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LICHENS AND AIR QUALITY IN

HERCULES GLADES WILDERNESS OF MARK TWAIN NATIONAL FOREST

FINAL REPORT

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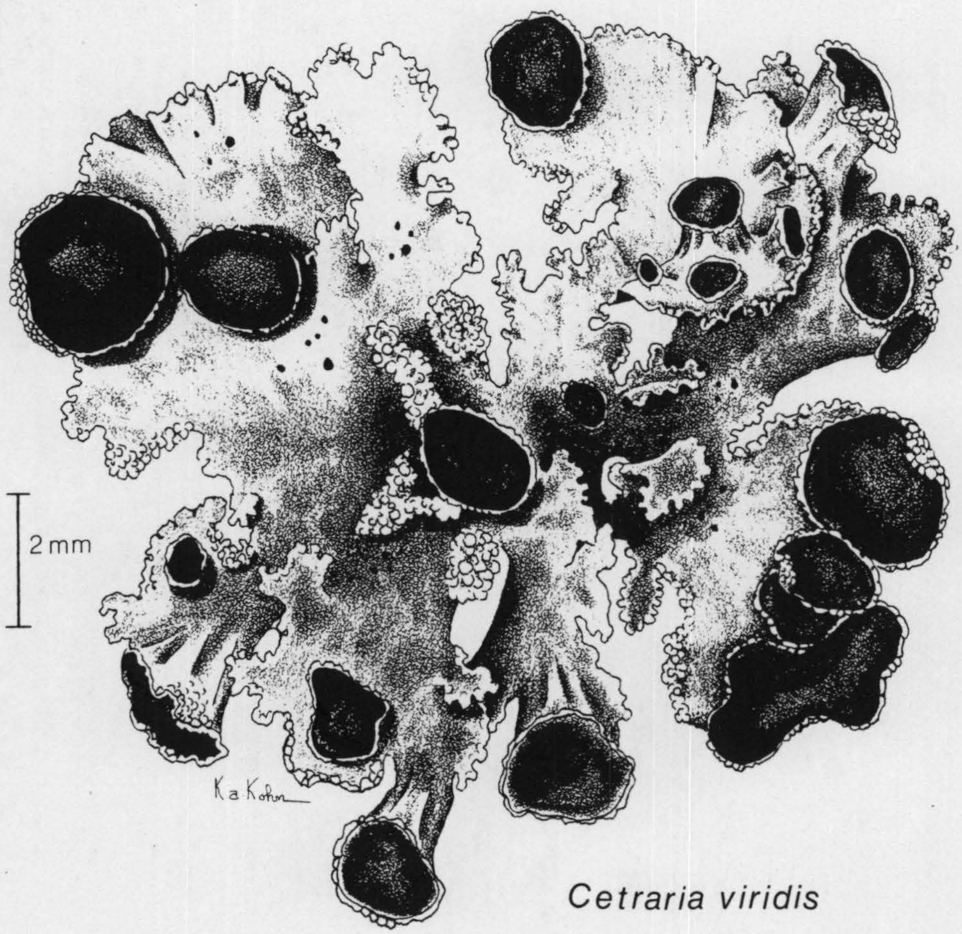

Cetraria viridis

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IN

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OF

MARK TWAIN NATIONAL FOREST

Final Report

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by

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TABLE OF CONTENTS

LICHENS OF HERCULES GLADES WILDERNESS

ABSTRACT

This study of the lichens of Hercules Glades Wilderness was designed 1) to collect lichens for a lichen flora census, 2) to collect lichens for elemental analysis, 3) to study the health and distributions of species most sensitive to air pollution, and 4) to assess the effects of air quality on lichens. Seventeen localities were studied throughout the wilderness. Samples of two species were collected at five localities for elemental analysis.

The lichen flora is quite diverse. There were 179 species present and several species very sensitive to sulfur dioxide. The distributions of these sensitive species do not show patterns that would suggest air quality problems. All of the lichens found were in good health and with normal fertility. The lichens studied by elemental analysis show normal levels of all elements with the possible exception of levels of manganese at Coy Bald. Therefore, there seem to be no indications of air quality problems in the wilderness.

Recommendations are for periodic (5 years) restudy of the lichens by elemental analysis. A complete lichen restudy of the lichen flora should be done every 10-15 years. If extensive manipulation of the vegetation of the balds is planned, a lichenologist should be consulted to prevent loss of species that grow only in the balds.

PREFACE

Under a contract with the U. S. Forest Service (USDA/42-649) a lichen study was to be performed in Hercules Glades Wilderness Area of the Mark Twain National Forest. This study was to survey the lichens of the wilderness, produce a census of the lichen flora, collect and analyze lichens for chemical contents and evaluate the lichen flora with reference to the air quality. This study was to establish baseline data for future restudy and determine the presence of any air quality problems that 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 Mr. Manfred Mielke, and with personnel on the Mark Twain National Forest.

The Forest Service 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 U. S. Forest Service, Mark Twain National Forest and NAS & PF Forest Health Protection. 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.

Some species of 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)(LeBlanc et al., 1972) or by nitrogen oxides at 3834-7668 ug/cubic meter or by other strongly oxidizing compounds such as ozone (Ross & Nash, 1983, Sigal & Nash, 1983). Other lichens are less sensitive and a few can tolerate levels of sulfur dioxide over 300 ug/cubic meter (Laundon, 1967, Trass, 1973). The algae of the thallus are the first to be damaged in areas with air pollution and the first indication of damage is discoloring and death of the algae, which quickly leads to the death of the lichen. After the lichen dies it disappears from the substrate within a few months to a year as it disintegrates and decomposes (Wetmore, 1982).

Lichens are more sensitive to air pollution when they are wet and physiologically active and are least sensitive when dry (Nash, 1973, Marsh & Nash, 1979) and are more sensitive when growing on acid substrates.

Contrary to some published reports (Medlin, 1985) there is little evidence that most lichens are good indicators of acid precipitation. However, Sigal & Johnston (1986) have reported that one species of _Umbilicaria_ shows visible damage due to artificial acid rain. They also report that similar symptoms were found in collections from various localities in North America. Lechowicz (1987) reported that acid rain only slightly reduced growth of _Cladina stellaris_, but Hutchinson et al. (1986) reported that extremely acid precipitation killed or damaged some mosses and lichens. Scott & Hutchinson (1987) showed temporary reduction of photosynthesis in _Cladina stellaris_ and _C. rangiferina_ after artificial acid rain.

Lichens are able to accumulate chemical elements in excess of their metabolic needs depending on the levels in the substrate and the air and, since lichens are slow growing and long lived, they serve as good summarizers of the 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 Hercules Glades Wilderness is located in the Ozark Mountains in southwestern Missouri. The land is rolling hills with hardwood forests and openings. Oak (Quercus), hickory (Carya), and hackberry (Celtis) dominate the forested areas with some stands of maple (Acer) or shortleaf pines (Pinus). The rock openings have thin soil over limestone rocks with scattered juniper (Juniperus). Some of the openings have been burned to retard the encroachment of the forest.

There has been no systematic lichen collecting done in the wilderness area, but various collectors have collected some lichens in the Ozarks in the past and some of these may have been from within the wilderness. No references have been found to reports of lichens from Hercules Glades Wilderness.

METHODS

Field work was done during August and September, 1991. Collections in the wilderness were made at 17 localities and 968 lichen collections were obtained. 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 wilderness, 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 special lichen products (lichen substances) where necessary. The original packet of each collection has been deposited in the University of Minnesota Herbarium and duplicates will be distributed to other herbaria. All specimens deposited at the University of Minnesota have been entered into the computerized data base maintained there.

LICHEN FLORA

The following list of lichens is based on my collections. There are no literature reports of lichens previously collected in the Hercules Glades Wilderness Area. Species found only once are indicated by "Rare". In the first columns the letters indicate the sensitivity to sulfur dioxide, if known, according to the categories proposed by Wetmore (1983): S=Sensitive, I=Intermediate, T=Tolerant. S-I is intermediate between Sensitive and Intermediate and I-T is intermediate between Intermediate and Tolerant. Species in the Sensitive category are absent when annual average levels of sulfur dioxide are above 50ug per cubic meter. The Intermediate category includes those species present between 50 and 100ug and those in the Tolerant category are present at over 100ug per cubic meter.

