreng.) Arvid & Gall. Britton, 1889
*Collema conglomeratum Hoffm. Wood, 1914
*Collema flaccidum (Ach.) Ach. Wood, 1914
*Collema fragrans (Sm.) Ach. Wood, 1914
*Collema fuscovirens (With.) Laund. Britton, 1889, Wood, 1914
*Collema leptaleum Tuck. Wood, 1914
*Collema nigrescens (Huds.) DC. Wood, 1914
*Collema ryssoleum (Tuck.) Schneid. Britton, 1889, Wood, 1914
Collema subflaccidum Degel.
*Collema tenax (Sw.) Ach. Britton, 1889, Wood, 1914
[*Collema verruciforme misident. Wood, 1914]
*Conotrema urceolatum (Ach.) Tuck. Wood, 1914
*Cyphelium tigillare (Ach.) Ach. Wood, 1914
*Dendriscocaulon intricatulum (Nyl.) Henss. Wood, 1914
*Dermatocarpon lachneum (Ach.) A. L. Sm. Britton, 1889, Wood, 1914
*Dermatocarpon luridum (With.) Laund. Wood, 1914
Dermatocarpon miniatum (L.) Mann Britton, 1889,
*Dermatocarpon tuckermanii (Rav.) Zahlbr. Wood, 1914
Dimelaena oreina (Ach.) Norm. Niering, 1953, Nash, 1972
*Dimerella pineti (Dicks.) Trev. Nash, 1972
Diplochistes scruposus (Schreb.) Norm. Wood, 1914
1 additional unidentified species of Diploschistes
Dirinaria frostii (Tuck.) Hale & W. Culb. Thomson, 1963
*Eopyrenula leucoplaca (Wallr.) R. Harris Wood, 1914
*Ephebe lanata (L.) Vain. Britton, 1889, Wood, 1914
I Evernia mesomorpha Nyl.
I *Graphis elegans (Borr. ex Sm.) Ach. Wood, 1914
I Graphis scripta (L.) Ach. Wood, 1914, Nash, 1972
I *Haematomma ochrophaeum (Tuck.) Mass. Nash, 1972

Haematomma pustulatum Brodo
*Heterodermia galactophylla (Tuck.) W. Culb. Wood, 1914
*Heterodermia hypoleuca (Muehl.) Trev. Wood, 1914
Heterodermia obscurata (Nyl.) Trev.
Heterodermia speciosa (Wulf.) Trev. Wood, 1914
*Hydothyria venosa Russ. Wood, 1914
*Hymenelia lacustris (With.) Poelt & Vezda Wood, 1914
I *Hyperphyscia adglutinata (Flörke) Mayrh. & Poelt Wood, 1914
I Hypogymnia physodes (L.) Nyl. Wood, 1914, Nash, 1972
*Icmadophila ericetorum (L.) Zahlbr. Britton, 1889, Wood, 1914
Lasallia papulosa (Ach.) Llano Llano, 1950, Niering, 1953, Nash, 1972, 1975
Lasallia pensylvanica (Hoffm.) Llano Britton, 1889, Llano, 1950, Niering, 1953, Nash, 1972, 1975
I *Lecanora allophana Nyl. Wood, 1914
*Lecanora cancriformis (Hoffm.) Vain. Wood, 1914
I *Lecanora chlarotera Nyl. Nash, 1972
*Lecanora cupressi Tuck. Wood, 1914
T Lecanora dispersa (Pers.) Somm.
T Lecanora hagenii (Ach.) Ach. Wood, 1914
Lecanora impudens Degel.
T Lecanora muralis (Schreb.) Rabenh. Britton, 1889, Wood, 1914
I *Lecanora pallida (Schreb.) Rabenh. Wood, 1914
Lecanora strobilina (Spreng.) Kieff.
I Lecanora symmicta (Ach.) Ach. Wood, 1914
*Lecanora tesselina (Tuck.) Zahlbr. Wood, 1914
Lecanora thysanophora ined.
*Lecanora varia (Hoffm.) Ach. Wood, 1914
*Lecanora willeyi Tuck. Wood, 1914
Lecidea aeruginosa Borr. in Hook. & Sowerb.
Lecidea anthracophila Nyl. Wood, 1914
*Lecidea athroocarpa (Ach.) Ach. Wood, 1914
Lecidea auriculata Th. Fr.
Lecidea cyrtidia Tuck. Nash, 1972
*Lecidea erratica Körb. Nash, 1972
Lecidea friesii Ach. in Liljebl.
*Lecidea geophana Nyl. Wood, 1914
Lecidea granulosa (Hoffm.) Ach. Wood, 1914, Nash, 1972
Lecidea helvola (Körb. ex Hellb.) Oliv.
Lecidea hypnorum Libert Wood, 1914
*Lecidea icteria (Mont.) Tayl. Wood, 1914
Lecidea russellii Tuck. Britton, 1889, Wood, 1914
*Lecidea russula Ach. Wood, 1914
I Lecidea scalaris(Ach.) Ach. Nash, 1972, 1975
*Lecidea tessellata Flörke Wood, 1914
*Lecidea varians Ach. Wood, 1914
S *Lecidea vernalis (L.) Ach. Britton, 1889, Wood, 1914
Lecidea viridescens (Schrad.) Ach. Wood, 1914, Nash, 1972
I *Lecidella elaeochroma (Ach.) Choisy Wood, 1914
Lecidella stigmatea (Ach.) Hert. & Leuck.

*Lempholemma myriococcum (Ach.) Th. Fr. Britton, 1889, Wood, 1914
Lepraria finkii (B. de Lesd. in Hue) R. Harris
I-T *Lepraria incana (L.) Ach. Nash, 1972, 1975
*Lepraria membranacea auct. Wood, 1914, Nash, 1972, 1975
Lepraria neglecta (Nyl.) Lett. Niering, 1953 Lepraria lobificans
Lepraria zonata Brodo Nash, 1972, 1975
*Leptogium byssinum (Hoffm.) Zw. ex Nyl. Wood, 1914
*Leptogium chloromelum (Sw. ex Ach.) Nyl. Wood, 1914
*Leptogium corniculatum (Hoffm.) Minks Wood, 1914
*Leptogium corticola (Tayl.) Tuck. Wood, 1914
Leptogium cyanescens (Rabenh.) Körb. Wood, 1914, Sierk, 1964
*Leptogium juniperinum Tuck. Sierk, 1964
Leptogium lichenoides (L.) Zahlbr. Wood, 1914, Sierk, 1964
*Leptogium saturninum (Dicks.) Nyl. Britton, 1889, Wood, 1914
*Leptogium tenuissimum (Dicks.) Körb. Wood, 1914
Leptorhapsis epidermidis (Ach.) Th. Fr. Wood, 1914
Lichenothelia scopularia (Nyl.) Hawksw.
S *Lobaria pulmonaria (L.) Hoffm. Wood, 1914, Jordan, 1973
*Lobaria quercizans Michx. Britton, 1889, Wood, 1914, Jordan, 1973
I *Lopadium pezizoideum (Ach.) Körb. Wood, 1914
*Maronea constans (Nyl.) Hepp Wood, 1914
*Melaspilea urceolata (Fr.) Almb. Wood, 1914
*Micarea denigrata (Fr.) Hedl. Wood, 1914
Micarea melaena (Nyl.) Hedl. Nash, 1972
*Micarea peliocarpa (Anzi) Coppins & Sant. Nash, 1972, 1975
Micarea prasina Fr. Nash, 1972
*Microthelia thelena (Ach.) Trev. Wood, 1914
*Mycocalicium fuscipes (Tuck.) Fink Wood, 1914
*Mycocalicium subtile (Pers.) Szat. Wood, 1914
*Mycoporum pycnocarpum Nyl. Wood, 1914
*Nephroma bellum (Spreng.) Tuck. Wood, 1914, Wetmore, 1960
*Nephroma helveticum Ach. Wood, 1914, Wetmore, 1960
*Nephroma resupinatum (L.) Ach. Wood, 1914
S Ochrolechia androgyna (Hoffm.) Arn.
Ochrolechia arborea (Kreyer) Almb.
*Ochrolechia pallescens (L.) Mass. Wood, 1914
*Ochrolechia parella (L.) Mass. Nash, 1972
Ochrolechia pseudopallescens Brodo
*Ochrolechia tartarea (L.) Mass. Wood, 1914
I *Opegrapha varia Pers. Wood, 1914
*Opegrapha viridis (Pers. ex Ach.) Nyl. Wood, 1914
I *Opegrapha vulgata Ach. Wood, 1914
*Pannaria leucophaea (Vahl) P. M. Jorg. Wood, 1914
Pannaria leucosticta (Tuck. in Darl.) Nyl. Wood, 1914
*Pannaria lurida (Mont.) Nyl. Wood, 1914
Parmelia aurulenta Tuck. Nash, 1972
Parmelia baltimorensis Gyeln.
*Parmelia borreri (Sm.) Turn. Wood, 1914

