LICHENS AS BIOINDICATORS AND MONITORS OF AIR POLLUTION IN THE FLAT TOPS WILDERNESS AREA, COLORADO

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Final Report: Forest Service Contract No. OM RFP R2-81-SP35
22 November 1982

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Summary

A baseline study of the lichens in the Flat Tops Wilderness Area was completed in July-August 1982. Twenty-one collecting sites were surveyed and inventoried and about 1000 lichen collections made. A total of 137 species was collected, representing 16 fruticose species, 47 foliose, and 74 crustose. Seven species are designated as indicator species, either because of their known sensitivity to air pollution or because of their value as bioaccumulators.

Twelve permanent lichen study plots were established at five major sites in the northeastern and southwestern sections of the Flat Tops. These 20 X 25 cm plots were documented with color photographs from which species composition and coverage can be determined and used in future comparisons.

Some 26 mass samples of the important indicator species were collected for elemental analysis. Lead and zinc, as well as sulfur, all occur in uniformly low concentration (lead 19-76 ppm, zinc 29-85 ppm, and sulfur 0.11-0.16%) over the whole region. Using this information alone we can conclude that there is minimal pollution impact in the Flat Tops at this time with no regional differences.

It is recommended that resurveys be made at appropriate intervals in order to assess any changes in the lichen flora or in elemental content which may be correlated with air pollution. Elemental assays and new photographs of the permanent study plots should be made within 3-5 years and a second inventory of the lichen flora started in about 10 years.

1. INTRODUCTION

Air pollution specialists are concerned with measuring levels of pollutants and their effect on the ecosystem. Most data have come from physical monitoring stations. Another promising approach is to use biomonitors, especially plants which by their presence or absence or state of vitality can provide a biological scale for estimating levels of pollution. These data can extend physical monitoring networks which are necessarily limited in scope by economic and other factors.

It is generally agreed that lichens are among the most sensitive and useful bioindicators. In recognition of this potential, the U.S. Forest Service proposed a long-term study of lichens and air pollution in the Flat Tops Wilderness Area in Colorado. This report gives results of a baseline program completed there in July-August 1982.

The program involved three major aspects, as follows:

1. A floristic inventory of the lichen species;
2. Establishment of permanent lichen study plots;
3. Analysis of sensitive species for content of air-borne elements.

2. OVERVIEW OF METHODOLOGIES

There are few established guidelines for setting up a monitoring program with lichens. Each study tends to be unique, adapted as necessary to vegetational, climatic, and local factors. Before presenting our results for the Flat Tops, it might be well to review past methodologies and their advantages and limitations.

Floristic Surveys

The purpose of a floristic survey is simply to inventory the flora of the area under study. The results are usually presented as a species list with--or more commonly without--notes on the relative abundance of the species. An inventory is a rather time-consuming but necessary task best conducted by a professional lichenologist since our knowledge of lichens is far less advanced than that for higher plants or even mosses. Careful floristic surveys have only rarely been made in the past and there are almost no modern state or local floras to draw on. Furthermore, even when older floristic data are available,

they are often out of date and require much taxonomic revision.

When good historical records are available in museum collections, an inventory repeated today can give us a rough measure of the loss of sensitive species of Usnea or Lobaria. These comparisons will often show a decline in the number of species in an area, depending on the amount of natural vegetational changes or man-made disturbances, or, if these factors appear to be constant, depending on the amount of air pollution.

There are several recent reports using the inventory approach, for example, one by Wetmore (1981)[1] over a ten-year period in Big Bend National Park (where no change was observed) or one by Arvidsson and Lindstrom (1980)[1] over a 20-year period in a botanical garden in Gothenburg, Sweden (where a nearly 60% decline was recorded, largely attributed to deteriorating air quality).

Most workers would agree, however, that presence-absence data on a typical lichen flora are not sensitive enough over the short term (less than 10 years) to detect the effects of air pollution, except of course near a dirty point source. This is true in particular for regions exposed to chronic, low-level pollution where damaging effects are more subtle, hard to measure, or long-term.

Sociological Surveys

One method to enhance presence-absence data is to make sociological surveys. In other words a lichen population is sampled, as with transects, in order to measure frequency, coverage, and vitality of the species. An example of this approach is a recent study by Eversman (1982)[2], who used a sample of 10 randomly selected trees near a power plant along a 50 m transect. The lichen species were tabulated in the four compass quadrants at 34 sites. Comparable quadrats can also be laid out on rocks.

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[1] These references are given in the first report by Hale (1981).

[2] These are new references given at the end of this section on p. 8.

Unfortunately few sampling techniques have been rigorously tested in practice and much research remains to be done here. Nor do we know the relative effect and speed of natural changes such as bark expansion, exfoliation, increasing canopy shading, fire, etc., and as a result we cannot always distinguish between natural and pollution-caused changes. However, a floristically based pollution study can be profitably enhanced with sociological surveys when time permits.