SPECIES

Acarospora fuscata (Nyl.) Arn.
Acarospora schleicheri (Ach.) Mass.
Anzia colpodes (Ach.) Stizenb.
Anzia colpodes (Ach.) Stizenb.
Arthonia caesia (Flot.) Körb.
Arthonia dispersa (Schrad.) Nyl. :Rare
Arthonia patellulata Nyl. :Rare
Arthonia pyrrhuliza Nyl. :Rare
1 additional unidentified species of _Arthonia_
Arthothelium ruanum (Mass.) Zw.
1 additional unidentified species of _Arthothelium_
Aspicilia caesiocinerea (Nyl. ex Malbr.) Arn. :Rare
Aspicilia cinerea (L.) Körb. :Rare
Aspicilia contorta (Hoffm.) Kremp.
I _Bacidia rubella_ (Hoffm.) Mass. :Rare
Bacidia suffusa (Fr.) Schneid.
Bacidia trachona (Ach.) Lett.
Buellia novomexicana B. de Lesd.
Buellia spuria (Schaer.) Anzi
Buellia stigmaea Tuck. :Rare
I _Buellia stillingiana_ Steiner
1 additional unidentified species of _Buellia_
Calicium abietinum Pers. :Rare
Calicium salicinum Pers. :Rare
Caloplaca camptidia (Tuck.) Zahlbr.
S-I _Caloplaca cerina_ (Ehrh.) Th. Fr.
Caloplaca chrysophthalma Degel.
Caloplaca cinnabarina (Ach.) Zahlbr.
Caloplaca citrina (Hoffm.) Th. Fr.
S _Caloplaca flavorubescens_ (Huds.) Laund.
Caloplaca flavovirescens (Wulf.) Dalla Torre & Sarnth.
Caloplaca holocarpa (Hoffm.) Wade
Caloplaca pollinii (Mass.) Jatta
Caloplaca sarcopisoides (Körb.) Zahlbr.
Caloplaca squamosa (B. de Lesd.) Zahlbr. :Rare
2 additional unidentified species of _Caloplaca_
S-I _Candelaria concolor_ (Dicks.) B. Stein
Candelaria fibrosa (Fr.) Müll. Arg.

Candelariella efflorescens R. Harris & Buck
S-I *Candelariella xanthostigma* (Ach.) Lett.
Catapyrenium lachneum (Ach.) R. Sant.
Catapyrenium tuckermanii (Rav. ex Mont.) Thoms.
Catillaria nigroclavata (Nyl.) Schuler :Rare
Cetraria viridis Schwein. in Halsey
Chaenothecopsis debilis (Turn. & Borr. ex Sm.) Tibell :Rare
Chaenothecopsis rubescens Vain. :Rare
Chaenothecopsis savonica (Räs.) Tibell
Chrysothrix candelaris (L.) Laund.
Cladina subtenuis (des Abb.) Hale & W. Culb.
Cladonia bacillaris Nyl.
I *Cladonia cristatella* Tuck.
Cladonia cryptochlorophaea Asah.
Cladonia furcata (Huds.) Schrad. :Rare
Cladonia grayi G. K. Merr. ex Sandst.
Cladonia parasitica (Hoffm.) Hoffm.
Cladonia peziziformis (With.) Laundon
Cladonia piedmontensis G. K. Merr. :Rare
Cladonia polycarpoides Nyl. in Zwackh
Cladonia pyxidata (L.) Hoffm.
Cladonia robbinsii Evans
Cladonia sobolescens (Nyl.) Vain. :Rare
Cladonia symphycarpa (Ach.) Fr.
Coccocarpia palmicola (Spreng.) Arvid. & Galloway
Collema conglomeratum Hoffm.
Collema nigrescens (Huds.) DC.
Collema polycarpon Hoffm. :Rare
Collema subflaccidum Degel.
Collema texanum Tuck.
1 additional unidentified species of *Collema*
Conotrema urceolatum (Ach.) Tuck.
Dermatocarpon miniatum (L.) Mann
Dimelaena oreina (Ach.) Norm. :Rare
Endocarpon pusillum Hedw.
Gonohymenia nigritella (Lett.) Henss.
I *Graphis scripta* (L.) Ach.
Haematomma elatinum (Ach.) Mass. :Rare
Haematomma pustulatum Brodo & W. Culb.
Heppia lutosa (Ach.) Nyl. :Rare
Heterodermia echinata (Tayl.) W. Culb.
Heterodermia granulifera (Ach.) W. Culb.
Heterodermia hypoleuca (Muhl.) Trev.
Heterodermia obscurata (Nyl.) Trev.
Heterodermia speciosa (Wulf.) Trev.
I *Hyperphyscia adglutinata* (Flörke) Mayrh. & Poelt
Hyperphyscia syncolla (Tuck. ex Nyl.) Kalb
Lecanora caesiorubella Ach.
Lecanora hybocarpa (Tuck.) Brodo
Lecanora minutella Nyl. :Rare
T *Lecanora muralis* (Schreb.) Rabenh.
Lecanora strobilina (Spreng.) Kieff.
Lecanora subimmergens Vain.

Lecanora valesiaca (Müll. Arg.) Stizenb.
 1 additional unidentified species of Lecanora
Lecidea berengeriana (Mass.) Nyl.
Lecidea erratica Körb. :Rare
 3 additional unidentified species of Lecidea
Lecidella euphorea (Flörke) Hert.
Lepraria finkii (B. de Lesd. in Hue) R. Harris
Leptogium burnetiae Dodge
Leptogium byssinum (Hoffm.) Zw. ex Nyl. :Rare
Leptogium chloromelum (Sw. ex Ach.) Nyl. :Rare
Leptogium cyanescens (Rabenh.) Körb.
Leptogium lichenoides (L.) Zahlbr.
Leptogium milligranum Sierk
Leptogium teretiusculum (Wallr.) Arn. :Rare
Maronea constans (Nyl.) Hepp
Megaspora verrucosa (Ach.) Hafeln. & Wirth
Micarea globulosella (Nyl.) Coppins :Rare
Micarea misella (Nyl.) Hedl.
 1 additional unidentified species of Micarea
Mycocalicium subtile (Pers.) Szat. :Rare
Ochrolechia arborea (Kreyer) Almb.
Ochrolechia verrucosa Kalb.
I Opegrapha varia Pers.
Pannaria lurida (Mont.) Nyl.
Parmelia angustiphylla (Gyeln.) ined.
Parmelia aurulenta Tuck.
Parmelia bolliana Müll. Arg.
I Parmelia caperata (L.) Ach.
Parmelia cetrata Ach.
Parmelia conspersa (Ach.) Ach.
Parmelia crinita Ach.
Parmelia cumberlandia (Gyeln.) Hale
Parmelia eurysaca Hue :Rare
Parmelia galbina Ach.
Parmelia hypoleucites Nyl.
Parmelia hypotropa Nyl.
Parmelia louisianae Hale :Rare
Parmelia margaritata Hue
Parmelia obsessa Ach. :Rare
Parmelia perforata (Jacq.) Ach. :Rare
Parmelia perreticulata (Räs.) Hale
S Parmelia reticulata Tayl. :Rare
I Parmelia rudecta Ach.
Parmelia subtinctoria Zahlbr.
Peltigera rufescens (Weis) Humb.
Peltula bolanderi (Tuck.) Wetm. :Rare
I Pertusaria amara (Ach.) Nyl. :Rare
Pertusaria hypothamnolica Dibb.
Pertusaria leucostoma (Bernh.) Mass. :Rare
Pertusaria paratuberculifera Dibb.
Pertusaria pustulata (Ach.) Duby
Pertusaria tetrathalamia (Fee) Nyl. :Rare
Pertusaria texana Müll. Arg. :Rare
Pertusaria valliculata Dibb.