I *Parmelia caperata* (L.) Ach. Wood, 1914, Nash, 1972, 1975
**Parmelia centrifuga* (L.) Ach. Wood, 1914
Parmelia conspersa (Ehrh. ex Ach.) Ach. Wood, 1914, Berry, 1941, Niering, 1953, Nash, 1972, 1975
**Parmelia crinita* Ach. Wood, 1914
Parmelia cumberlandia (Gyeln.) Hale Nash, 1972
Parmelia flaventior Stirt.
Parmelia galbina Ach. Wood, 1914
Parmelia hypopsila Müll. Arg.
I **Parmelia olivacea* (L.) Ach. Wood, 1914
Parmelia perforata (Jacqu.) Ach. Wood, 1914
S **Parmelia perlata* (Huds.) Vain. Britton, 1889, Wood, 1914
Parmelia plittii Gyeln. Nash, 1972, 1975
**Parmelia quercina* (Will.) Vain. Wood, 1914
I *Parmelia rudecta* Ach. Wood, 1914, Berry, 1941, Nash, 1972, 1975
I **Parmelia saxatilis* (L.) Ach. Wood, 1914, Berry, 1941, Nash, 1972, 1975
**Parmelia somediosa* Almb. Nash, 1972
S *Parmelia squarrosa* Hale
S *Parmelia subaurifera* Nyl. Esslinger, 1977a
Parmelia subrudecta Nyl. Nash, 1972
I-T *Parmelia sulcata* Tayl. Wood, 1914, Nash, 1972
Parmelia taractica Kremp. Nash, 1972, 1975
Parmelia tasmanica Hook. f. & Tayl. Nash, 1972
I *Parmeliopsis aleurites* (Ach.) Nyl. Wood, 1914, Nash, 1972
I *Parmeliopsis ambigua* (Wulf.) Nyl. Wood, 1914
**Peltigera aphthosa* (L.) Willd. Wood, 1914
Peltigera canina (L.) Willd. Wood, 1914
**Peltigera didactyla*(With.) Laund. Wood, 1914, Thomson, 1950
Peltigera evansiana Gyeln.
I **Peltigera horizontalis* (Huds.) Baumg. Wood, 1914
Peltigera neckeri Müll. Arg.
**Peltigera polydactyla* (Neck.) Hoffm. Britton, 1889, Wood, 1914, Thomson, 1950
Peltigera rufescens (Weis) Humb. Wood, 1914, Thomson, 1950
**Peltigera venosa* (L.) Hoffm. Wood, 1914
Peltula euploca (Ach.) Ozend. & Clauz.
Pertusaria concosians Dibb.
**Pertusaria globularis* (Ach.) Tuck. Wood, 1914
**Pertusaria leioplaca* DC. in Lam. & DC. Wood, 1914
Pertusaria macounii (Lamb) Dibb.
I **Pertusaria multipunctoides* Dibb. Dibben, 1980
**Pertusaria ophthalmiza* (Nyl.) Nyl. Wood, 1914
**Pertusaria osteolata* Dibb. Dibben, 1980
**Pertusaria pertusa* misident. Wood, 1914, Nash, 1972
**Pertusaria pustulata* (Ach.) Duby Wood, 1914, Dibben, 1980
Pertusaria texana Müll. Arg.
**Pertusaria trachythallina* Erichs. Dibben, 1980
Pertusaria velata (Turn.) Nyl. Wood, 1914, Dibben, 1980
**Phaeocalicium curtisii* (Tuck.) Tibell Wood, 1914
Phaeocalicium polyporaeum (Nyl.) Tibell

I *Phaeographis dendritica (Ach.) Müll. Arg. Wood, 1914
Phaeophyscia adiastola (Essl.) Essl. Esslinger, 1977b
*Phaeophyscia ciliata (Hoffm.) Moberg Wood, 1914
*Phaeophyscia endococcina (Körb.) Moberg Wood, 1914
Phaeophyscia imbricata (Vain.) Essl.
I Phaeophyscia orbicularis (Neck.) Moberg Thomson, 1963, Nash, 1972
Phaeophyscia rubropulchra (Degel.) Moberg Thomson, 1963, Esslinger, 1977b
*Phyllopsora parvifolia (Pers.) ined. Wood, 1914
I Physcia aipolia (Ehrh.) Hampe
Physcia americana Merr. Nash, 1972
*Physcia caesia (Hoffm.) Furnrohr Wood, 1914
Physcia intermedia Vain.
I Physcia millegrana Degel. Nash, 1972, 1975
*Physcia phaea (Tuck.) Thoms. Thomson, 1963
I Physcia stellaris (L.) Nyl. Wood, 1914
Physcia subtilis Degel. Nash, 1972, 1975
I *Physcia tenella (Scop.) DC in Lam. & DC Wood, 1914
I Physconia detersa (Nyl.) Poelt Thomson, 1963
I *Physconia distorta (With.) Laund. Wood, 1914
Physconia muscigena (Ach.) Poelt
Placynthiella icmalea (Ach.) Coppins & James
Placynthiella oligotropha (Laund.) Coppins & James
Placynthiella uliginosa (Schrad.) Coppins & James Wood, 1914
Placynthium nigrum (Huds.) S. Gray Wood, 1914
Plagiocarpa hyalospora (Nyl.) R. Harris Wood, 1914
Platismatia tuckermanii (Oakes) W. & C. Culb. Wood, 1914
Polyblastiopsis fallaciosa (Stizenb. ex Arn.) Zahlbr.
*Polyblastiopsis lactea (Mass.) Zahlbr. Wood, 1914
*Polysporina simplex (Dav.) Vezda Wood, 1914
*Porina chlorotica (Ach.) Müll. Arg. Britton, 1889,
Porpidia albocaerulescens (Wulf.) Hert. & Knopf Nash, 1972, 1975
Porpidia macrocarpa (DC.) Hert. & Schwab. Nash, 1972
*Pseudevernia cladonia (Tuck.) Hale & W. Culb. Wood, 1914
Pseudevernia consocians (Vain.) Hale & W. Culb. Wood, 1914
*Pseudocyphellaria crocata (L.) Vain. Wood, 1914
Psorotychia schaereri (Mass.) Arn. Britton, 1889,
Pycnothelia papillaria (Ehrh.) Duf. Wood, 1914
*Pyrenopsis phaeococca Tuck. Britton, 1889,
I *Pyrenula nitida (Weig.) Ach. Wood, 1914
*Pyxine cocoes (Sw.) Nyl. Wood, 1914
Pyxine sorediata (Ach.) Mont. Wood, 1914, Nash, 1972
S *Ramalina americana Hale Wood, 1914
S *Ramalina calicaris (L.) Fr. Wood, 1914
S *Ramalina farinacea (L.) Ach. Wood, 1914
Ramalina intermedia (Del. in Nyl.) Nyl.
Rhizocarpon badioatrum (Flörfe ex Spreng.) Th. Fr.
*Rhizocarpon concentricum (Dav.) Beltr. Wood, 1914
*Rhizocarpon geminatum Körb. Wood, 1914
Rhizocarpon grande (Flörke ex Flot.) Arn. Nash, 1972

Rhizocarpon plicatile (Leight.) A. L. Sm. Nash, 1972
1 additional unidentified species of Rhizocarpon
Rhizoplaca chrysoleuca (Sm.) Zopf Britton, 1889, Nash, 1972
Rinodina archaea (Ach.) Arn.
*Rinodina confrogosa (Ach.) Körb. Wood, 1914
I Rinodina exigua (Ach.) S. Gray Wood, 1914
[*Rinodina sophodes misident. Britton, 1889, Wood, 1914]
Rinodina subminuta Magn.
*Sarcogyne clavus (DC in Lam & DC) Kremp. Nash, 1972
Sarcogyne privigna (Ach.) Mass.
Sarcogyne regularis Körb. Britton, 1889,
I Scolicosporum chlorococcum (Stenham.) Vezda Nash, 1972, 1975
*Scolicosporum umbrin~~a~~um (Ach.) Arn. Wood, 1914, Nash, 1972
*Sphinctrina anglica Nyl. Wood, 1914
Staurothele diffractella (Nyl.) Tuck. Britton, 1889,
*Stenocybe pullatula (Ach.) B. Stein. Wood, 1914
*Stereocaulon paschale (L.) Hoffm. Britton, 1889,
*Stereocaulon tomentosum Fr. Britton, 1889, Wood, 1914
*Stereocaulon vesuvianum Pers. Britton, 1889, Wood, 1914
*Strigula stigmatella (Ach.) R. Harris Wood, 1914
*Teloschistes chrysopthalmus (L.) Th. Fr. Wood, 1914
Thelocarpon laureri (Flot.) Nyl.
*Thrombium epigaeum (Pers.) Wallr. Britton, 1889, Wood, 1914
Trapelia coarctata (Sm.) Choisy in Werner Britton, 1889,
Trapelia involuta (Tayl.) Hert.
*Trypethelium virens Tuck. ex Michx. in Darl. Wood, 1914
Umbilicaria mammulata (Ach.) Tuck. Britton, 1889, Llano, 1950, Niering, 1953, Nash, 1972, 1975
Umbilicaria muehlenbergii (Ach.) Tuck. Britton, 1889, Wood, 1914, Llano, 1950, Niering, 1953, Nash, 1972, 1975
*Umbilicaria vellea (L.) Ach. Wood, 1914, Llano, 1950
*Usnea angulata Ach. Wood, 1914
[*Usnea barbata misident. Wood, 1914]
S *Usnea ceratina Ach. Wood, 1914
S *Usnea filipendula Stirt. Wood, 1914
S *Usnea florida (L.) Web. in Wigg. Wood, 1914
S-I Usnea hirta (L.) Web. in Wigg. Wood, 1914
[*Usnea plicata misident. Wood, 1914]
*Usnea strigosa (Ach.) A. Eat. Wood, 1914
Verrucaria aethiobola Wahlenb. in Ach.
*Verrucaria fuscella (Turn.) Winch. Britton, 1889,
Verrucaria muralis Ach.
Verrucaria nigrescens Pers. Britton, 1889, Nash, 1972
Verrucaria rupestris Schrad.
2 additional unidentified species of Verrucaria
S-I *Xanthoria fallax (Hepp.) Arn. Wood, 1914
I *Xanthoria parietina (L.) Th. Fr. Wood, 1914
I *Xanthoria polycarpa (Hoffm.) Rieber Wood, 1914

DISCUSSION OF FLORA

This list includes 184 species collected for this study. Of the 308 species reported in the literature for the area only 112 were found in this study (=36%). There has been a loss of 196 species (=64%) since 1889. Of the 184 species found in this study 72 were not recorded in the literature and 112 were previously known for the area. Some of the differences in numbers are probably due to misidentifications or different species concepts but the loss of species is major and the numbers would only be slightly changed by these differences. There are an additional 11 unidentified species. The total potential lichen flora (literature records + new records) is 380 species. This loss of species is probably due to regional air pollution.

Species concepts and nomenclature have changed considerably since these earliest records were published but in most cases the old records can be correlated with present names and this has been done as far as possible. I cases where an old species has been split into several new taxa (such as *Cladonia chlorophaea*) it is impossible to determine which of the new taxa was originally found. In the case of *Cladonia chlorophaea*, I found *Cladonia grayi*, which was formerly included in *C. chlorophaea*, and the historical species actually may have been *C. grayi*. A similar case is *Lepraria incana* and *L. membranacea* of the historical records. We now know plants referred to these names are called several other things and some may be undescribed. Since I found three species of Lepraria, the species in the park now may be the same as those found by other workers. Where the lichen referred to by the original name is not in North America the old name is included in brackets and not counted in the totals. The only way to resolve these differences would be to locate the original specimens and compare them with recent collections.

This list of species includes 72 new records for the park and there are still a few unidentified species and some of these may be undescribed. The most common species are Cladonia coniocraea, Parmelia rudecta, Phaeophyscia rubropulchra, Acarospora fuscata, Buellia dialyta, Graphis scripta, and Porpidia albocaerulescens.