Measurements of Vitality

Given the fact that floristic and sociological approaches to assessing the biomonitoring potential of lichens are still at an early stage of development and demand a considerable expenditure of time, lichenologists have looked for other properties of lichens which could give more immediate, quantitative results. When subjected to pollution stress, for example, lichens do exhibit cellular or physiological responses long before external symptoms of damage show up and the thallus actually dies. These responses can be measured and quantified with more rigorous techniques than visual, often subjective inspections. A major drawback with these methods is that rather sophisticated laboratory techniques and equipment are employed to take measurements. Also, one needs to use living specimens so that retrospective studies using museum collections are not possible.

At least five different physiological parameters have been measured: (1) changes in cell wall membranes; (2) percentage of plasmolyzed algal cells in the lichen thallus; (3) photosynthetic rate of the algae; (4) respiration rate of the thallus (presumably reflecting mostly fungal metabolism); and (5) changes in cell fine structure viewed with a transmission electron microscope (TEM).

All of these methods have been studied to some extent in laboratory experiments, either independently or in connection with air pollution effects. For example, SO_2 alters cell wall permeability, resulting in leakage of electrolytes which can be measured as in an increase in conductivity. In recent work Pearson and Rodgers[2] detected significant changes after only two weeks of experimental field fumigations.

SO_2 also causes plasmolysis of algal cells and levels of air pollution can be assumed to be proportional to number of plasmolyzed cells in a thallus sample examined under a microscope. Rate of photosynthesis is obviously closely related to degree of plasmolysis of the green algal component. Much less is known about respiration rate of lichens except to say that it seems to be less sensitive to pollution than photosynthetic rate.

The fifth measure, changes in fine structure of cell organelles, is probably more difficult to interpret at this time. Virtually nothing is known of seasonal changes in fine structure, those induced by drought, moisture, temperature, etc., as opposed to pollution (Holopainen, 1982).[2]

The main problem in using data on vitality derived from laboratory studies is how to relate it to the uncontrolled conditions found in nature. Beekley and Hoffman (1981)[2] discuss these problems in detail on the basis of additional experiments which show considerable variation--or in some cases little significant variation--for various fumigation levels. Obviously we need more baseline data as well as better laboratory studies before general principles can be drawn and applied to air quality monitoring programs.

Assay of Elemental Accumulation

Lichens efficiently accumulate many elements from both dryfall and rainfall. These elements are immobilized in cell walls in concentrations that would be detrimental to other plants. The uptake is rapid, in extreme cases measurable in a few weeks, and a maximum level (or equilibrium state) is reached in a few months in pollution-stressed habitats. This maximum level varies from species to species and depends on total concentration of elements in the atmosphere as well as thallus morphology.

Elemental analysis is now commonly employed to measure lead fallout along highways (Lawrey and Hale, 1981).[1] In addition, it is possible to analyze museum collections in order to establish baseline retrospective values. In fact, most studies so far indicate that lichens are excellent short-term biomonitors of common air-borne elements such as lead and zinc and fluorine, metals associated with both urban and inudstrial pollution. It is also possible to assay SO_2 directly in the thallus.

One of the great advantages with this method is that a survey can be made with a few common, easily recognized species of lichen. A drawback, as with other methods, is that we lack sufficient baseline values for most regions and cannot easily interpret the significance of elevated values. We are still trying to determine the rate and time scale for uptake from low-level pollution, although research in this area is slowly advancing.

Establishing Quality Standards

The goal of any monitoring program is to measure air pollutants and determine how the detected levels agree with established air quality standards. For example, given a national ambient air quality standard (NAAQS) of 0.14 ppm SO_2 (for a 24 hour period), it is a relatively simple matter to set up monitoring equipment which samples the air and tells us when a value of 0.14 ppm is exceeded.

When the monitor is a lichen (or other plant), we are not now able to translate information on species presence-absence, elemental content, physiological damage, etc., into specific air quality standards in the U.S.A. European lichenologists, on the other hand, have determined SO_2 threshold values for a few well studied indicator species (especially Hypogymnia physodes) and are closer to the goal of using lichens as true biomonitors.

Eventually we may be able to specify that a 10% reduction in lichen coverage or frequency would indicate pollution exceeding a NAAQS. Or a lead value of 500 ppm or 10X baseline value. A start is being made in this direction but for the time being lichen biomonitoring is more a qualitative than quantitative tool.

References

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Holopainen, T. H. 1982. Summer versus winter condition of the ultrastructure of the epiphytic lichens Bryoria capillaris and Hypogymnia physodes in central Finland. Ann. Bot. Fennici 19: 39-52.