Pertusaria velata (Turn.) Nyl.
3 additional unidentified species of *Pertusaria*
Phaeophyscia cernohorskyi (Nadv.) Essl.
Phaeophyscia chloantha (Ach.) Moberg
Phaeophyscia ciliata (Hoffm.) Moberg
Phaeophyscia imbricata (Vain.) Essl. :Rare
Phaeophyscia melanchra (Hue) Hale
I *Phaeophyscia orbicularis* (Neck.) Moberg
Phaeophyscia pusilloides (Zahlbr.) Essl.
Phaeophyscia rubropulchra (Degel.) Essl.
I *Physcia aipolia* (Ehrh. ex Humb.) Fürnr.
Physcia americana G. K. Merr. in Evans & Meyrow.
T *Physcia dubia* (Hoffm.) Lett. :Rare
I *Physcia millegrana* Degel. :Rare
I *Physcia stellaris* (L.) Nyl.
Physcia subtilis Degel. :Rare
I *Physconia detersa* (Nyl.) Poelt
Placynthiella icmalea (Ach.) Coppins & James
Placynthium nigrum (Huds.) Gray
Porpidia albocaerulescens (Wulf.) Hert. & Knoph
Protoblastenia rupestris (Scop.) Steiner
Psora pseudorussellii Timdal
Psora russellii (Tuck.) A. Schneid.
Psorula rufonigra (Tuck.) G. Schneid.
Pyrenula pseudobufonia (Rehm.) R. Harris
Pyxine caesiopruinosa (Nyl.) Imsh.
Pyxine sorediata (Ach.) Mont.
S *Ramalina americana* Hale
1 unidentified species of *Rinodina*
Sarcogyne clavus (DC. in Lam. & DC.) Kremp. :Rare
Sarcogyne privigna (Ach.) Mass. :Rare
Sarcogyne regularis Körb.
Sphinctrina turbinata (Pers.) De Not. :Rare
Synalissa symphorea (Ach.) Nyl.
Teloschistes chrysophthalmus (L.) Th. Fr.
Thyrea pulvinata (Schaer.) Mass.
Trapeliopsis flexuosa (Fr.) Coppins & James
Trapeliopsis granulosa (Hoffm.) Lumbsch.
Usnea strigosa (Ach.) A. Eaton
Verrucaria fuscella (Turn.) Winch
Verrucaria glaucovirens Grumm. :Rare
Verrucaria muralis Ach.
Verrucaria nigrescens Pers.
2 additional unidentified species of *Verrucaria*
I *Xanthoria candelaria* (L.) Th. Fr.
S-I *Xanthoria fallax* (Hepp in Arn.) Arn. :Rare

DISCUSSION OF FLORA

This list of 179 species presents the first listing of lichens for the wilderness and includes some species rare in eastern North America, such as *Caloplaca sarcopisoides*, *C.*

camptidia, and Anzia colpodes. There are still 17 unidentified species and some of these may be undescribed. Some of the species, such as Buellia novomexicana and Collema texanum, were previously only known from western North America. The most common species are Cladina subtenuis, Collema conglomeratum, Leptogium milligranum, Parmelia reticulata, P. subtinctoria, and Physconia detersa.

There were no cases where lichens sensitive to sulfur dioxide were observed to be damaged or killed. All species normally found fertile were also fertile in the wilderness. The numerous "Rare" species seem to be rare because of special ecological requirements or they are rare throughout their distributional range in North America and are not rare because of air pollution. These observations indicate that there is no air quality degradation in the area due to sulfur dioxide that causes observable damage to the lichen flora.

Another way of analyzing the lichen flora of an area is to study the distributions of the sensitive species within the 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 only a few lichens in the wilderness with known sensitivity to sulfur dioxide according to the list presented in Wetmore (1983) and many of these are not very common.

Species in the most sensitive category are usually absent when sulfur dioxide levels are above 50ug per cubic meter average annual concentrations. The S-I category is between Sensitive and Intermediate. The species that occur in the wilderness in these two most sensitive categories are as follows with the sensitivity category indicated in the first column.

S-I *Caloplaca cerina* (Ehrh.) Th. Fr.
S *Caloplaca flavorubescens* (Huds.) Laund.
S-I *Candelaria concolor* (Dicks.) B. Stein
S-I *Candelariella xanthostigma* (Ach.) Lett.
S *Parmelia reticulata* Tayl.
S *Ramalina americana* Hale
S-I *Xanthoria fallax* (Hepp in Arn.) Arn.

The distributions of these species are mapped (Fig. 2-8). Although these species are not found at all localities and some are 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 two species were collected in spunbound olefin bags at various localities in different parts of the wilderness for laboratory analysis. At some localities both species were not present in quantities needed for the analysis. Species collected and the substrates were *Cladina subtenuis* on soil and rocks, and *Parmelia rudecta* on trees. These species were selected because they are the only ones present in abundance and relatively easy to clean.

Five localities were selected for elemental analysis and are indicated on the map of collection localities. These localities are: 2 miles northwest of Hercules Lookout Tower, 0.5 miles north of Persimmon Hollow, along trail south of Long Creek (no other lichens collected here, indicated by square on map), 0.5 miles northwest of Hercules Lookout Tower, and 0.5 miles northeast of Coy Bald. Ten to 20 grams of each species were collected at each locality.

Lichens were air dried and cleaned of all bark and detritis under a dissecting microscope, but thalli were not washed. Three samples of each collection were submitted for analysis. 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

Table 1. Elemental Analysis of Hercules Glades Lichens
Values in ppm of thallus.

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
C. subtenuis	522	1830	689	462	271	172	43.29	180.78	13.16	2.17	1.35	2.67	0.76	0.86	#	600	Coy Bald
C. subtenuis	484	1721	682	436	323	205	41.59	159.86	12.84	2.00	1.35	5.24	*0.32	0.68	#	620	Coy Bald
C. subtenuis	460	1712	684	455	275	177	45.32	155.81	12.61	1.98	1.13	2.25	0.64	0.73	#	650	Coy Bald
C. subtenuis	303	1426	883	367	412	289	26.60	74.45	11.56	1.78	1.43	4.16	#	0.83	0.17	490	Persimmon Holl.
C. subtenuis	355	1693	1048	420	280	194	29.00	83.68	10.90	1.96	1.28	*0.76	#	0.38	*0.06	470	Persimmon Holl.
C. subtenuis	337	1576	993	409	317	219	29.79	82.93	10.83	1.78	1.14	2.13	#	0.45	0.25	570	Persimmon Holl.
C. subtenuis	326	1364	801	319	267	181	23.65	66.04	10.91	1.80	1.15	1.11	0.64	0.40	0.13	510	Persimmon Holl. @
C. subtenuis	326	1395	822	319	255	179	22.11	66.25	10.73	1.63	1.23	2.73	*0.32	0.28	*0.06	500	Persimmon Holl. @
C. subtenuis	352	1491	859	341	271	183	27.47	69.04	11.61	1.78	1.12	7.76	0.52	0.58	0.16	500	Persimmon Holl. @
C. subtenuis	275	1180	660	202	428	279	37.18	65.34	11.48	1.24	1.13	#	0.70	0.56	#	630	.5 NW Herc. Tower
C. subtenuis	307	1288	716	206	338	217	37.45	70.85	11.28	1.34	1.14	#	*0.32	0.31	#	635	.5 NW Herc. Tower
C. subtenuis	344	1413	679	207	339	215	39.42	66.29	12.01	1.44	0.96	#	0.78	0.41	#	630	.5 NW Herc. Tower
P. rudecta	339	1622	89564	279	334	199	25.51	108.33	13.47	2.80	0.92	11.78	1.08	1.10	0.58	720	Coy Bald
P. rudecta	346	1591	91191	261	238	131	25.71	104.55	13.03	2.57	0.67	7.76	1.51	0.82	0.15	790	Coy Bald
P. rudecta	421	1838	97117	277	303	163	24.38	105.36	15.19	2.96	0.64	12.42	1.44	1.07	0.48	720	Coy Bald
P. rudecta	557	1922	73088	323	368	216	16.80	54.03	16.79	2.38	0.83	11.49	0.70	0.90	0.16	840	Persimmon Holl.
P. rudecta	629	2033	61482	443	408	256	16.90	79.14	16.77	2.52	1.17	9.15	1.75	0.97	0.33	780	Persimmon Holl.
P. rudecta	632	2139	65578	415	422	248	15.87	81.11	17.28	2.76	1.16	7.19	1.16	1.18	0.18	810	Persimmon Holl.
P. rudecta	569	2105	57321	320	609	375	17.98	68.51	13.71	3.50	1.70	15.46	1.05	0.92	0.21	810	2 NW Herc. Tower
P. rudecta	476	1866	77371	280	554	293	16.91	50.64	13.83	2.80	1.33	7.21	1.53	0.79	0.34	880	2 NW Herc. Tower
P. rudecta	541	2074	71622	308	600	316	16.62	51.45	14.09	2.86	1.26	10.06	1.53	0.63	0.44	950	2 NW Herc. Tower
P. rudecta	528	2097	88498	325	365	216	16.00	14.16	25.20	3.21	0.89	12.81	0.98	0.61	0.27	1000	Long Creek
P. rudecta	453	1799	109110	275	459	268	15.33	12.59	20.21	3.32	1.12	13.27	1.85	0.98	0.35	860	Long Creek
P. rudecta	500	1903	114128	273	340	211	16.43	11.82	23.22	3.49	1.01	12.52	2.48	1.62	0.56	1090	Long Creek
P. rudecta	374	1525	127012	224	314	209	14.23	15.26	14.06	3.48	0.77	13.76	1.93	1.19	0.52	1220	.5 NW Herc. Tower
P. rudecta	450	1799	106586	278	401	265	16.99	17.16	17.95	3.73	0.96	15.00	1.41	1.07	0.30	1130	.5 NW Herc. Tower
P. rudecta	484	1852	116318	284	441	281	19.68	16.26	17.58	3.86	1.27	14.90	2.20	1.29	0.52	1160	.5 NW Herc. Tower
NBS-PEACH	1154	3680	4135	1128	479	160	16.23	665.36	64.83	3.18	16.92	12.77	2.63	2.44	0.15		
Cladina stand.	200	688	246	267	441	573	83.34	20.51	18.38	2.81	1.75	15.45	0.88	1.03	0.23	428	

* = one value at or below detection limit; included as 0.7 of detection limit
# = two or more values at or below detection limit; not included in calculations
@ = ground before dividing into replicates

Table 2. Summary of Elemental Analysis of Hercules Glades Lichens
Values in ppm of thallus.