Many of the lichens with blue green algae have disappeared from the park. Of the 17 species in the category most sensitive to sulfur dioxide, only four species remain and only four of the seven species in the Sensitive-Intermediate category were found. There is also a distinct species gradient in total species from north to south with fewer species at the southern localities. On the eastern ridgetops in the southern part of the park the lichens are small and in poor health, frequently sterile and there are many fewer species and numbers of thalli than in the northern parts of the park and in the protected valleys in the south. Many of the lichens on the southeastern ridges are near the ground level and lichens are quite rare higher in the trees. This indicates that there is more severe air pollution entering the park from the southeast. None of the species most sensitive to sulfur dioxide occur on the ridges in the southeast (see below). There is a smokestack visible from Mt. Minsi and Mt. Tammany to the southeast that may be the Metropolitan Edison Power Plant near Portland, N. J.. This is about 6 miles from the park boundary but the park personnel have no information on the emissions from this smokestack. The metropolitan New York City area is about 65 miles ESE of the southern end of the park but this is probably too far away for direct sulfur dioxide effects of the severity shown 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 with known sensitivity to sulfur dioxide according to the list presented in Wetmore (1983) and most of these are not very common. Species in the most sensitive category (S) 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 categories are as follows.

S	<u>Caloplaca flavorubescens</u>	1 collection
S	<u>Ochrolechia androgyna</u>	1 collection
S	<u>Parmelia squarrosa</u>	11 collections
S	<u>Parmelia subaurifera</u>	6 collections
S-I	<u>Candelaria concolor</u>	5 collections
S-I	<u>Candelariella xanthostigma</u>	1 collection
S-I	<u>Cetraria ciliaris</u>	3 collections
S-I	<u>Usnea hirta</u>	1 collection

The distributions of these species are mapped (Fig. 2-9). Although these species are not found at all localities and most are rare, there is an indication that the voids in the distributions are due to poor air quality. None of these species occurs on the ridges in the southeastern part of the park. Two do occur at Sunfish Pond but this locality is in a protected valley. The locality at Delaware Water Gap is also at low elevation and on the west side of the ridge. These distribution maps by themselves are not complete proof of air pollution from the southeast but tend to support the other evidence of sulfur dioxide pollution from the southeast.

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 <u>Umbilicaria</u> do show damage from acid precipitation by dying at the margins. A few specimens of these lichens were seen in the park with dead margins that might be due to acid rain.

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 park for laboratory analysis. Species collected and the substrates were <u>Cladina</u> <u>rangiferina</u> (on soil), <u>Parmelia</u> <u>rudecta</u> and <u>Parmelia</u> <u>caperata</u> (on chestnut oak and hickory). These species were selected because they are the only ones present in abundance and relatively easy to clean. Not all species were present at all localities.

Six localities were selected from north to south and east to west within the park and are indicated on the map of collection localities. These localities are: half mile NE of Adams Creek; 2 miles S of Wallpack Center; hill above Bushkill Access; Kittatinny Mt. along Appalachian Trail 1.5 miles S of Poxono Isl.; Worthington State Forest at Sunfish Pond; and Mt. Minsi 4 miles E of Stroudsburg. At most sites a bag of lichens was collected from each of two trees at least 50 feet apart. Ten to 20 grams of each species were collected per bag at each locality. At Adams Creek lichens were collected on two dates: 30 July and 13 August and this is indicated on Table 2. Different trees were sampled at different localities and these are shown on Table 1.

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. One bag of each species was ground before splitting into the two replicate samples for analysis to show instrument error and are indicated as analytical split on 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 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. Some values for Cd in C rangiferina were below detection limits of the instrument and these are indicated on Table 2.

Table 1 Analysis of Delaware Lichens
Values in ppm of thallus

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality	Tree
C. rangiferina	212	963	125	100	124	106	23.4	21.4	16.0	1.4	0.7	4.5	1.0	0.3	<.1	600	@ Adams Creek	
C. rangiferina	219	975	128	103	128	112	24.2	21.1	15.8	1.5	0.7	5.3	0.5	0.2	<.1	580	@ Adams Creek	
C. rangiferina	354	1389	129	139	161	116	18.3	31.3	24.1	1.6	0.9	5.4	1.2	0.3	0.1	700	Adams Creek	
C. rangiferina	333	1366	131	140	165	121	16.8	34.6	24.0	1.7	0.9	5.3	1.1	0.4	0.1	760	Adams Creek	
C. rangiferina	699	2110	263	207	114	97	13.3	60.5	23.0	1.8	1.1	2.7	0.4	0.2	<.1	680	Adams Creek	
C. rangiferina	700	2058	262	217	117	101	14.7	63.0	23.5	1.8	1.0	4.1	0.9	0.2	<.1	740	Adams Creek	
C. rangiferina	427	1466	136	161	142	131	19.1	31.2	17.8	1.6	0.9	7.0	0.6	0.3	<.1	630	Adams Creek	
C. rangiferina	481	1543	143	171	150	127	18.6	33.4	19.3	1.6	0.9	6.6	1.0	0.2	<.1	600	Adams Creek	
C. rangiferina	505	1398	74	115	207	134	22.9	17.2	30.0	1.4	0.7	4.9	0.7	0.2	<.1	705	Wallpack C.	
C. rangiferina	565	1588	79	122	173	119	22.1	17.3	28.8	1.5	0.5	4.2	0.8	0.3	0.1	630	Wallpack C.	
C. rangiferina	452	1424	99	143	213	174	27.4	21.5	26.6	1.6	0.7	7.5	1.3	0.2	0.1	790	Wallpack C.	
C. rangiferina	477	1499	101	141	229	161	26.8	21.7	27.7	1.6	0.9	6.3	1.1	0.3	0.1	740	Wallpack C.	
P. caperata	581	3511	38562	235	232	150	9.1	225.1	202.0	4.8	2.5	24.3	2.2	0.2	2.6	1490	Adams Creek	hick.
P. caperata	622	3614	39916	242	240	157	15.9	223.7	199.1	5.0	2.6	26.2	2.2	0.3	2.7	1560	Adams Creek	hick.
P. caperata	859	4497	8153	280	385	404	19.0	104.8	233.6	7.3	4.5	35.7	2.3	0.6	0.7	1900	Adams Creek	hick.
P. caperata	938	4932	8161	290	376	378	16.2	107.0	235.1	7.2	4.6	33.3	2.5	0.5	0.7	1810	Adams Creek	hick.
P. caperata	984	5227	19338	359	381	404	19.8	96.2	62.3	5.3	2.5	48.6	2.0	0.5	1.0	1540	@ Adams Creek	oak
P. caperata	957	5115	14301	352	430	446	20.2	97.0	60.5	5.7	2.6	53.0	2.2	0.5	0.9	1570	@ Adams Creek	oak
P. caperata	1120	4871	27147	352	277	298	17.7	178.4	51.5	4.4	2.2	42.9	1.8	0.5	1.3	1510	Adams Creek	oak
P. caperata	1046	4724	22858	347	269	291	15.0	158.0	53.5	4.4	2.1	36.6	1.8	0.4	1.2	1620	Adams Creek	oak
P. caperata	701	4440	32769	271	214	185	10.7	163.1	196.2	5.4	2.5	37.9	2.3	0.5	1.9	1670	Wallpack C.	hick.
P. caperata	729	4515	36530	275	229	206	13.0	167.2	206.8	5.8	2.4	40.6	2.4	0.4	2.1	1710	Wallpack C.	hick.
P. caperata	995	5264	17349	307	218	169	13.0	101.1	194.1	5.8	2.5	46.6	1.7	0.3	1.3	1960	Wallpack C.	hick.
P. caperata	1015	5396	17262	316	216	171	14.6	100.5	198.5	6.1	2.5	43.0	2.5	0.2	1.3	1960	Wallpack C.	hick.
P. caperata	1457	5901	9058	414	219	242	25.0	60.2	94.8	5.7	2.4	38.8	2.0	0.3	0.8	1850	Bushkill Acc.	oak
P. caperata	1426	5696	7829	391	205	231	20.6	56.6	86.2	5.4	2.2	36.2	1.9	0.4	0.7	1830	Bushkill Acc.	oak
P. caperata	1654	6547	3634	372	184	206	19.1	58.2	77.4	6.0	3.0	26.6	1.7	0.4	0.4	1845	Bushkill Acc.	oak
P. caperata	1626	6617	3027	368	188	210	17.2	57.3	80.0	5.9	3.0	24.8	1.4	0.3	0.4	1830	Bushkill Acc.	oak
P. caperata	964	4688	13281	303	183	176	12.4	37.3	74.5	5.1	1.7	27.4	1.4	0.3	0.7	1710	Sunfish Pond	oak
P. caperata	1072	5126	18675	330	186	182	13.3	39.3	75.4	5.2	1.6	29.4	1.5	0.2	0.9	1720	Sunfish Pond	oak
P. caperata	917	4225	19623	315	269	292	14.5	41.4	138.5	7.1	3.8	126.2	2.6	0.4	1.4	1720	Mt. Minsi	oak
P. caperata	934	4260	20942	314	279	329	14.0	41.1	135.8	7.1	3.5	133.0	2.8	0.4	1.5	1830	Mt. Minsi	oak