Pearson, L. G. and G. A. Rodgers. 1982. Air pollution damage to cell membranes in lichens III. Field experiments. Phyton (Austria) 22: 329-337.

3. RESULTS OF THE FLAT TOPS STUDY

Description of the Area

The Flat Tops Wilderness Area encompasses most of the White River Plateau in Garfield and Rio Blanco Counties. The Tops are rolling, essentially treeless, alpine meadows lying at 10,500 to 11,500 feet elevation. Several isolated volcanic peaks jut up to nearly 13,000 feet. The perimeter is demarcated by spectacular sheer cliffs, especially on the eastern side. Access points generally lie in spruce forest in national forest campgrounds at 7000 to 9500 feet elevation.

The geology of the Flat Tops is fairly complex. While most of the northern and eastern sides consist of volcanic strata tilting upward slightly toward the east, the southwestern corner, in the Blair Mountain area, consists entirely of sandstone and quartzite cliffs. At lower elevations veins of dolomite limestones are exposed, as near the South Fork Campground and at Indian Camp Pass. Below this there are large intrusions of batholith granite, easily accessible in the South Fork of the White River east of South Fork Campground.

Lichens are known to be substrate specific but the lichen flora on volcanic rocks, granite, and sandstone appears to be nearly the same. Only limestone outcrops have a unique, and much poorer, lichen flora not found on the other rock types.

The Floristic Survey

The purpose of a floristic survey is to inventory the lichen flora as it exists now, hopefully before pollution begins or is at a very low level. The amount of damage to the lichens or loss of species, when compared with the first survey, are considered to be proportional to increases in air pollution. In this study a fairly standard approach was used and a summaryof the results is presented below in three parts: (1) location of collecting sites; (2) an annotated list of the species; and (3) checklists of the species at each site.

Collecting Sites

Floristic surveys were made at 21 sites spaced around the Wilderness Area as regularly as access permitted. One to four hours were spent at each site searching and collecting voucher specimens.

Full data on the location of the sites are given below in order of date; Asterisks indicate permanent lichen study plot is at the site. All localities are in the White River National Forest, except 21, which is Routt National Forest. All localities are also in Garfield County except for 11, 12, 13, 14, 15 and 16, which are in Rio Blanco County.

1. Exposed rocky hill about 1 mi NNW of Wall Lake, overlooking the Amphitheater. Elevation 11360 ft. 17 July 1982.

*2. Exposed west-facing ledge about ½ mi NE junction of trails 1814 and 1803, east of the Chinese Wall above Trappers Lake. Elevation 10500 ft. 18 September 1981 and 19 July 1982.

3. Along Wall Lake trail beginning at Wilderness boundary and going south about 1.1 mi. Elevation about 9800 ft. 19 July 1982.

*4. Talus area above the boat docks at NE side of Trappers Lake. Elevation 9650 ft. 20 July 1982.

*5. Quartzite-sandstone outcrops about 1000 ft S of hill indicated as "Limestone 11374," S end of Blair Mountain, overlooking Elk Lakes. Elevation 11200 ft. 22 July 1982.

*6. Sandstone and quartzite outcrops in saddle about 1500 ft N of "Limestone 11374" at mid section of Blair Mountain. Elevation about 11200 ft. 22 July 1982.

*7. Along trail descending to Crater Lake, ledges and large quartzite-sandstone talus. Elevation about 10700 ft. 23 July 1982.

8. Forested talus area just above N side of Crater Lake, sandstone and granite. Elevation 10300 ft. 23 July 1982.

9. Sandstone ledges in forested area on jeep road to Crater Lake, about ½ mi from trail end at cliff. Elevation 10800 ft. 24 July 1982.

10. Open spruce forest on hillside west and just above Meadow Creek Campground. Elevation 9600 ft. 24 July 1982.

11. Spruce forest near Marvine Creek Campground. Elevation 8100 ft. 25 July 1982.

12. Open spruce-aspen groves along trail to Slide Lake, 1-1.5 mi from Marvine Creek Campground. Elevation about 8300 ft. 26 July 1982.

13. Scattered volcanic rocks at Slide Lake. Elevation 8600 ft. 26 July 1982.

14. Scattered granitic and sandstone boulders and juniper-oak groves along trail from South Fork Campground to Spring Cave. Elevation 7700-7800 ft. 29 July 1982.

15. Limestone and sandstone talus in sheltered aspen-spruce forest along trail near Wilderness boundary on south fork of White River, .1-.5 mi from South Fork Campground. Elevation 7600 ft. 30 July 1982.

*16. Large batholith granite outcrops and scattered pinyon pine-oak groves, 1-1.2 mi from Wilderness boundary on trail from South Fork Campground to Budges Resort. Elevation 7700 ft. 30 July 1982.