Cladina subtenuis

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	489	1754	685	451	289	184	43.4	165.5	12.9	2.1	1.3	3.4	*0.6	0.8	#	623	Coy Bald
Std. dev.	32	66	4	14	29	18	1.9	13.4	0.3	0.1	0.1	1.6	*0.2	0.1	#	25	Coy Bald
Mean	332	1565	975	399	336	234	28.5	80.4	11.1	1.8	1.3	*2.3	#	0.6	*0.2	510	Persimmon Holl.
Std. dev.	27	134	84	28	68	49	1.7	5.1	0.4	0.1	0.1	*1.7	#	0.2	*0.1	53	Persimmon Holl.
Mean	335	1416	828	326	264	181	24.4	67.1	11.1	1.7	1.2	3.9	*0.5	0.4	*0.1	503	Persimmon Holl. @
Std. dev.	15	66	29	13	8	2	2.8	1.7	0.5	0.1	0.1	3.5	*0.2	0.2	*0.1	6	Persimmon Holl. @
Mean	309	1293	685	205	368	237	38.0	67.5	11.6	1.3	1.1	#	*0.6	0.4	#	632	.5 NW Herc. Tower
Std. dev.	35	117	28	3	52	36	1.2	2.9	0.4	0.1	0.1	#	*0.2	0.1	#	3	.5 NW Herc. Tower

Parmelia rudecta

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	369	1683	92624	273	292	164	25.2	106.1	13.9	2.8	0.7	10.7	1.3	1.0	0.4	743	Coy Bald
Std. dev.	45	134	3975	10	49	34	0.7	2.0	1.1	0.2	0.2	2.5	0.2	0.2	0.2	40	Coy Bald
Mean	606	2031	66716	394	399	240	16.5	71.4	16.9	2.6	1.1	9.3	1.2	1.0	0.2	810	Persimmon Holl.
Std. dev.	43	109	5886	63	28	21	0.6	15.1	0.3	0.2	0.2	2.2	0.5	0.1	0.1	30	Persimmon Holl.
Mean	529	2015	68771	303	588	328	17.2	56.9	13.9	3.1	1.4	10.9	1.4	0.8	0.3	880	2 NW Herc. Tower
Std. dev.	48	130	10325	20	29	42	0.7	10.1	0.2	0.4	0.2	4.2	0.3	0.1	0.1	70	2 NW Herc. Tower
Mean	494	1933	103912	291	388	232	15.9	12.9	22.9	3.3	1.0	12.9	1.8	1.1	0.4	983	Long Creek
Std. dev.	38	151	13583	30	63	32	0.6	1.2	2.5	0.1	0.1	0.4	0.8	0.5	0.1	116	Long Creek
Mean	436	1725	116639	262	385	252	17.0	16.2	16.5	3.7	1.0	14.6	1.8	1.2	0.4	1170	.5 NW Herc. Tower
Std. dev.	56	176	10217	33	65	38	2.7	1.0	2.1	0.2	0.3	0.7	0.4	0.1	0.1	46	.5 NW Herc. Tower

* = one value at or below detection limit; included as 0.7 of detection limit
\# = two or more values at or below detection limit; not included in calculations
@ = ground before dividing into replicates

material was dry ashed in a 20 ml high form silica crucible at 485 degrees Celsius for 10-12 hrs. Crucibles were covered during the ashing as a precaution against contamination. The dry ash was boiled in 2N HCl to improve the recovery of Fe, Al and Cr and followed by transfer of the supernatant to 7 ml plastic disposable tubes for direct determination by ICP.

RESULTS AND DISCUSSION

Table 1 gives the results of the analyses for all replicates arranged by species. Table 2 gives the means and standard deviations for each set of replicates. Some of the reported values were at or below the lower detection limits of the instruments. If one value of the set of 3 replicates was at or below the detection limit, 0.7 of the detection limit was used in the calculations and the value is listed with "*" in the tables. If two or more values were at or below the detection limit, no caluclations were done and these are indicated with "#" in the tables.

All of the levels found in the Hercules Glades Wilderness lichens are within typical limits for similar lichens in clean areas. The levels in *Parmelia rudecta* are similar to those reported from Minnesota and Wisconsin by Wetmore (1991). The slightly higher level of manganese at Coy Bald in both species is an exception. According to Mr. Jerry Gott of the Mark Twain National Forest, some of the balds have high concentrations of manganese in the soils, and some even have iron-manganese concretions on the soil surface or manganese stains on the rocks. The higher levels of manganese in the lichens at Coy

Bald may reflect the soil conditions.

The sulfur levels in lichens tested range from 470 to 1220 ppm for all samples and these values are near background levels as cited by Solberg (1967) Erdman & Gough (1977), Nieboer et al (1977) and Puckett & Finegan (1980) for other species of lichens. Levels may be as low as 200-300 in the arctic (Tomassini et al, 1976) while levels in polluted areas are 4300-5200 ppm (Seaward, 1973) or higher. Different species may accumulate different amounts of elements and this is evident when comparing sulfur levels of the two species. Cladina subtenuis has lower levels than Parmelia rudecta. Even when taking these differences into account there is no clear trend in accumulated levels of sulfur.

CONCLUSIONS

There is no indication that the lichens of the Hercules Glades Wilderness are being damaged by air quality. The lichen flora is reasonably diverse for such an area and there is no impoverishment of the lichen flora in any part of the Hercules Glades. There are only a few species with known sensitivies to sulfur dioxide in the wilderness and some of those that are most sensitive are quite rare. This rarity seems to be due more to ecological and climatic conditions than pollution since these species are quite healthy when present. The maps of the distributions of the more sensitive species do not show any significant voids that are not due to normal ecological conditions. There is no evidence of damaged or dead lichens in any area where healthy ones are not also present. The elemental analyses do not show abnormal accumulations of polluting elements at any locality, with the exception of manganese at Coy Bald.

RECOMMENDATIONS

Although there seem to be no air quality problems in the Hercules Glades Wilderness now, periodic restudy is recommended. Elemental analysis should be done every 5 years and a complete floristic restudy done every 10-15 years.

If plans are developed to do extensive manipulations of the vegetation in the balds to control tree encrochment, a lichenologist should be consulted to help design the work so that lichens that grow only in the balds are not lost from the lichen flora.

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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.

Taney County, Missouri

1 68258-68304 Hercules Glades, Mark Twain Nat. For. 0.75 miles west of Herculese Lookout Tower. On hilltop with oaks, sassafras and some hickory. Sec. 14, T23N, R18W. 28 Aug. 1991.

2 68305-68357 Hercules Glades, Mark Twain Nat. For. 1.75 miles west of Hercules Lookout Tower at small stream. Along stream on rocks and with oaks, hackberry and juniper. Sec. 10, T23N, R18W. 28 Aug. 1991.

3 68358-68423 Hercules Glades, Mark Twain Nat. For. 2 miles northwest of Hercules Lookout Tower. In open glade with limestone and scattered grass and juniper and oaks. Sec. 11, T23N, R18W. 29 Aug. 1991. CHEM

4 68424-68440 Hercules Glades, Mark Twain Nat. For. 1.5 miles northwest of Hercules Lookout Tower. On hilltop with pines, oaks and hockory, recently logged and burned. Sec. 11, T23N, R18W. 29 Aug. 1991.

5 68441-68518 Hercules Glades, Mark Twain Nat. For. 1 mile north of Persimmon Hollow. On southwest facing slope with patchy open calcareous rock outcrops and juniper, oak, hickory and persimmon. Sec. 21, T23N, R18W. 30 Aug. 1991.

6 68519-68571 Hercules Glades, Mark Twain Nat. For. 0.5 miles north of Persimmon Hollow. On saddle ridge west of trail with open areas, hickory, oaks and juniper. Sec. 20, T23zn, R18W. 30 Aug. 1991. CHEM.

7 68572-68633 Hercules Glades, Mark Twain Nat. For. Pees Hollow at trail crossing. Along dry stream with juniper, maple, hackberry and dogwood. Sec. 2, T23N, R18W. 31 Aug. 1991.