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality	Tree
P. rudecta	494	2264	64751	300	122	151	9.5	235.9	225.2	2.9	0.7	28.3	2.4	0.3	3.0	1380	Adams Creek	hick.
P. rudecta	514	2288	51980	307	166	173	4.8	228.1	223.2	2.7	0.7	27.0	2.1	0.2	2.7	1420	Adams Creek	hick.
P. rudecta	530	2297	5065	357	419	483	13.0	127.8	245.7	4.0	1.8	15.7	2.3	0.9	0.6	1590	Adams Creek	hick.
P. rudecta	515	2250	5195	347	397	448	11.2	125.4	228.6	3.8	1.8	18.8	2.2	0.8	0.6	1650	Adams Creek	hick.
P. rudecta	768	3088	33368	306	278	332	16.9	103.8	70.7	2.4	1.3	22.1	1.6	0.4	1.2	1170	Adams Creek	oak
P. rudecta	714	3036	28782	311	322	360	10.6	104.6	68.3	2.5	1.4	20.6	1.4	0.4	1.0	1170	Adams Creek	oak
P. rudecta	1572	4098	2567	428	253	316	11.8	135.7	58.5	3.3	1.5	8.3	1.2	0.4	0.3	1610	@ Adams Creek	oak
P. rudecta	1629	4224	2438	449	265	335	12.2	138.2	59.9	3.4	1.6	9.2	1.4	0.5	0.3	1530	@ Adams Creek	oak
P. rudecta	549	2976	85969	296	22	112	9.8	195.7	165.5	2.4	0.8	35.7	1.7	0.2	3.8	1180	Wallpack C.	hick.
P. rudecta	540	3045	73488	308	48	114	7.7	195.0	174.3	2.2	0.6	30.3	1.4	0.2	3.5	1150	Wallpack C.	hick.
P. rudecta	572	2951	40555	301	192	211	5.1	122.1	244.8	2.9	0.8	44.0	1.4	0.4	1.8	1300	Wallpack C.	hick.
P. rudecta	528	2801	45078	293	188	219	6.4	127.2	251.4	3.0	0.8	43.2	1.8	0.4	2.0	1360	Wallpack C.	hick.
P. rudecta	951	3016	19363	384	173	211	6.5	80.0	88.8	3.3	1.0	29.2	1.4	0.2	0.9	1685	Bushkill Acc.	oak
P. rudecta	1036	3121	21893	392	170	210	10.3	81.9	78.6	3.6	0.9	29.9	1.5	0.4	1.1	1770	Bushkill Acc.	oak
P. rudecta	1026	3800	5266	445	298	396	17.4	64.9	81.7	3.9	1.7	16.0	1.4	0.6	0.4	1630	Bushkill Acc.	oak
P. rudecta	1057	3848	3393	449	328	448	18.2	65.5	88.3	4.2	1.7	11.6	2.0	0.8	0.3	1590	Bushkill Acc.	oak
P. rudecta	1121	3629	51428	363	114	180	6.3	52.9	84.6	3.5	0.9	46.7	1.6	0.2	1.2	1670	Kittatinny Mt.	oak
P. rudecta	991	3234	46656	325	115	168	7.3	48.7	77.5	3.2	0.7	45.2	1.7	0.2	1.0	1560	Kittatinny Mt.	oak
P. rudecta	899	3625	18537	328	234	271	11.5	33.4	96.5	3.8	1.0	18.3	1.8	0.4	0.6	1400	Sunfish Pond	oak
P. rudecta	977	3839	11540	345	252	303	18.8	34.3	99.1	4.2	1.0	16.2	2.0	0.6	0.5	1490	Sunfish Pond	oak
P. rudecta	1321	3013	64873	321	130	256	14.3	51.8	103.0	4.1	1.1	55.5	1.8	0.5	2.1	1710	Mt. Minsi	oak
P. rudecta	1088	2892	64453	305	137	245	12.4	51.1	106.8	3.8	0.9	58.7	1.6	0.3	2.1	1800	Mt. Minsi	oak

@= analytical split
hick.= shagbark hickory; oak= chestnut oak

Table 2 Summary of Analysis of Delaware Lichens
Values in ppm of thallus

Cladina rangiferina

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	216	969	126	102	126	109	23.8	21.3	15.9	1.5	0.7	4.9	0.8	0.2	0.1*	590	@ Adams Creek
Std. dev.	5	9	2	2	3	4	0.6	0.2	0.1	0.1	<.1	0.6	0.4	0.1	<.1	14	30 Jul.
Mean	344	1377	130	140	163	118	17.6	33.0	24.1	1.6	0.9	5.3	1.2	0.3	0.1	730	Adams Creek
Std. dev.	15	17	1	1	3	4	1.0	2.3	<.1	<.1	<.1	0.1	0.1	<.1	<.1	42	30 Jul.
Mean	700	2084	262	212	116	99	14.0	61.7	23.2	1.8	1.1	3.4	0.7	0.2	#	710	Adams Creek
Std. dev.	1	37	1	7	2	3	1.0	1.7	0.3	<.1	<.1	1.0	0.3	<.1	#	42	13 Aug.
Mean	454	1504	139	166	146	129	18.8	32.3	18.5	1.6	0.9	6.8	0.8	0.3	#	615	Adams Creek
Std. dev.	38	54	5	7	5	3	0.3	1.5	1.1	<.1	<.1	0.3	0.3	0.1	#	21	13 Aug.
Mean	535	1493	77	119	190	126	22.5	17.3	29.4	1.5	0.6	4.5	0.8	0.2	0.1	668	Wallpack C.
Std. dev.	42	134	3	4	24	11	0.6	<.1	0.8	0.1	0.1	0.5	<.1	<.1	<.1	53	Wallpack C.
Mean	464	1461	100	142	221	168	27.1	21.6	27.2	1.6	0.8	6.9	1.2	0.2	0.1	765	Wallpack C.
Std. dev.	18	53	1	2	11	9	0.4	0.1	0.7	<.1	0.2	0.8	0.1	<.1	<.1	35	Wallpack C.

Parmelia caperata

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	601	3562	39239	238	236	153	12.5	224.4	200.5	4.9	2.6	25.3	2.2	0.3	2.6	1525	Adams Creek
Std. dev.	29	73	957	5	5	5	4.8	1.0	2.0	0.2	0.1	1.4	<.1	<.1	0.1	49	30 Jul.
Mean	898	4714	8157	285	380	391	17.6	105.9	234.3	7.2	4.6	34.5	2.4	0.5	0.7	1855	Adams Creek
Std. dev.	56	307	6	7	6	19	2.0	1.6	1.1	0.1	0.1	1.7	0.2	<.1	<.1	64	30 Jul.
Mean	970	5171	16820	355	405	425	20.0	96.6	61.4	5.5	2.6	50.8	2.1	0.5	1.0	1555	@ Adams Creek
Std. dev.	20	79	3562	5	35	30	0.3	0.5	1.2	0.3	0.1	3.1	0.1	0.0	0.1	21	13 Aug.
Mean	1083	4797	25003	349	273	295	16.4	168.2	52.5	4.4	2.2	39.8	1.8	0.5	1.2	1565	Adams Creek
Std. dev.	52	103	3033	3	6	5	1.9	14.4	1.4	<.1	<.1	4.5	<.1	<.1	0.1	78	13 Aug
Mean	715	4477	34650	273	221	195	11.9	165.1	201.5	5.6	2.4	39.3	2.4	0.4	2.0	1690	Wallpack C.
Std. dev.	20	53	2659	3	11	15	1.6	2.9	7.6	0.2	<.1	1.9	0.1	<.1	0.2	28	Wallpack C.
Mean	1005	5330	17306	311	217	170	13.8	100.8	196.3	6.0	2.5	44.8	2.1	0.3	1.3	1960	Wallpack C.
Std. dev.	14	93	62	6	2	1	1.1	0.4	3.1	0.2	<.1	2.5	0.6	<.1	<.1	0	Wallpack C.
Mean	1442	5799	8444	402	212	237	22.8	58.4	90.5	5.6	2.3	37.5	1.9	0.4	0.8	1840	Bushkill Acc.
Std. dev.	22	145	869	16	10	8	3.1	2.6	6.1	0.2	0.1	1.9	0.1	<.1	0.1	14	Bushkill Acc.
Mean	1640	6582	3331	370	186	208	18.2	57.8	78.7	5.9	3.0	25.7	1.6	0.3	0.4	1838	Bushkill Acc.
Std. dev.	20	50	429	2	3	3	1.3	0.7	1.8	0.1	0.0	1.3	0.2	0.1	<.1	11	Bushkill Acc.
Mean	1018	4907	15978	317	184	179	12.9	38.3	74.9	5.2	1.7	28.4	1.5	0.2	0.8	1715	Sunfish Pond
Std. dev.	76	310	3814	19	2	4	0.6	1.5	0.6	0.1	<.1	1.4	0.1	<.1	0.1	7	Sunfish Pond
Mean	925	4243	20283	314	274	310	14.3	41.2	137.2	7.1	3.7	129.6	2.7	0.4	1.4	1775	Mt. Minsi
Std. dev.	12	25	933	1	7	26	0.4	0.2	1.9	<.1	0.2	4.9	0.1	<.1	<.1	78	Mt. Minsi

<u>Parmelia rudecta</u>

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	504	2276	58366	303	144	162	7.1	232.0	224.2	2.8	0.7	27.6	2.3	0.3	2.8	1400	Adams Creek
Std. dev.	14	17	9030	5	31	16	3.3	5.5	1.4	0.1	<.1	0.9	0.2	<.1	0.2	28	30 Jul.
Mean	522	2274	5130	352	408	466	12.1	126.6	237.1	3.9	1.8	17.3	2.2	0.8	0.6	1620	Adams Creek
Std. dev.	11	33	92	6	15	25	1.3	1.7	12.1	0.2	<.1	2.2	0.1	<.1	<.1	42	30 Jul.
Mean	741	3062	31075	308	300	346	13.8	104.2	69.5	2.5	1.4	21.4	1.5	0.4	1.1	1170	Adams Creek
Std. dev.	38	37	3243	4	31	20	4.4	0.6	1.7	0.1	0.1	1.0	0.1	<.1	0.1	<1	13 Aug.
Mean	1601	4161	2502	438	259	326	12.0	136.9	59.2	3.4	1.6	8.7	1.3	0.5	0.3	1570	@ Adams Creek
Std. dev.	40	89	91	15	9	13	0.3	1.8	1.0	0.1	0.1	0.6	0.1	0.1	<.1	57	13 Aug.
Mean	544	3010	79729	302	35	113	8.8	195.3	169.9	2.3	0.7	33.0	1.6	0.2	3.6	1165	Wallpack C.
Std. dev.	7	48	8825	9	18	1	1.5	0.5	6.2	0.1	0.1	3.8	0.2	<.1	0.2	21	Wallpack C.
Mean	550	2876	42817	297	190	215	5.8	124.7	248.1	2.9	0.8	43.6	1.6	0.4	1.9	1330	Wallpack C.
Std. dev.	32	106	3198	6	3	5	0.9	3.6	4.7	<.1	<.1	0.5	0.3	<.1	0.1	42	Wallpack C.
Mean	994	3068	20628	388	172	211	8.4	80.9	83.7	3.4	0.9	29.6	1.4	0.3	1.0	1728	Bushkill Acc.
Std. dev.	60	74	1789	6	2	<1	2.7	1.4	7.2	0.2	<.1	0.5	0.1	0.1	0.1	60	Bushkill Acc.
Mean	1042	3824	4329	447	313	422	17.8	65.2	85.0	4.0	1.7	13.8	1.7	0.7	0.4	1610	Bushkill Acc.
Std. dev.	22	34	1324	3	21	37	0.6	0.4	4.7	0.2	<.1	3.1	0.4	0.1	0.1	28	Bushkill Acc.
Mean	1056	3431	49042	344	115	174	6.8	50.8	81.0	3.3	0.8	45.9	1.7	0.2	1.1	1615	Kittatinny Mt.
Std. dev.	92	280	3374	27	1	8	0.7	3.0	5.0	0.2	0.1	1.1	0.1	<.1	0.1	78	Kittatinny Mt.
Mean	938	3732	15039	336	243	287	15.1	33.9	97.8	4.0	1.0	17.2	1.9	0.5	0.5	1445	Sunfish Pond
Std. dev.	55	152	4948	13	13	22	5.2	0.6	1.8	0.3	<.1	1.4	0.2	0.1	0.1	64	Sunfish Pond
Mean	1205	2952	64663	313	134	250	13.3	51.4	104.9	4.0	1.0	57.1	1.7	0.4	2.1	1755	Mt. Minsi
Std. dev.	165	86	297	12	5	8	1.3	0.5	2.7	0.2	0.1	2.3	0.1	0.1	<.1	64	Mt. Minsi

*= 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

@= analytical split

When cleaning the lichens for analysis it was noticed that the lichens from Mt. Minsi and Kittatinny Mt. were very brittle and this may indicate poor healty of the lichens. Erbisch et al. (1977) found that radiation damaged lichens broke easier and had less tensile strength.