17. Low volcanic cliffs facing south and west on hill above and NW of Indian Camp Pass, about 4.5 mi N Deep Lake Campground. Elevation 10666 ft. 2 August 1982.

18. Open limestone outcrops above and about .2 mi NW of Wilderness access point at Indian Camp Pass. Elevation 9800 ft. 2 August 1982.

19. Limestone outcrops in spruce forest on south side of Sweetwater Lake, west of the Sweetwater Campground. Elevation 7800 ft. 3 August 1982.

20. Exposed volcanic outcrops and ledges at the gap just west of the Stillwater Reservoir-Hooper Lake trail, at foot of Derby Peak. Elevation about 11800 ft. 6 August 1982.

21. Spruce forest along trail from Stillwater Reservoir to Hooper Lake, just above Wilderness boundary. Elevation 10400 ft. 6 August 1982.

Exact locations of these sites are indicated on the following standard USGS topographic maps.

BUFORD 25 MI.
12'30"
Crescent Lake
(INDEFINITE)
Trappers Lake Campground
Scotts Lake
Site no. 4
Coffin Lake
Spring
PACK TRAIL
Little Trappers Lake
Chinese Wall
Site no. 3
WILDERNESS BOUNDARY
Trappers Lake
Anderson Lake
PACK TRAIL
Fraser
Site no. 1
Amphith
Creek
Wall Lake
Parvin Lake
Trappers Peak

PEAKS
11935
10490
10400
LDERNE
Causeway Lake
PACK
10564
11683
WALL
10910
11685
10930
TRAIL
THE
11600
11728
Skinny
Skinny Fish Lake
RIVER
PACK
TRAIL
Devils Causeway
Fish
11931
11405
10460
FLAT
McGinnis Lake
10158
Basin
11723
Rainbow Lake
10764
FOREST
TOPS
11443
10968
CHINESE
TRAIL
11582
Skillet Lake
PACK
11604
10250
WALL
Site
no. 2
11635
Mosquito
Mosquito Lake
10620
BASE LINE
11325
10965
14
12'30"
312
(TRAPPERS LAKE)
314
10'
316

T 3 S
Site no. 7
Site no. 8
Site no. 9
Site no. 6
Site no. 5
Crater Lake
10263
Blair Lake
10466
Shadow Lake
10456
Jet Lake
10335
Limestone
11375
I T E
R I V E R
I L D E R N E S S
O N A L
F O R E S T
BLAIR MOUNTAIN
Patterson Creek
JEEP TRAIL
PACK TRAIL
UTE TRAIL
(PACK)
INDEFINITE BOUNDARY
R 90 W
R 89 W
10592
10321
10521
10822
11084
10789
10625
11087
15
12

R I V E R
F O R E S T
Site
no. 10
Meadow Creek
Campground
R91W
R90W
6
5
16
9800
9550
JEEP
TRAIL
Spring
Meadow Creek
Lake
9884
Creek
UTE
TRAIL
(JEEP)
9418
9600
9644
9575
TRAIL
Corral
9514
JEEP
9625
TRAIL
JEEP
9628
9615
9400
Creek
Elk
9817
9725
Main
MESA
441
440
47
440
440
440

SCALE 1:24000

OYSTER LAKE QUADRANGLE
COLORADO
7.5 MINUTE SERIES (TOPOGRAPHIC)

MEADOW CREEK LAKE QUADRANGLE
COLORADO
7.5 MINUTE SERIES (TOPOGRAPHIC)

Site
no. 17
Site
no. 18
Indian Camp
Pass
Springs
Dry
Creek
Triangle
Mountain
Spring
Sweetwater
Creek
PACK
TRAIL
INDEFINITE
BOUNDARY
R I V E R
F O R E S T
T O P S
Buck
Creek
UTE
TRAIL
(SWEETWATER LAKE)
4563 I SW
SWEETWATER GUARD STATION 6 MI
50'
47'
4412
4411
4410
4406
20

Hack Lake
Spring
Springs
PACK
TRAIL
Sweetwater
Sweetwater Guard Sta
Sweetwater Lake
Falls
Campground
Cafe
Site
no. 19
Creek
Hack
Cease
Ridland
Spring
(SUGARLOAF MOUNTAIN)
4563 I SE
DOTSERO 14 MI.
4410
4408
4407
4405

Twin Mandall Lakes
Mud Mandall Lake
Mandall Creek
PACK TRAIL
BOUNDARY
(INDEFINITE)
WC
Upper Stillwater Reservoir (Yampa Reservoir)
Gaging S
WILDERNESS
Smith Lake
Smith Creek
Bear River
Horseshoe Campground
Cold Springs
Cold Springs Campground
MOSQUITO LAKE 2.1 MI.
Stillwater Reservoir
24
19
26
25
35
36
22
6
Site no. 21
Site no. 20
FLAT TOPS WILDERNESS
Flattop
Flat Top Mountain
THE FLAT TOP
WHITE RIVER NATIONAL FOREST
LINE
1635 Edge
40°00′
107°07′30″
1 550 000 FEET (CENTRAL)
R 87 W
R 86 W
5′