8 68634-68685 Hercules Glades, Mark Twain Nat. For. Along Blair Ridge at southern edge of wilderness. On hill north of road with oaks and hickory. Sec. 27, T23N, R18W. 1 Sept. 1991.

9 68686-68710 Hercules Glades, Mark Twain Nat. For. Along trail south of Long Creek. On southeast facing slope in openings with sandstone rock and grass. Sec. 15, T23N, R18W. 1 Sept. 1991.

10 68711-68772 Hercules Glades, Mark Twain Nat. For. Blair Ridge at end of Long Creek. On ridge with oaks, hickory and some maple. Sec. 13, T23N, R18W. 2 Sept. 1991.

11 68773 68839 Hercules Glades, Mark Twain Nat. For. 0.5 miles northeast of Hercules Lookout Tower. On ridge in openings with sandstone and limestone rocks and patches of trees of oaks, hickory and persimmon. Sec. 12, T23N, R18W. 2 Sept. 1991.

12 68840-68910 Hercules Glades, Mark Twain Nat. For. Coy Bald at western side of wilderness. On hilltop with limestone outcrops and scattered patches of junipers. Sec. 17, T23N, R18W. 3 Sept. 1991.

13 68911-68972 Hercules Glades, Mark Twain Nat. For. Along trail 0.5 miles southwest of Upper Pilot Knob. On ridge near small pond with oak, hickory, juniper and maple. Sec. 9, T23N, R18W. 5 Sept. 1991.

14 68973-69030 Hercules Glades, Mark Twain Nat. For. Central hill of Upper Pilot Knob. On southwest facing slope in grass openings with juniper and along edge of forest with oaks. Sec. 4, T23N, R18W. 5 Sept. 1991.

15 69031-69103 Hercules Glades, Mark Twain Nat. For. One mile southeast of Coy Bald. On west facing hillside around openings with juniper and oaks and some hickory. Sec. 6, T23N. R18W. 6 Sept. 1991.

Hercules Glades, Mark Twain Nat. For. Along trail south of Long Creek (= loc. of 1 Sept. but 0.5 miles SE). On ridge and northewst slope in openings, junipers and oaks. Sec. 14, T23N, R18W. 7 Sept. 1991. CHEM.

16 69104-69166 Hercules Glades, Mark Twain Nat. For. 0.5 miles northwest of Hercules Lookout Tower. On ridge and northeast slope with hickory, oaks and juniper. Sec. 12, T23N, R18W. 7 Sept. 1991. CHEM.

17 69167-69225 Hercules Glades, Mark Twain Nat. For. 0.5 miles northeast of Coy Bald. On plateau near small rock piles among oaks, hickory and juniper with small openings. Sec. 9, T23N, R18W. 8 Sept. 1991. CHEM.

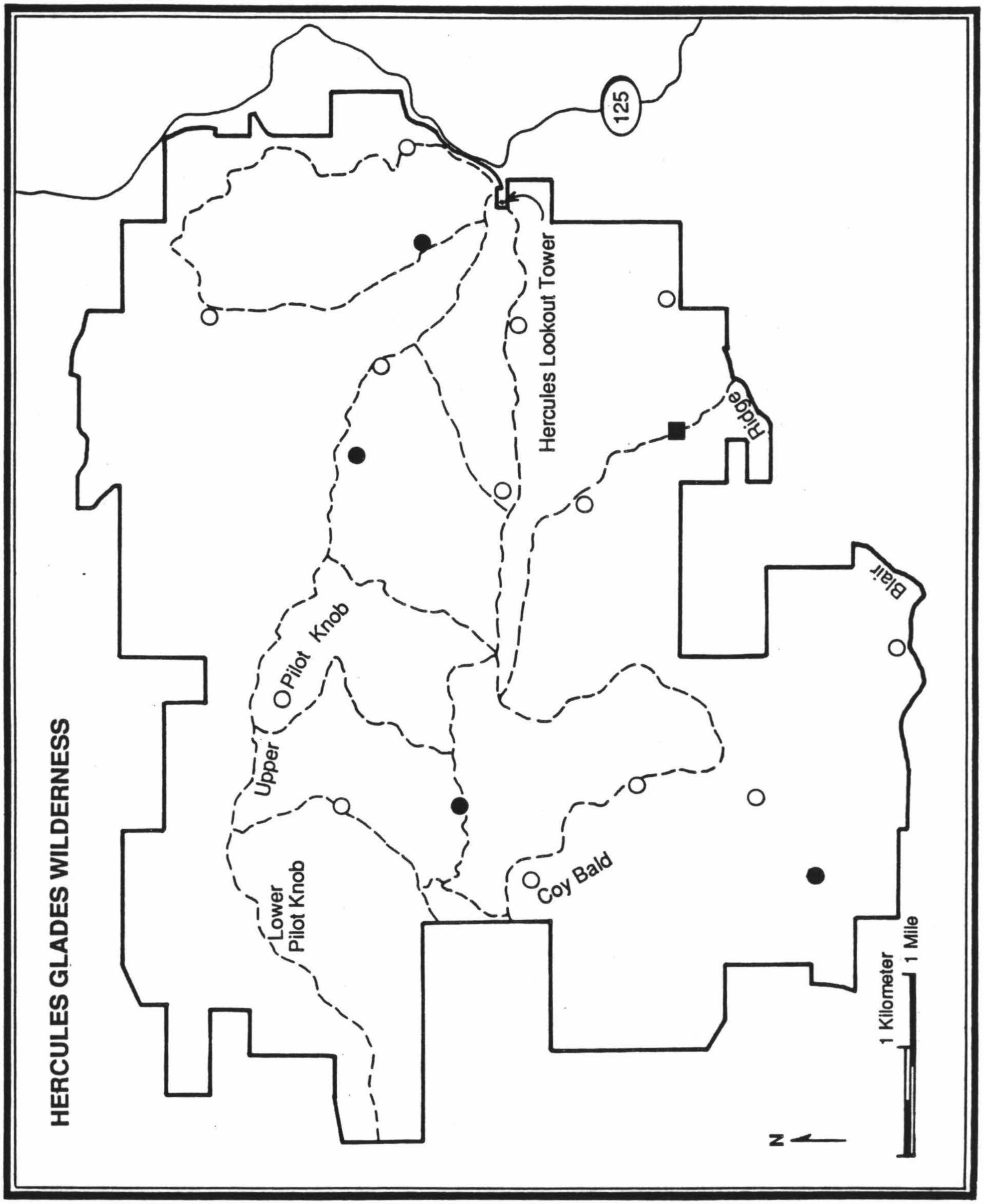

Fig. 1. Open circles are collection localities, solid circles are elemental analysis localities and collection localities, solid square is elemental analysis locality only.

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 Hercules Glades Wilderness 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-I *Caloplaca cerina* (Ehrh.) Th. Fr.
Fig. 3 S *Caloplaca flavorubescens* (Huds.) Laund.
Fig. 4 S-I *Candelaria concolor* (Dicks.) B. Stein
Fig. 5 S-I *Candelariella xanthostigma* (Ach.) Lett.
Fig. 6 S *Parmelia reticulata* Tayl.
Fig. 7 S *Ramalina americana* Hale
Fig. 8 S-I *Xanthoria fallax* (Hepp in Arn.) Arn.