The sulfur levels found in the Delaware lichens are higher than the levels found in known clean areas. There are no literature reports for sulfur for P. caperata or P. rudecta but levels for C. rangiferina may be as low as 200-300 in the arctic (Tomassini et al, 1976). The sulfur levels in this species from Delaware range from 580 to 790 ppm and this is significantly higher than for the same species in Acadia NP (488), Voyageurs NP (342) and Isle Royale (360). The sulfur levels in P. rudecta range from 1150-1800 ppm and this is similar to levels found in this species in Cuyahoga Valley NRA where pollution is know to be heavy.

Different species may accumulate different amounts of elements and this is evident when comparing sulfur levels between the species. C. rangiferina has lower levels than either Parmelia caperata or P. rudecta. There is no trend in sulfur levels in Delaware Water Gap between localities, at different dates or different trees.

Of the other elements, zinc is especially high in P. rudecta and P. caperata at all localities and lead is higher at Mt. Minsi. The high zinc indicates widespread air pollution and the high lead at Mt. Minsi probably is because the locality is directly above the interstate expressway.

There is also a significant difference in elemental levels between trees of the same species at the same locality but only slight difference between tree species.

CONCLUSIONS

The present lichen flora of the park is considerably less diverse than that reported 100 years ago with a loss of 64% of the species. Many of the species most sensitive to sulfur dioxide are no longer present including many of the lichens with blue green algae. The distributions of the sensitive species are absent in the southeast indicating higher pollution there. The lichens at ridge-top localities in the southeast have few species and the ones present are in poor health. The elemental analysis shows no significant trends in accumulation levels but all sulfur levels are higher than in clean areas. There is apparently both a broad regional pollution and an additional local pollution entering the park from the southeast.

RECOMMENDATIONS

Air quality monitoring instruments should be set up in the southeastern part of the park to monitor levels of pollutants there. They should be located on Mt. Minsi or Mt. Tammany or near the river on the east side of the water gap. The ridgetop sites would reflect less influence from the highway. Also, data should be obtained on the effluents from nearby smokestacks.

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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.

Pike Co., Pa.

55710-55742 1 mile SW of Milford, southwest of golf course. Along SW slope of hill S of highway in sugar maple, hickory and oaks, elev. 900 ft. 29 July 1986.

55743-55782 Raymondskill Falls (1.5 mi SW of Milford). Around falls and stream and on rocks SW of falls in hemlocks, elev. 600 ft. 29 July 1986.

55783-55810 Northwest of Milford Cemetery at south edge of Milford. On hillside and along edge of cemetery with mixed hardwoods, elev. 640 ft. 29 July 1986.

55811-55834 Dingmans Falls. On ridges south of falls and along stream (3 miles SW of Milford). Hemlock with some hardwoods, elev. 600 ft. 30 July 1986.

55835-55879 Near headwaters of Dry Brook (4.25 miles SW of Milford). Around hilltop with pines and hickory and on rocky knoll, elev. 900 ft. 30 July 1986.

55880-55920 Half mile NE of Adams Creek (5.5 miles SW of Milford). Along cliffs and ridgetop above shale pit. Open oak-hickory forest with some pines and juniper, elev. 600 ft. 30 July 1986. Chemical analysis.

55921-55944 Hornbecks Creek, 1 mile from highway 209 (2 miles SSW of Dingmans Ferry Bridge). On knoll north of road on SW facing slope with mixed hardwoods and some pines and hemlock, elev. 880 ft. 1 August 1986.

55945-55984 1 mile SE of Pocono Education Center (4 miles S of Dingmans Ferry Bridge). On ridge N of road with oaks and rock outcrops, elev. 700 ft. 1 August 1986.

55985-56019 Northeast branch of Toms Creek, half mile from highway 209 (3.5 miles NE of Bushkill). In deep valley with hemlock, sugar maple and along roadbanks, elev. 700 ft. 1 August 1986.

56020- 2 miles NE of Bushkill. Along ridge and valley NE of

56069 road with oaks, hardwoods and some pine and hemlock, elev. 700 ft. 3 August 1986.

56070- 56105 1 mile west of Bushkill. On slate ridgetop with oaks, hickory and some pine, elev. 840 ft. 3 August 1986.

Monroe Co., Pa.

56106- 56122 Peninsula 2 miles NE of park headquarters, 2 miles E of Bushkill. Lowland forest along Delaware River with ash, silver maple, birch, basswood and tulip tree, elev. 350 ft. 3 August 1986.

Sussex Co., N. J.

56123- 56167 1.5 miles WNW of Hainesville (4 miles S of Milford). Along west facing slope of ridge NE of highway junction in mixed hardwood forest with some pines, elev. 550 ft. 4 August 1986.

56168- 56187 1 mile S of Milford, E of highway 206 near E bank of Delaware River. Along stream valley with mixed hardwoods, sugar maple, ash and some oak, elev. 440 ft. 4 August 1986.

Monroe Co., Pa.

56188- 56221 Hilltop half mile E of Hidden Lake (3.5 miles SSW of Bushkill). On ridge with some openings in oaks, maples and birch, elev. 840 ft. 5 August 1986.

56222- 56264 High peak half mile NW of Tocks Island (6 miles SW of Bushkill). On peak with limestone in forest of oaks, hickory, ash and basswood, elev. 860 ft. 5 August 1986.

56265- 56276 Along shore of Delaware River opposite Poxono Island (3 miles S of Bushkill). At shoreline with oaks, ash, walnut, sumac and brush, elev. 320 ft. 5 August 1986.

Sussex Co., N. J.

56277- 56297 Half mile north of Dingmans Ferry Bridge on E side of Delaware River. In gravel pit and surrounding pines and brush, elev. 460 ft. 6 August 1986.

56298- 56334 Indian Hills, 1 mile NW of Long Pine Pond (4 miles S of Wallpack Center). On granitic ridge with few pines and oaks, elev. 1200 ft. 7 August 1986.

Monroe Co., Pa.

56335- 56362 Mt. Minsi 4 miles E of Stroudsburg. On ridgetop near old fire tower in oaks and some pines, elev. 1450 ft. 8

August 1986. Chemical analysis.

56363- South edge of town of Delaware Water Gap along
56377 Appalachian Trail. Along ridge above river by trail in oak-ash forest, elev. 550 ft. 8 August 1986.

Sussex Co., N. J.

56378- 1 mile south of Peters Valley (2 miles SE of Dingmans
56423 Ferry Bridge). On hill W of highway with limestone outcrop and oaks, hickory and some pines, elev. 700 ft. 9 August 1986.

56424- 2 miles S of Wallpack Center. On low ridge with
56478 hickory and oaks and some limestone boulders, elev. 600 ft. 9 August 1986. Chemical analysis.

56479- 3 miles S of Wallpack Center. On steep hill
56502 overlooking Delaware River along old mine road with hickory, sugar maple, hemlock and oaks, elev. 500 ft. 9 August 1986.

Warren Co., N. J.

56503- Half mile NW of Millbrook (2.5 miles E of Bushkill). On
56532 ridge along trail in oaks, hickory, junipers and some pines, elev. 900 ft. 10 August 1986.

56533- 1 mile S of Millbrook at Appalachian Trail (3 miles SE
56550 of Bushkill). Around swamp and stream with oaks, maples and hemlock, elev, 1270 ft. 10 August 1986.

56551- Kittatinny Mountain along Appalachian Trail 1.5 miles
56578 S of Poxono Island. On ridgetop with oaks and rock openings, elev. 1460 ft. 10 August 1986. Chemical analysis.

56579- One mile S of Poxono Island along creek up from old
56615 copper mine area. On level open area half way to ridge with oaks, hickory and rocks, elev. 950 ft. 11 August 1986.

56616- Worthington State Forest. Ridge N of Sunfish Pond (6
56638 miles NE of Stroudsburg). On ridge NW of pond with oaks and few maples and hickory, elev. 1440 ft. 11 August 1986. Chemical analysis.

56639- Worthington State Forest. Mt. Tammany (5 miles E of
56666 Stroudsburg). On ridge NE of gap with oaks, maple and some hickory and rock outcrops, elev. 1520 ft. 12 August 1986.

56667- Worthington State Forest. Along Dunnfield Creek 1 mile

56694 from Delaware River (4 miles E of Stroudsburg). In level area up from creek in opening with oaks, elev. 700 ft. 12 August 1986.

Pike Co., Pa.

56695-56729 Hill above Bushkill Access (2 miles NE of Bushkill). On high hill above shale pit with oaks, elev. 800 ft. 13 August 1986. Chemical analysis.

Sussex Co., N. J.

56730-56738 Just N of Milford Bridge. Along east shore of Delaware River on shore rocks, elev. 400 ft. 13 August 1986.

Monroe Co., Pa.

56739 2 miles SW along highway 209 from Bushkill. On picnic table in yard at Wade House, elev. 460 ft. 13 August 1986.