Annotated List of Species Collected

Approximately 1000 specimens of lichens were collected in the Flat Tops Wilderness Area. This included 137 species. These were curated and studied in the lichen laboratory at the Department of Botany, Smithsonian Institution, with appropriate morphological, spore and chemical tests. Dr. Roger Anderson of the University of Denver helped with identification of the commoner Lecanora and Lecidea species. All of the specimens have been filed in the collections of the Smithsonian Institution and are available for reference or study.

After the species were identified, the data were assembled on sheets (see next page for a sample). Using these sheets I prepared a summary of the species which are listed below in alphabetical order. Notes are given for pertinent information on rock type or tree substratum, elevation, estimated commonness, chemical tests, and number of collections made.

The localities where each species occurred can be determined from the checklists for individual sites, beginning on p. . The localities for "limestone areas" and "forested trails, however, are mentioned separately since they are lumped in the checklists.

This species list is typical for comparable high montane regions in Colorado (see Egan, 1970). Additional field work could perhaps add 10-20 rarer species but I doubt that the flora exceeds 150 species. A number of unidentified specimens of Lecanora and Lecidea remain to be studied but these are all relatively rare and would not affect the ranking of the species which have been positively identified.

Forty-two of the commonest species are illustrated in color photographs in the appendix of this report.

FLAT TOPS WILDERNESS CHECKLIST

Aspicilia caesiocinerea
TLC: negative

Lava areas:

~~.....~~ Wall Lake area

..... Chinese Wall area

..✓.. Stillwater-Derby Mtn.

..✓.. Indian Camp Pass

..... Trappers Lake Talus

..✓.. Slide Lake

Sandstone-quartzite-granites:

..✓.. Blair Mtn. (saddle & S end)

..✓.. Crater Lake area

..✓.. South Fork Canyon area

Limestone areas:

..✓.. South Fork: cave trail & boundary

..... Sweetwater Reservoir

..... Indian Camp Pass (lower part)

Forested trails:

..... Lower Wall Lake Trail

..... Stillwater-Derby Mtn. trail

..... Little Trappers area

..✓.. Meadow Creek Lake area

..... Marvine-Slide Lake

Substrates:
granite
sandstone

Habitats:

Acarospora chlorophana (Wahl.) Mass.

Conspicuous (but often hard to collect) at higher elevations on the most exposed volcanic and granitic rocks (5 collections). This is probably a pollution-sensitive species.

Acarospora fuscata (Nyl.) Arn.

Common at higher elevations on exposed volcanic and granitic rocks, often growing in cracks or sheltered surfaces (10 collections).

Aspicilia alphoplaca (Wahl.) Poelt

Rather common at higher elevations on moist, sheltered volcanic and granitic rocks (8 collections).

Aspicilia caesiocinerea (Nyl.) Arn.

Very common everywhere on volcanic and granitic rocks and sandstone. This and the following Aspicilias are known to be quite resistant to air pollution. Known from 26 collections.

Aspicilia calcarea (L.) Mudd.

Very common everywhere on volcanic and granitic rocks and sandstone (17 collections).

Aspicilia gibbosa (Ach.) Korb.

Very common everywhere on volcanic and granitic rocks and sandstone (22 collections).

Bryoria fuscescens (Gyel.) Brodo & Hawks.

Rare on spruce in undisturbed forest (2 collections: Sweetwater and Meadow Lake).

Buellia parasema (Ach.) Poelt

Rare on dead logs in disturbed spruce forests (2 collections: South Fork and Wall Lake trail).

Caloplaca adnexa Vezda

Very common on all rock types (20 collections).

Caloplaca arenaria (Pers.) Mull. Arg.

Rather rare (probably overlooked) on pebbles and volcanic and granitic outcrops (9 collections).

Caloplaca cinnamomea (Th. Fr.) Oliv.

Rare on detritus in spruce forest (1 collection: Sweetwater Reservoir).

Caloplaca holocarpa (Hoffm.) Wade

Widespread on spruce and aspen in open forests (4 collections: South Fork, Wall Lake trail, Marvine campground).

Caloplaca jungermanniae (Vahl) Th. Fr.

Rare on mosses and Selaginella at higher elevations (2 collections).

Caloplaca saxicola (Hoffm.) Nordin

Rare on acidic rocks (1 collection).

Caloplaca trachyphylla (Tuck.) Zahlbr.

Widespread on volcanic and grnitic rocks as well as limestone (8 collections).