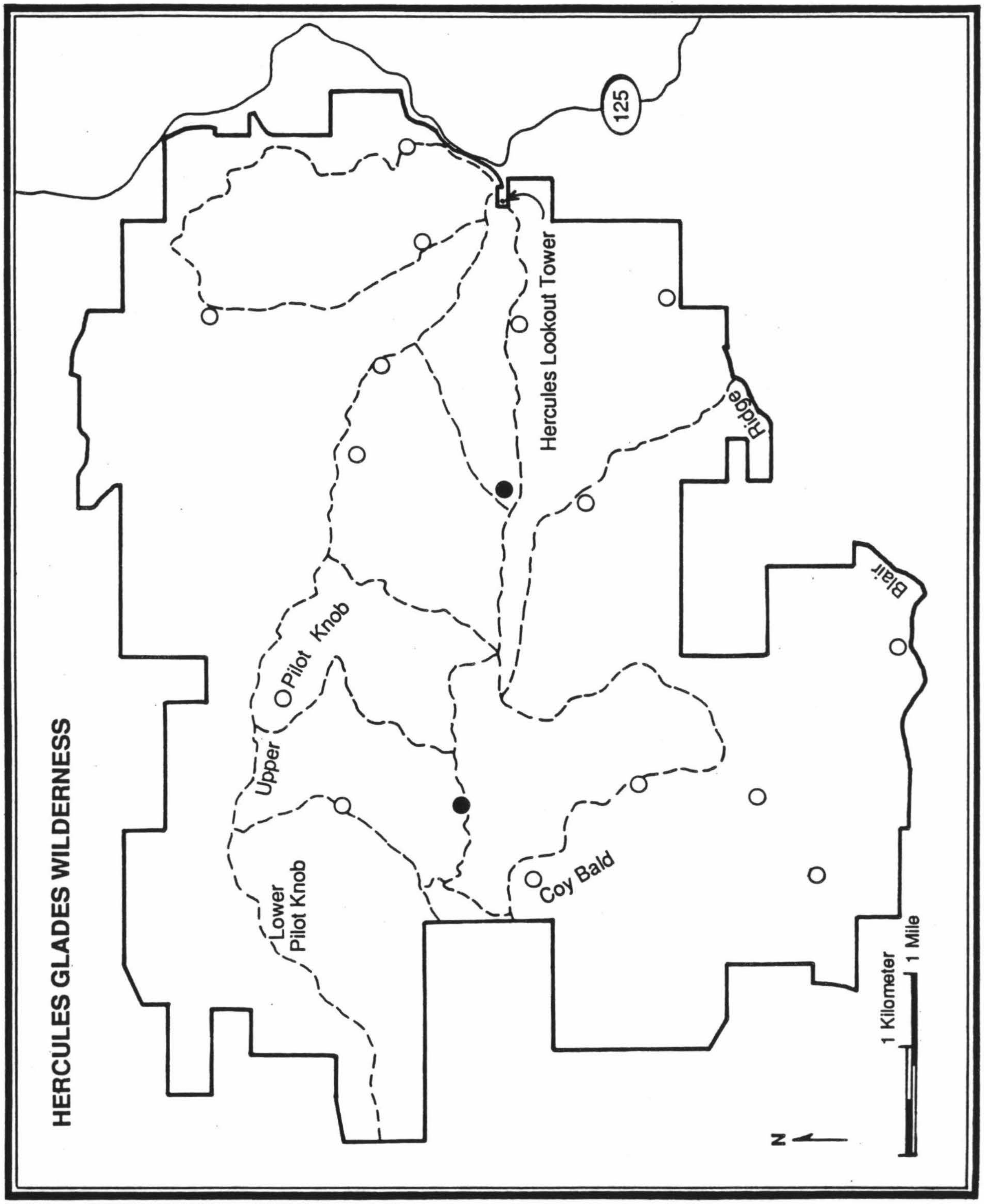

Fig. 2. Distribution of <u>Caloplaca cerina</u>.

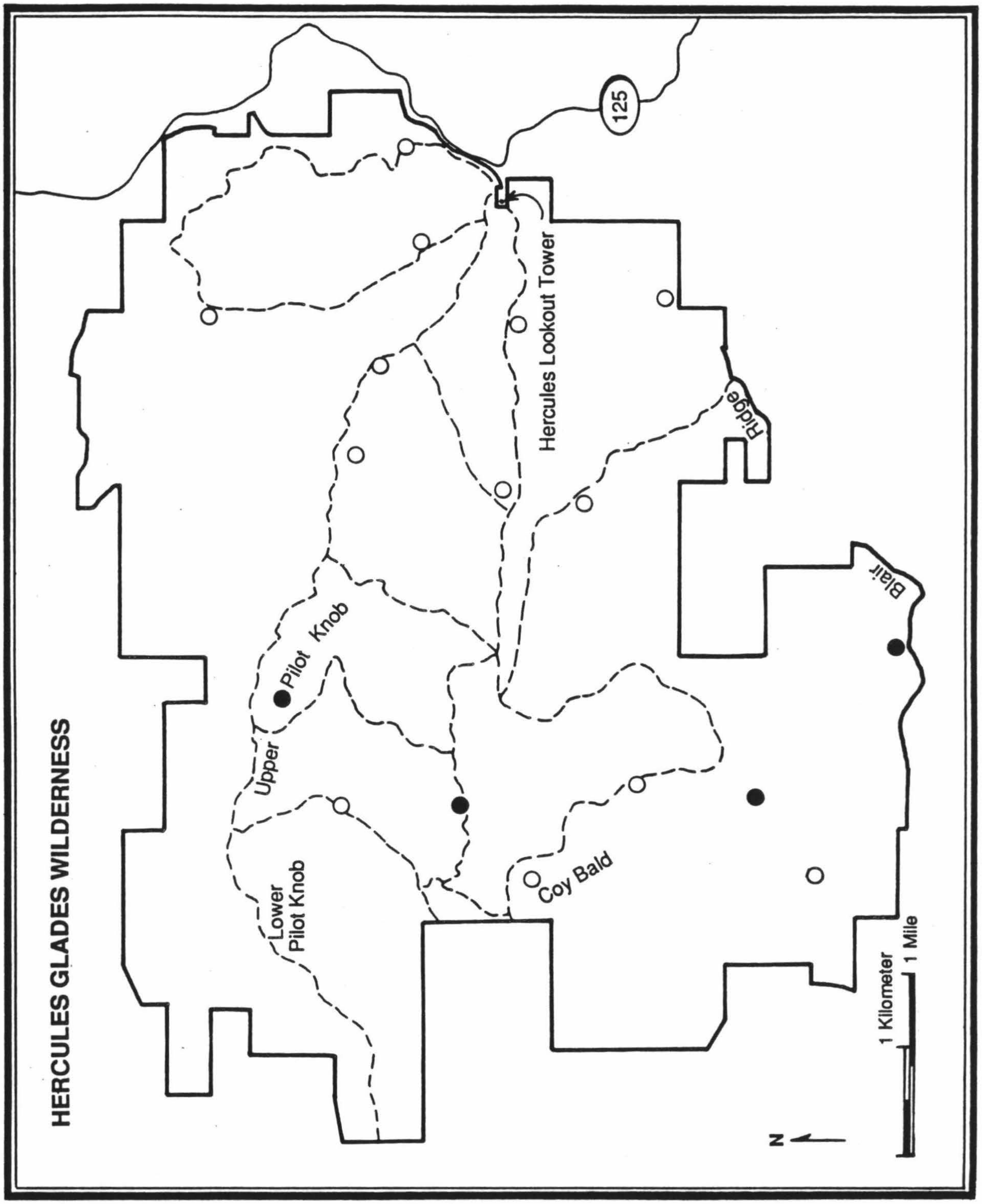

Fig. 3. Distribution of Caloplaca flavorubescens.