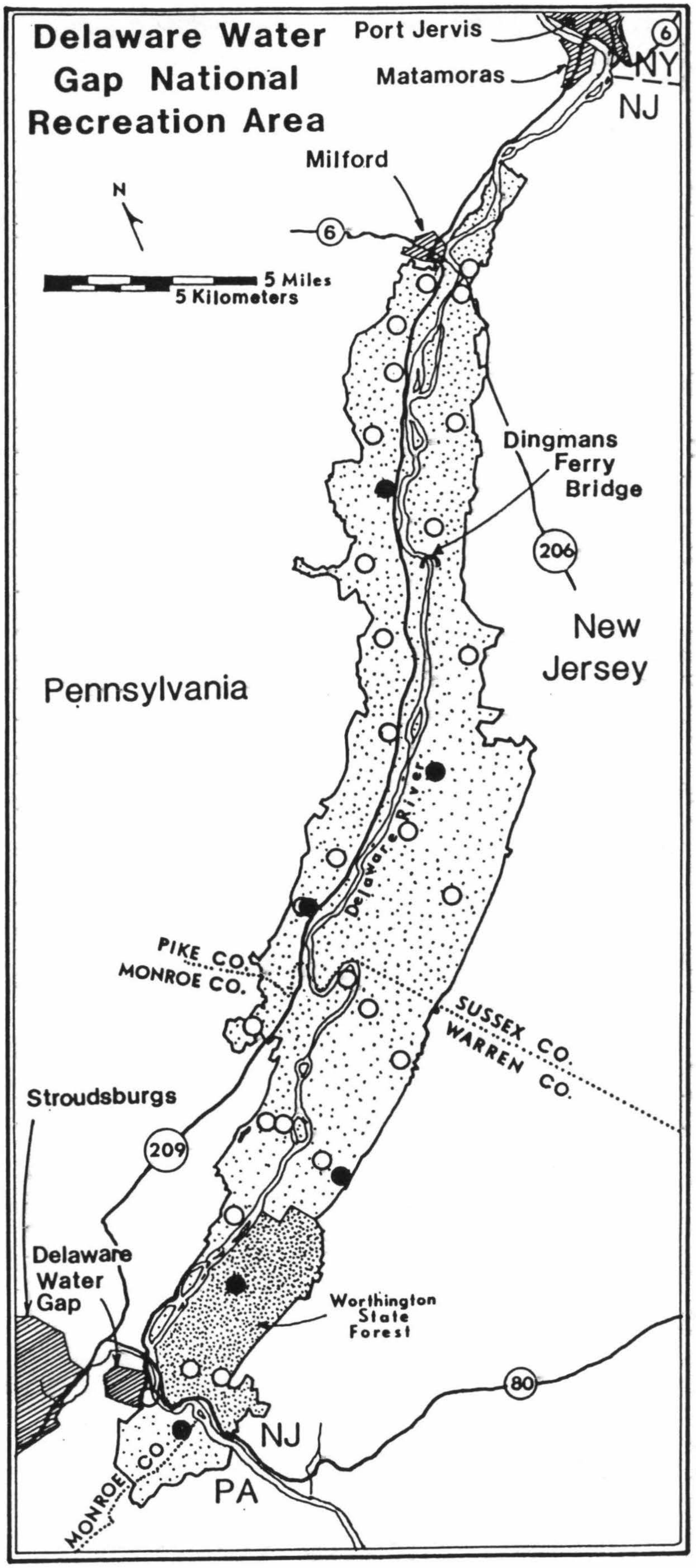

Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities.

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 Sequoia National Park 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	*Caloplaca flavorubescens*	1 collection
Fig. 3	S	*Ochrolechia androgyna*	1 collection
Fig. 4	S	*Parmelia squarrosa*	11 collections
Fig. 5	S	*Parmelia subaurifera*	6 collections
Fig. 6	S-I	*Candelaria concolor*	5 collections
Fig. 7	S-I	*Candelariella xanthostigma*	1 collection
Fig. 8	S-I	*Cetraria ciliaris*	3 collections
Fig. 9	S-I	*Usnea hirta*	1 collection