Candelariella aurella (Hoffm.) Zahlbr.

Rare on volcanic rocks at higher elevations (1 collection).

Candelariella rosulans (Mull. Arg.) Zahlbr.

Very common on all rock types, detritus, and mosses (27 collections).

Catapyrenium lachneum (Ach.) R. Sant.

Widespread on soil, humus and mosses (6 collections). This is one of the soil consolidators.

Cladonia cariosa (Ach.) Spreng.

Widespread on soil along trail banks and in open forest (5 collections: all forest trails except Meadow lake and at South Fork).

Cladonia carneola (Fr.) Fr.

Rarely collected on mosses and dead wood (2 collections: WallLake trail and Marvine-Slide Lake).

Cladonia chlorophaea (Flk.) Spreng.

Common on soil in talus slopes and in open forest (9 collections: South Fork, Sweetwater Reservoir, Wall Lake trail, Stillwater-Derby Peak, and Little Trappers area). Many of the sterile Cladonia squamules are probably this species.

Cladonia coniocraea (Flk.) Spreng.

Very common on rotting logs and soil in spruce forests (11 collections: South Fork and all forested trails).

Cladonia cyanipes (Somm.) Nyl.

Rarely collected on rotting logs (2 collections: Stillwater-Derby Peak and Marvine-Slide Lake).

Cladonia fimbriata (L.) Fr.

Rare on rotted logs and on soil in spruce forest (3 collections: Meadow Lake and Marvine-Slide Lake).

Cladonia gracilis (L.) Willd.

Rare on soil in talus slopes and along trail banks (2 collections: Little Trappers Lake area).

Cladonia macrophyllodes Nyl.

Widespread (and probably undercollected) on soil in open forests (4 collections: South Fork and Sweetwater Reservoir). Three specimens contained norstictic acid and one fumarprotocetraric acid. The taxonomy of the common sterile Cladonia

squamules is not well worked out at this time.

Cladonia pyxidata (L.) Hoffm.

Widespread and common on soil in all areas (7 collections: South Fork, Indian Camp Pass, Wall Lake trail, Marvine-Slide Lake trail). Many of the sterile Cladonia squamules probably represent this species. All contain fumarprotocetraric acid.

Collema polycarpon Hoffm.

Common on limestone outcrops (3 collections: South Fork and Indian Camp Pass).

Collema tenax (Sw.) Ach.

Rare on soil (1 collection: South Fork). This inconspicuous species is a soil consolidator and nitrogen fixer. It is easily overlooked and probably occurs widely.

Dermatocarpon miniatum (L.) Mann

Very common on all rock types everywhere, usually in sheltered crevices or in moist sites (14 collections: South Fork, Indian Camp Pass, Wall Lake trail, Meadow Creek).

Dermatocarpon reticulatum Magn.

Locally common on sandstone and granites (3 collections: South Fork and Meadow Lake).

Dimelaena oreina (Ach.) Norm.

Widespread on volcanic and granitic outcrops in the most exposed ledges (11 collections). Six specimens contain gyrophoric acid, 4 contain stictic acid, and one is negative on TLC. This species often occurs with Acarospora chlorophana.

Diploschistes scruposus (Schreb.) Norm.

Widespread but not common on soil in talus slopes and on volcanic rocks (3 collections: Indian Camp Pass).

Endocarpon pulvinatum Th. Fr.

Rarely collected on volcanic and granitic rocks, often in moist crevices (3 collections). This dark brown lichen was probably overlooked at many localities.

Evernia divaricata (L.) Ach.

Rarely collected on spruce in undisturbed forests (1 collection: Meadow Lake Campground). This is one of the most pollution-sensitive lichens but it is unfortunately very rare at the Flat Tops.

Foraminella ambigua (Wulf.) Fr. Meyer

Rare at the base of conifers and on dead logs (2 collections: Wall Lake trail and Stillwater-Derby-Peak).

Foraminella hyperopta (Ach.) Fr. Meyer

Rare at the base of conifers in spruce forests (2 collections: Wall Lake trail and Stillwater-Derby Peak).

Hypocenomyce scalaris (Ach.) Choisy

Rarely collected on charred stumps in spruce forests (1 collection: Marvine-Slide Lake). This small squamulose lichen can probably be found on almost any charred stump.

Lecanora badia (Pers.) Ach.

Probably common at higher elevations on volcanic rocks (3 collections).

Lecanora bicincta Ram.

Common on volcanic rocks at higher elevations, growing in sheltered habitats (7 collections).

Lecanora cf. cladonioides Lynge

Common on volcanic rocks at higher elevations (7 collections). Tentative identification was made by Roger Anderson for this little known, white bullate species. Our material contains atranorin, zeorin, fatty acids, and an unknown spot.

Lecanora dispersa (Pers.) Somm.