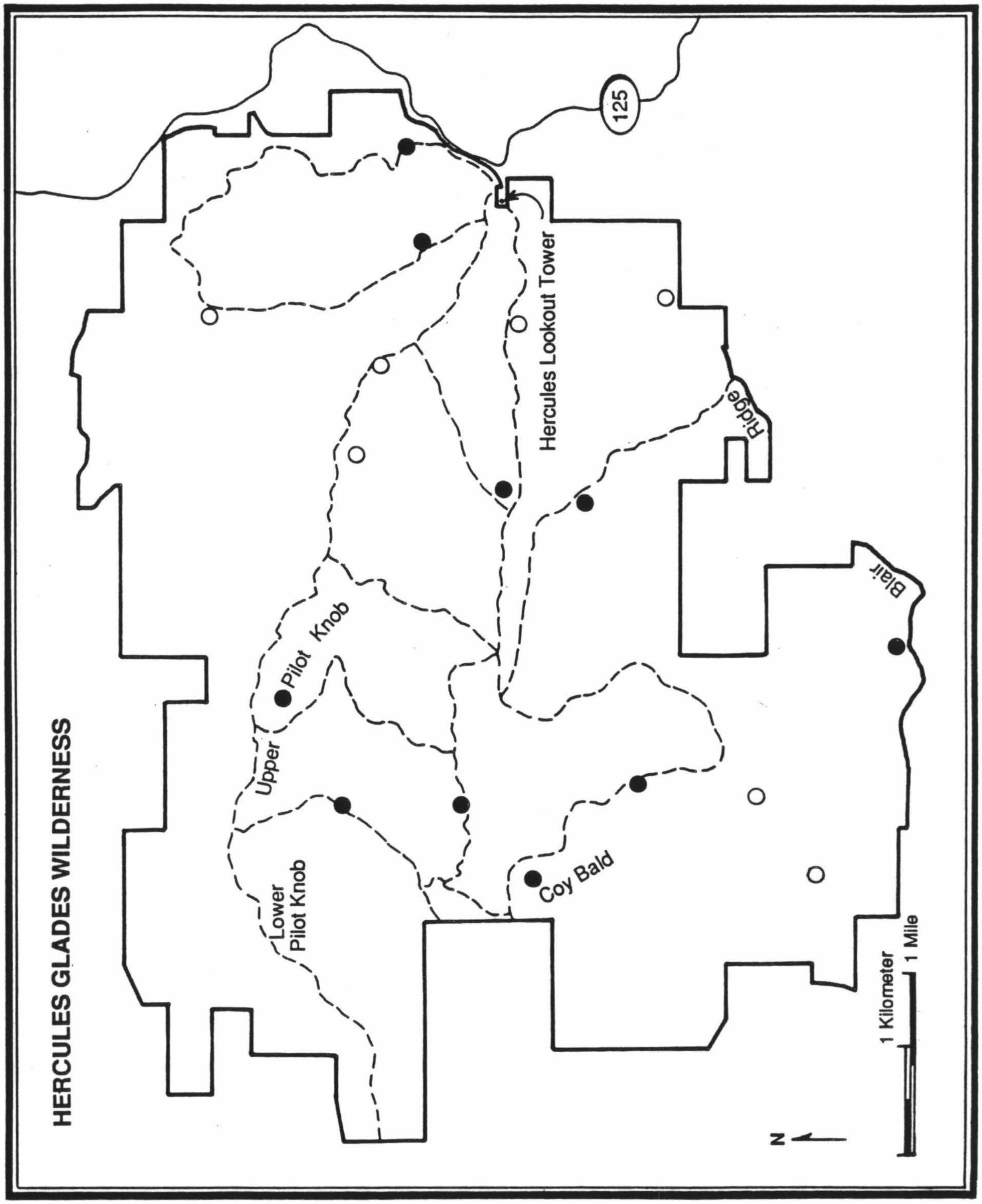

Fig. 4. Distribution of Candelaria concolor.

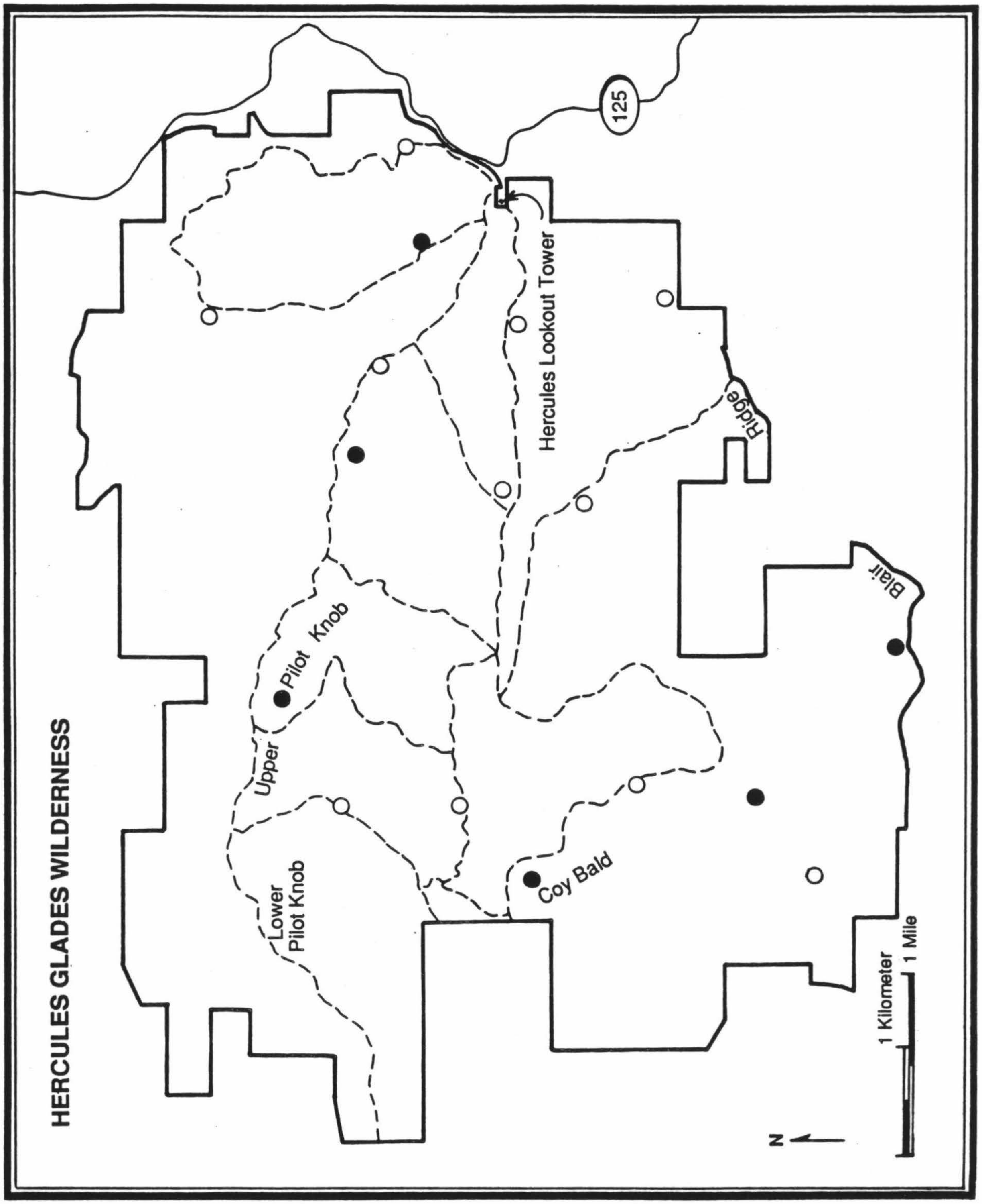

Fig. 5. Distribution of Candelariella xanthostigma.

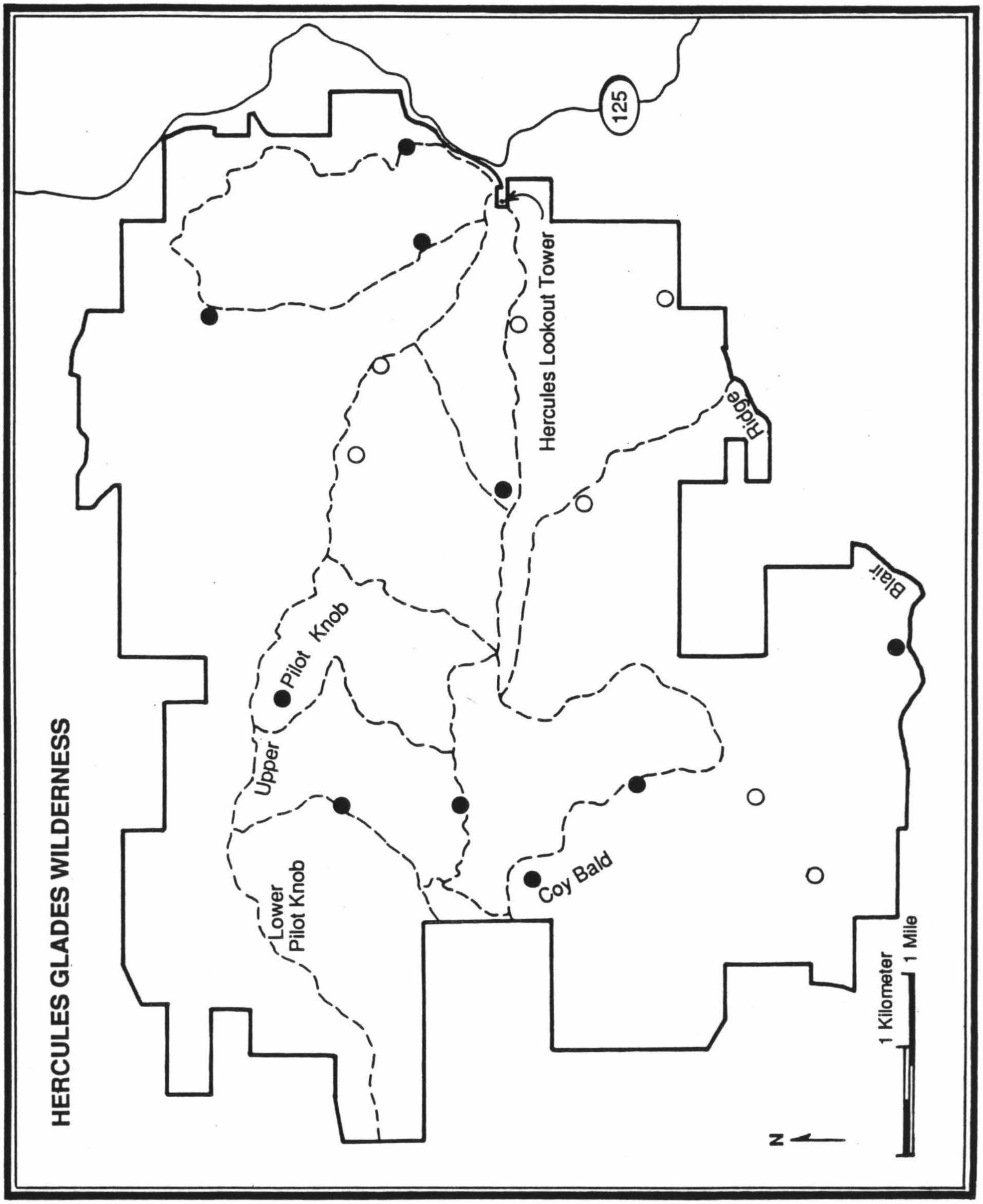

Fig. 6. Distribution of <u>Parmelia</u> <u>reticulata</u>.