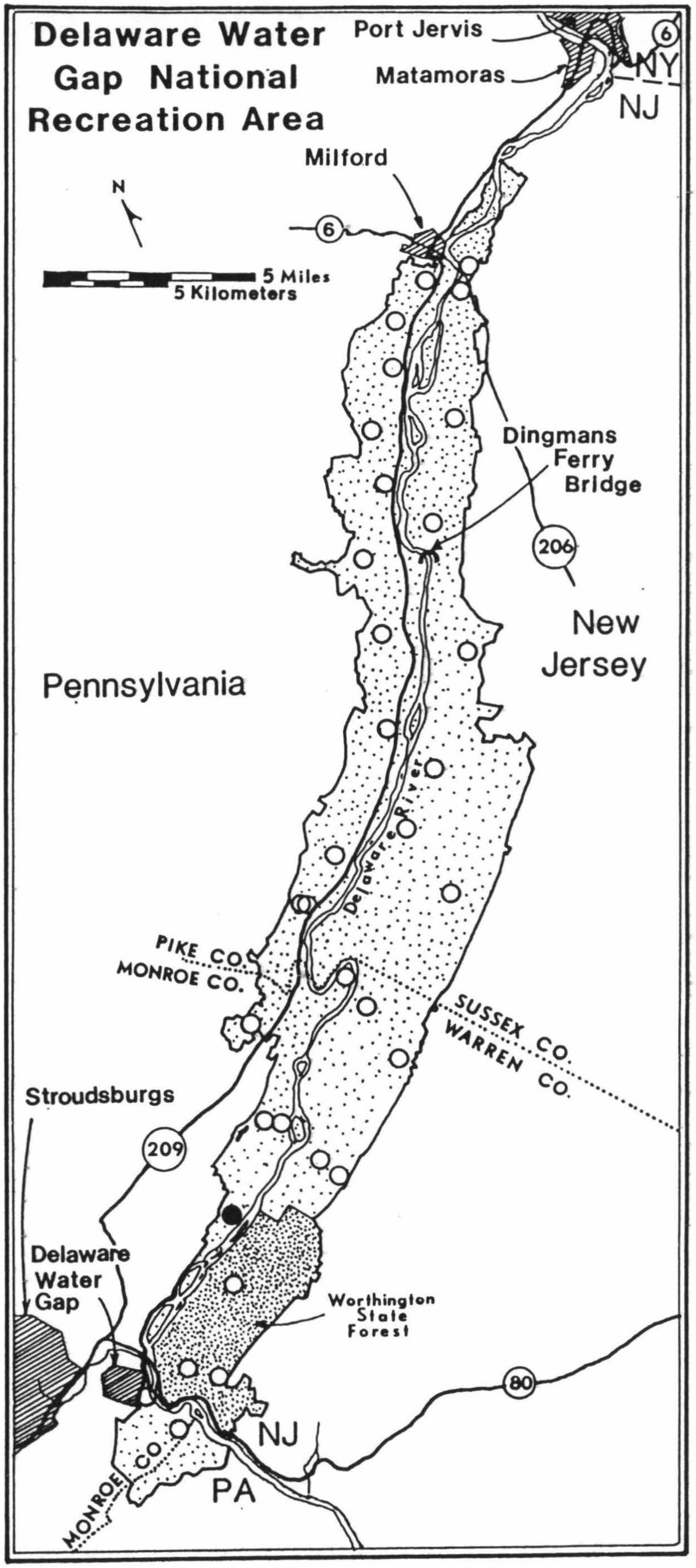

Fig. 2. Caloplaca flavorubescens

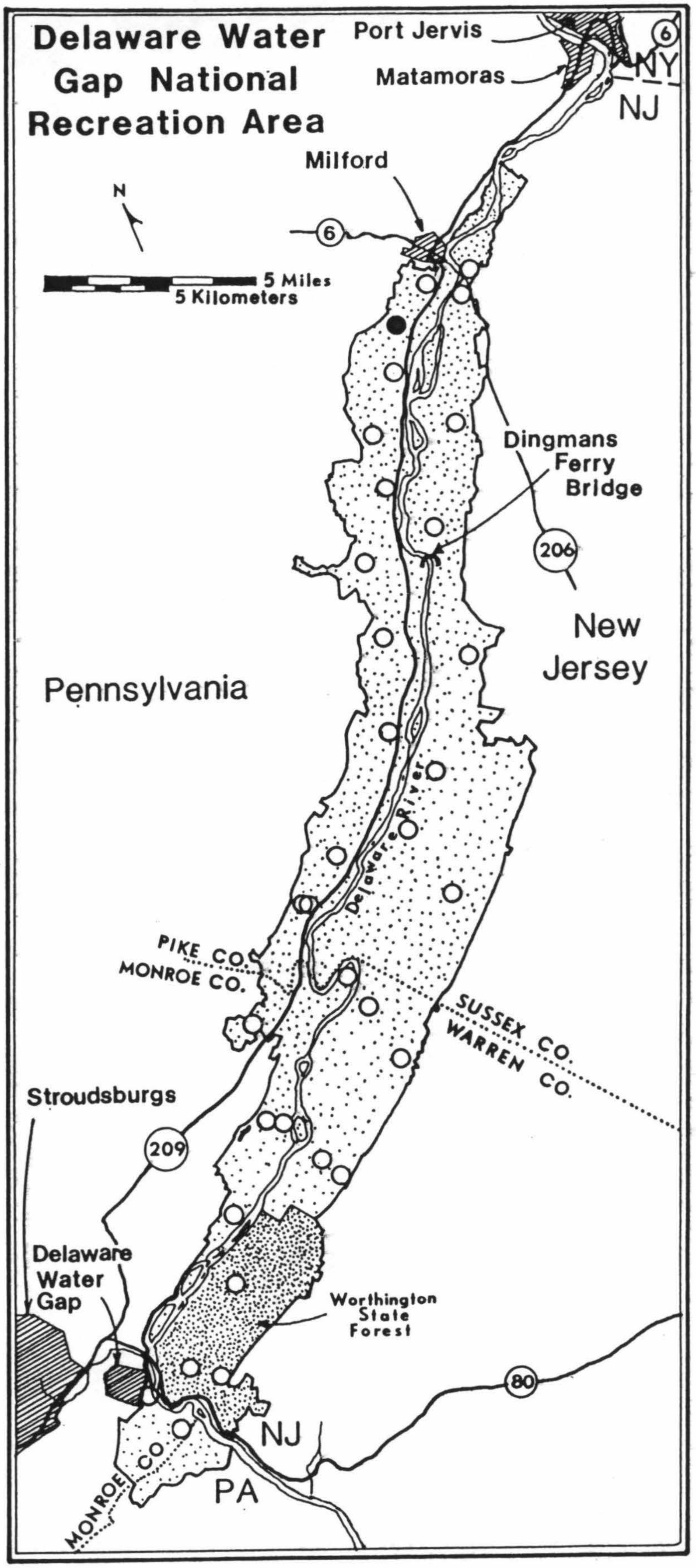

Fig. 3. Ochrolechia androgyna

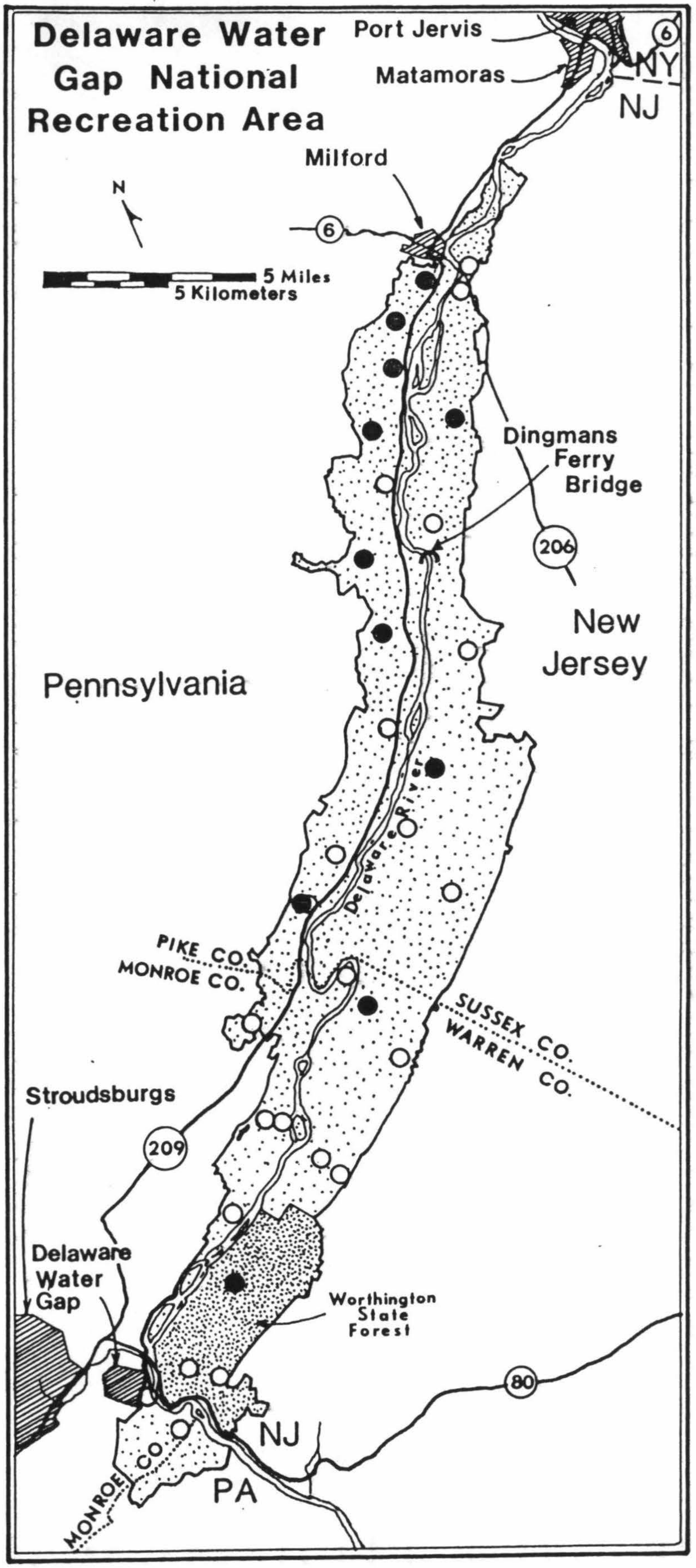

Fig. 4. Parmelia squarrosa

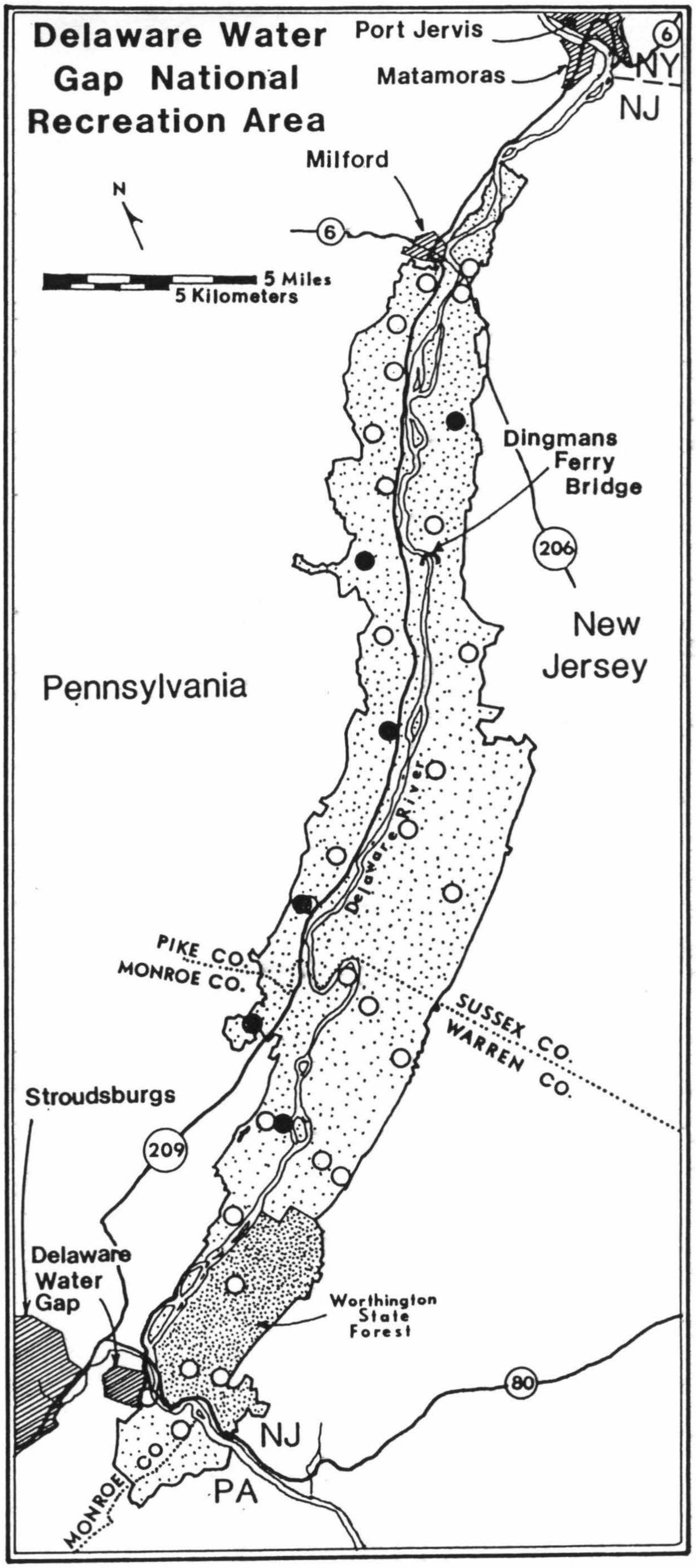

Fig. 5. Parmelia subaurifera