Rare on volcanic and granitic rocks and sandstone (2 collections: Wall Lake area and South Fork).

Lecanora frustulosa (Dicks.) Ach.

Common on volcanic and granitic rocks and sandstone at higher elevations (13 collections). The specimens all contain atranorin and zeorin.

Lecanora muralis (Schreb.) Rabenh.

Quite common on volcanic and granitic rocks and sandstone and limestone but usually in protected sites or along open trails (18 collections: South Fork and Indian Camp Pass). All specimens contain usnic acid and terpenes related to leucotylin.

Lecanora mutabilis Somm.

Widespread on volcanic rocks (4 collections: Wall Lake trail). This species intergrades with Lecanora polytropa.

Lecanora novomexicana Magn.

Extremely commmon on volcanic and granitic rocks, quartzite, and sandstone at higher elevations (38 collections). All specimens contain usnic and psoromic acids. Together with Xanthoparmelia cumberlandia, this is one of the most important indicator species.

Lecanora polytropa (Hoffm.) Rabenh.

Widespread on volcanic rocks and sandstone at higher elevations, usually growing in more sheltered sites (5 collections).

Lecanora subfusca (L.) Ach.

Widespread on aspen trees (1 collection: Indian Camp Pass). This lichen was obviously overlooked in most of the forested trail localities.

Lecanora thomsonii Magn.

Rather common on volcanic and granitic rocks at higher elevations (7 collections). The specimens contain usnic and psoromic acids. They are separated from closely related L. novomexicana by the rugose, bullate thallus without distinct marginal lobation.

Lecanora varia (Hoffm.) Ach.

Rarely collected on spruce and dead wood (2 collections).

Lecanora sp. #1

Widespread (and probably overlooked) on volcanic rocks, limestone, and sandstone (4 collections: Limestone areas, Wall Lake). This species has large spores, a thick pruinose rim and pale yellowish disc.

Lecanora sp. #2

Rather common on volcanic and granitic rocks at higher elevations (7 collections). This bullate species has plane apothecia with a pruinose rim. Atranorin and the same fatty acid found in L. cf. cladonioides are present.

Lecidea armeniaca (DC.) Fr.

Rare on volcanic rocks at high elevations in the most exposed habitats (4 collections).

Lecidea atrobrunnea (Ram.) Schaer.

Extremely common on volcanic and granitic rocks and sandstone everywhere (50 collections). This is the most abundant crustose lichen in the Flat Tops area. There are several chemically different populations whose taxonomy has not been worked out: confluentic acid group (19 specimens), ?stictic acid (10 specimens), hypostictic acid (5 specimens), and TLC negative (16 specimens).

Lecidea auriculata Th. Fr.

Common on sandstones at Blair Mountain (3 collections).

Lecidea berengeriana (Mass.) Nyl.

Widepsread on mosses along trails in spruce forest (4 collections: Sweetwater Reservoir, Wall Lake trail, Stillwater-Derby Peak trail).

Lecidea leucothallina Arn.

Rare on volcanic rocks at higher elevations (2 collections).

Lecidea plana (Lahm.) Nyl.

Common on sandstone and limestone (10 collections: Indian Camp Pass).

Lecidea syncarpa Zahlbr.

Common on volcanic rocks and sandstone (27 collections). All specimens contained norstictic acid. Externally they are close to L. atrobrunnea.

Lecidea tessellata (Ach.) Flk.

Very common on volcanic and granitic rocks and sandstone (13 collections). This is one of the more conspicuous crustose lichens.

Lecidella elaeochroma (Ach.) Choisy

Very common on twigs of oak and spruce and on dead wood (12 collections). This is the most widespread crustose lichen on trees in the area.

Lecidella stigmatea (Ach.) Hert. & Leuck.

Very common on all rock types in the area (24 collections). All specimens contained atranorin and zeorin.

Lepraria arctica (Lynge) Wetm.

Common on soil among boulders at higher elevations (4 collections). This is an effective soil consolidator. All specimens contained atranorin.

Lepraria finkii (B. deLesd.) Harris

Widespread as a loose crust over mosses and on shaded soil along trails (2 collections). Stictic acid is the diagnostic component.

Lepraria sp.

Widespread on soil along trails, base of trees in forest, and on mosses (5 collections). I have included here the common diffuse crustose form with extremely variable chemistry, probably representing several species: fumarprotocetraric acid, protocetraric acid, high pink unknown in TLC.

Massalongia carnosa (Dicks.) Korb.

Very rare over mosses in ledges at higher elevation (1 collection).

Melanelia disjuncta (Erichs.) Essl.

Very rare on sandstone talus in protected habitats (1 collection at Crater Lake).

Melanelia elegantula (Zahlbr.) Essl.