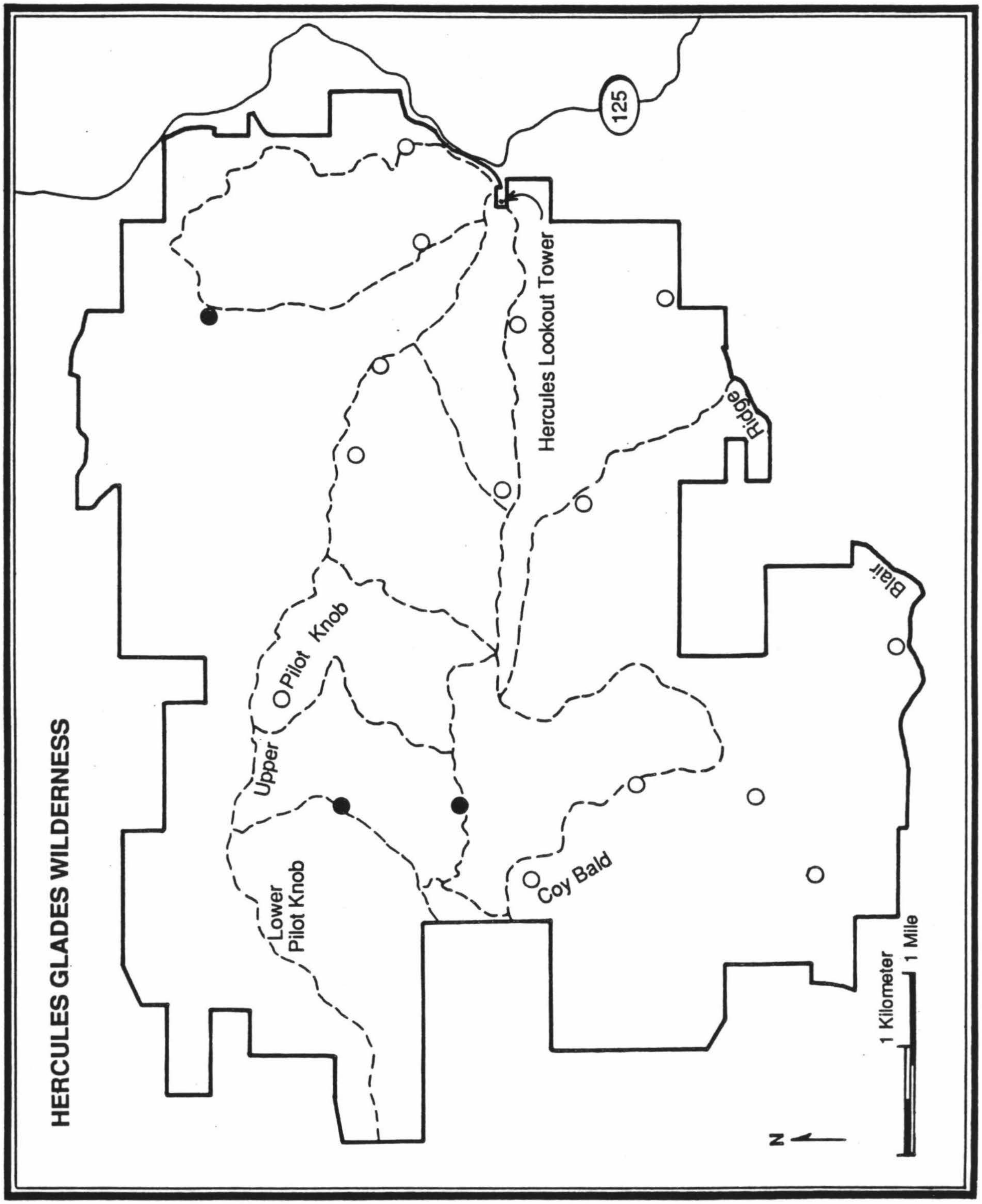

Fig. 7. Distribution of <u>Ramalina americana</u>.

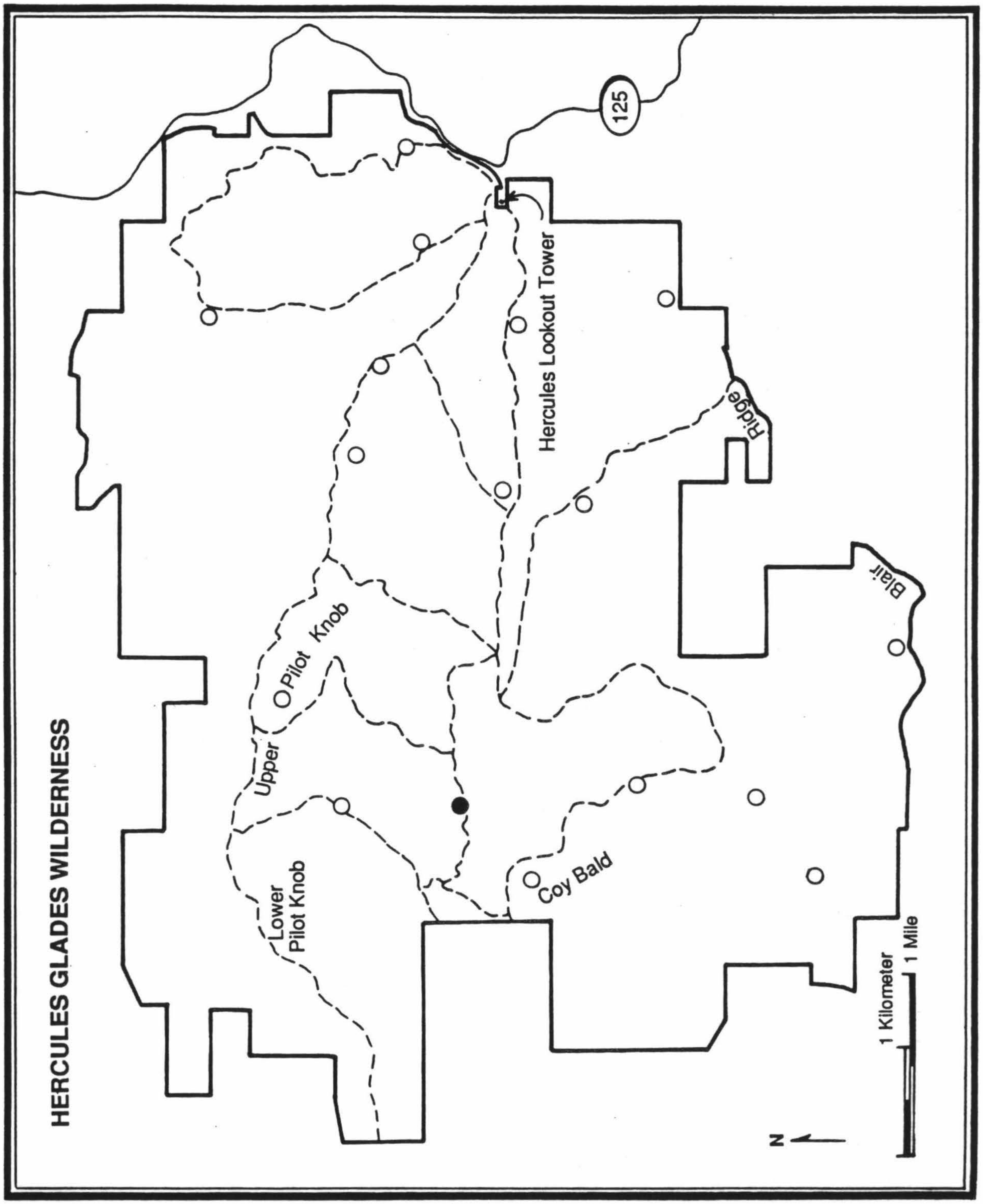

Fig. 8. Distribution of *Xanthoria fallax*.