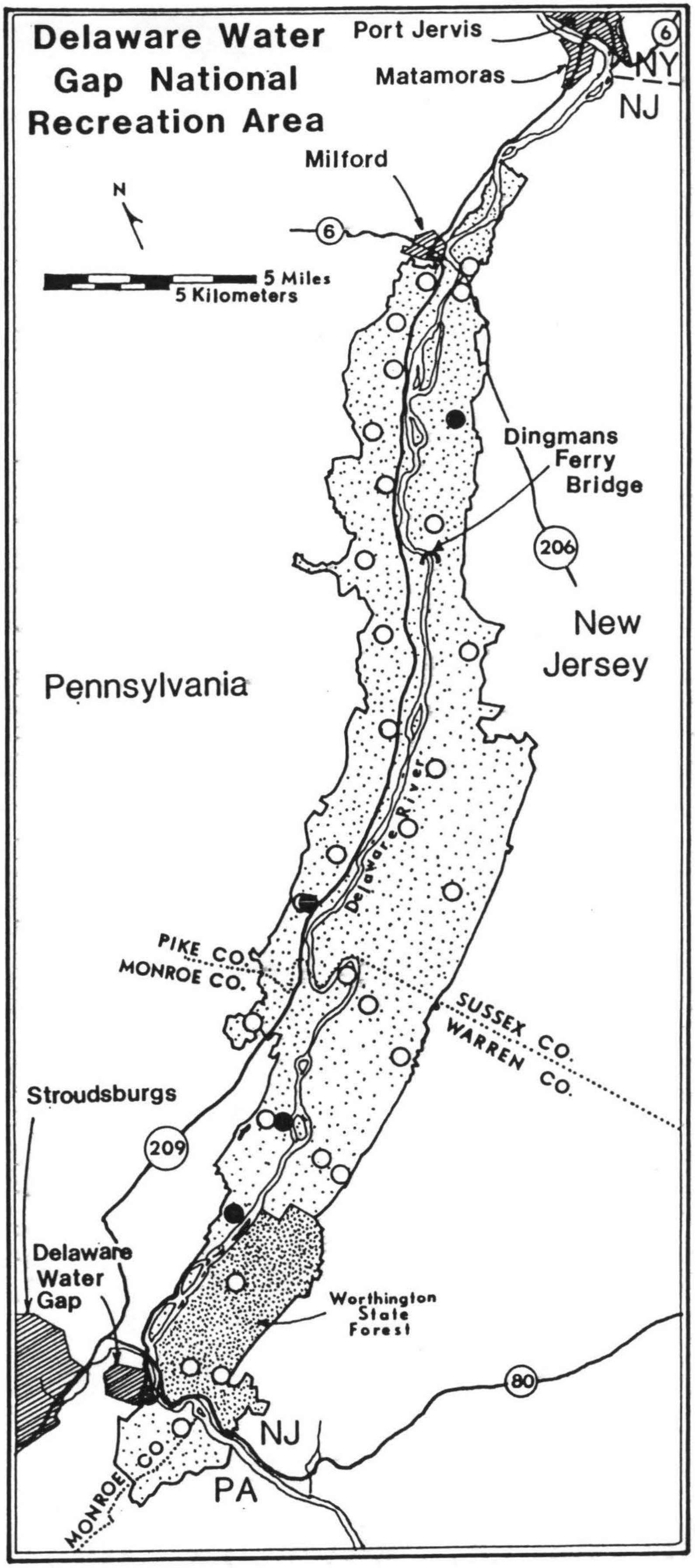

Fig. 6. *Candelaria concolor*

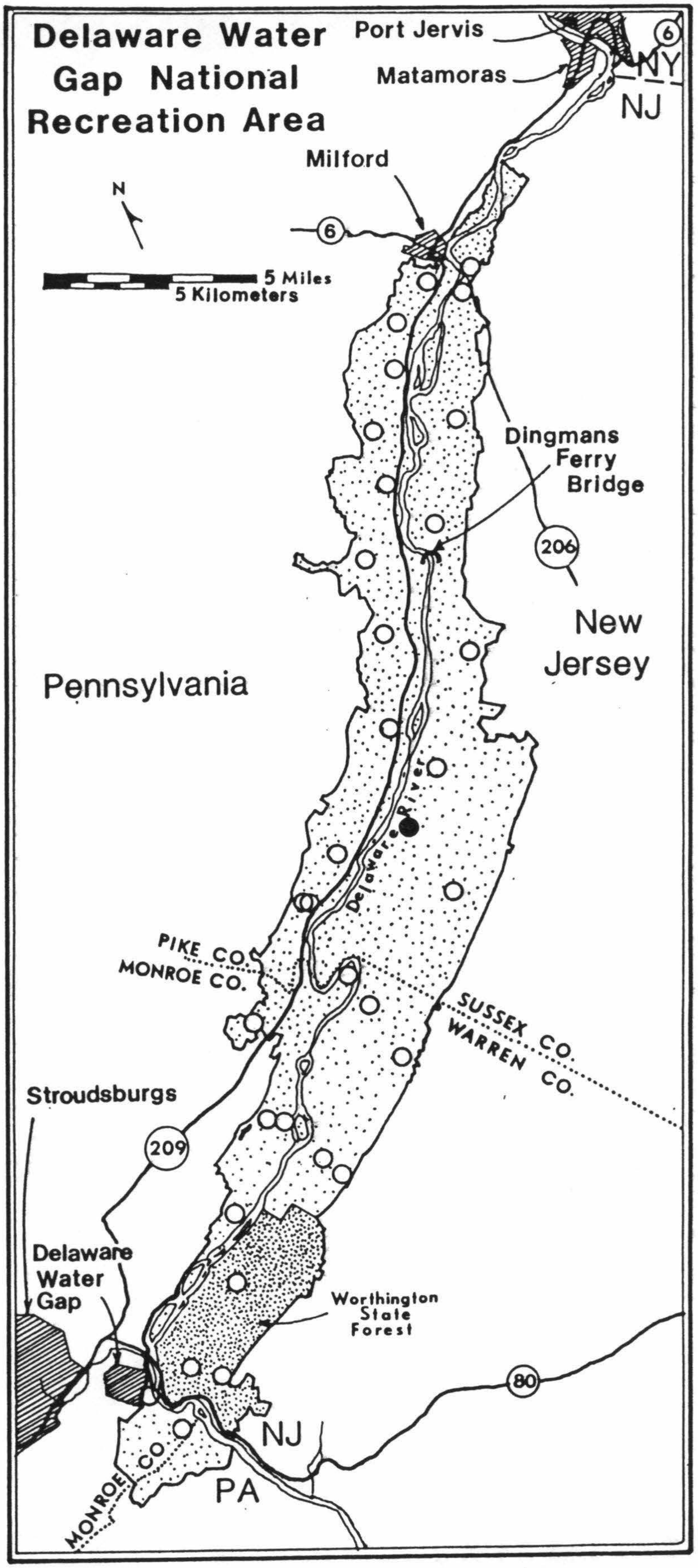

Fig. 7. Candelariella xanthostigma

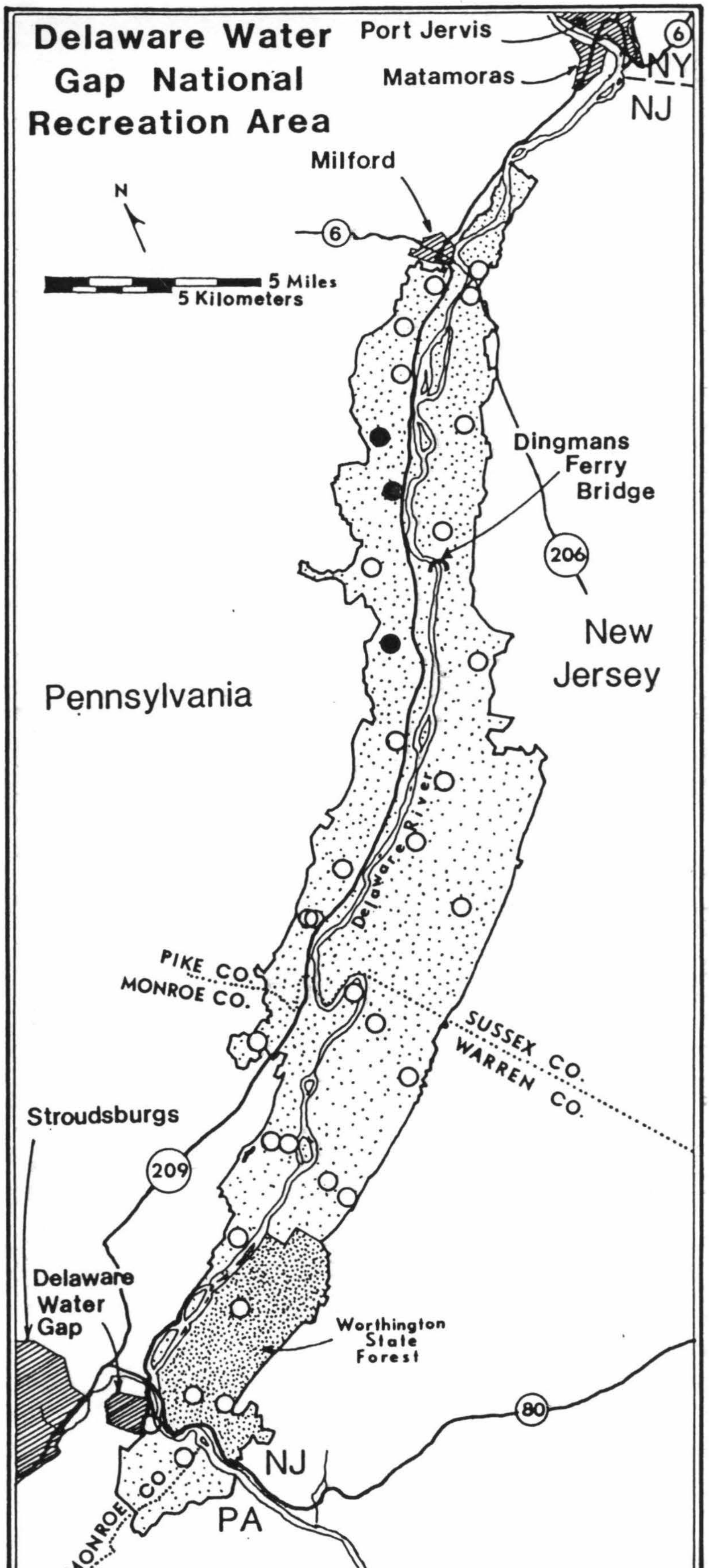

Fig. 8. Cetraria ciliaris

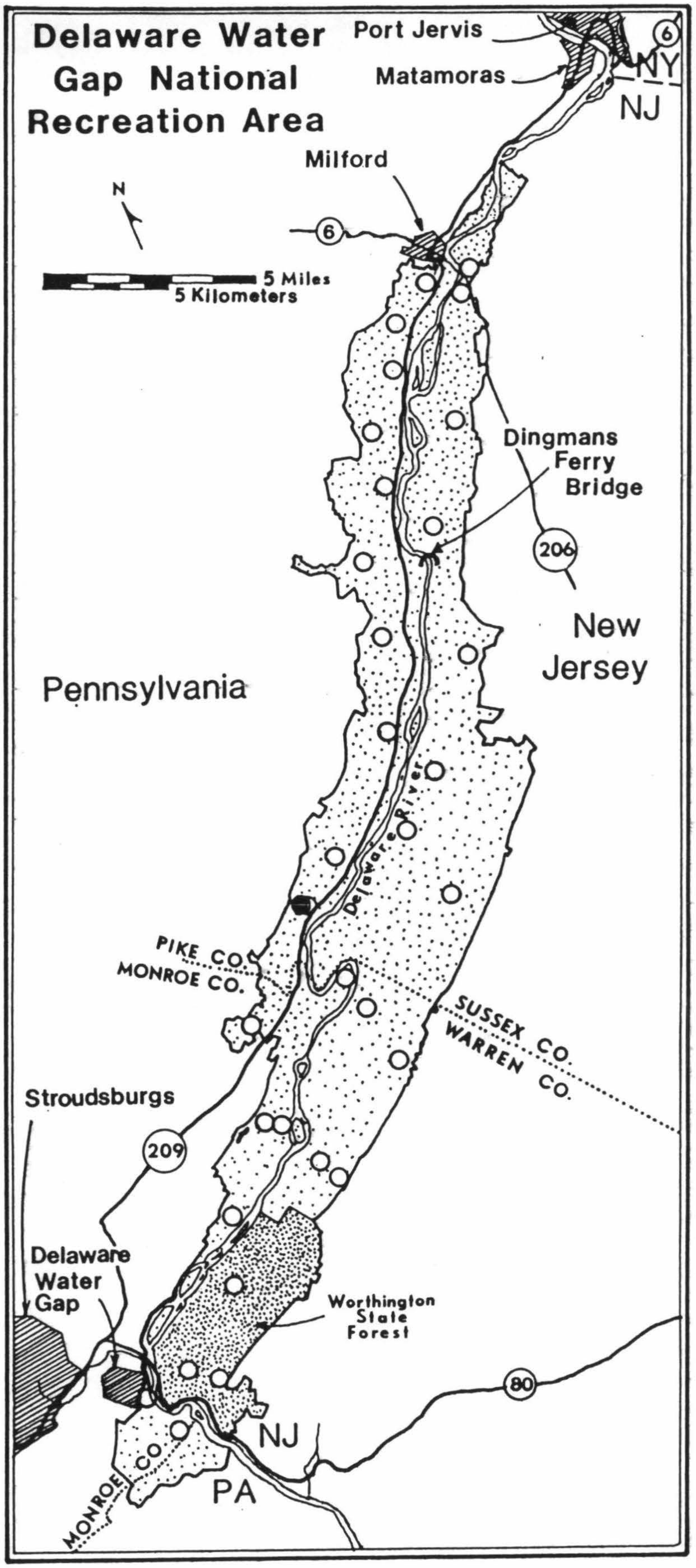

Fig. 9. Usnea hirta