Common on spruce and pinyon pine and on volcanic rocks (7 collections: South Fork and Wall Lake trail).

Melanelia exasperatula (Nyl.) Essl.

On twigs and branches of spruce and on dead wood (6 collections: South Fork, Sweetwater Reservoir, Wall Lake, Marvine-Slide Lake).

Melanelia subolivacea (Nyl.) Essl.

On spruce twigs (3 collections: South Fork and Sweetwater Reservoir).

Melanelia substygia (Ras.) Essl.

Rather rare on volcanic and granitic rocks at higher elevations (4 collections).

Ochrolechia upsaliensis (L.) Mass.

Common on dead plant remains at Derby Peak (1 collection).

Pachyospora verrucosa (Ach.) Mass.

Rare on mosses in sheltered areas on volcanic ledges (2 collections).

Peltigera aphthosa (L.) Willd.

Common at two sites on soil and humus in spruce forest (3 collections: Wall Lake trail and Stillwater-Derby Peak trail). This is a well known nitrogen fixer.

Peltigera canina (L.) Willd.

Very common on soil in open areas or in spruce forest (13 collections: South Fork, Indian Camp Pass, all forested trails except Wall Lake). This is the most frequently collected nitrogen-fixing Peltigera. Some specimens in exposed habitats might be identified as P. rufescens but I made no attempt to distinguish between these two species.

Peltigera degenii Gyel.

Rare among talus boulders at Trappers Lake (1 collection).

Peltigera polydactyla (Neck.) Hoffm.

Widespread on soil and humus at higher elevations and in forested areas (5 collections: South Fork, Sweetwater Reservoir, Wall Lake trail).

Peltigera venosa (L.) Hoffm.

On moist soil along trail banks in forested areas (Wall Lake trail, Stillwater-Derby Peak trail).

Peltula euploca (Ach.) Poelt

Rarely collected on granite at higher elevation (1 collection).

Phaeophyscia ciliata (Hoffm.) Moberg

Rare on spruce and aspen (2 collections: South Fork and Marvine-Slide Lake).

Phaeophyscia chloantha (Ach.) Moberg

Rare on aspen trunks at South Fork.

Phaeophyscia decolor (Kashiw.) Essl.

Widespread on sheltered volcanic and granitic rocks at higher elevations (8 collections).

Phaeophyscia nigricans (Flk.) Moberg

Rare on volcanic and granitic rocks at higher elevations (3 collections).

Phaeophyscia orbicularis (Neck.) Moberg

Very common in crevices of volcanic and granitic rock ledges, sandstone, and over mosses on limestone (20 collections). This species is frequently grazed by snails.

Phaeophyscia sciastra (Ach.) Moberg

Rare on granites at South Fork (1 collection).

Phaeorrhiza nimbosa (Fr.) Poelt

Common on soil and mosses at higher elevations (12 collections). Most collections contained atranorin.

Physcia adscendens (Fr.) Oliv.

On spruce twigs and over mosses on rocks at lower elevations (5 collections: South Fork, Wall Lake trail, Meadow Lake, Marvine-Slide Lake).

Physcia aipolia (Ehrh.) Furnr.

Rare on spruce twigs at lower elevations (2 collections: South Fork, Marvine-Slide Lake).

Physcia biziana (Mass.) Zahlbr.

Spruce and juniper twigs at lower elevations (2 collections: South Fork and Sweetwater Reservoir). The specimens contain only atranorin.

Physcia cf. biziana (Mass.) Zahlbr.

Common in sheltered crevices of volcanic and granitic rocks (10 collections: Meadow Lake area). These have the pruinosity of P. biziana but contain zeorin in addition to atranorin. The taxonomy of the genus in the Rocky Mountains is poorly worked out.

Physcia caesia (Hoffm.) Furnr.

Common on all rock types in sheltered habitats every where (14 collections: South Fork, Meadow Lake area).

Physcia dubia (Hoffm.) Lett.

Very common on all rock types and on dead wood everywhere (31 collections: all limestone areas, Wall Lake trail and Meadow Lake area).

Physcia phaea (Tuck.) Thoms.

Rare on granite at South Fork (1 collection).

Physcia stellaris (L.) Ach.

Rare on spruce twigs near South Fork Campground (1 collection).

Physconia detersa (Nyl.) Poelt

Common on mosses over limestone and volcanic rocks and sandstone from open ledges to spruce forest (6 collections: Sweetwater Reservoir, Wall Lake trail, Meadow Lake area).

Physconia muscigena (Ach.) Poelt

Common on humus and over mosses on volcanic rocks, sandstone, and limestone in crevices (8 collections: Indian Camp Pass).

Polysporina simplex (Dav.) Vezda

Rather rare on sandstone and limestone (5 collections: Indian Camp Pass).

Pseudephebe minuscula (Arn.) Brodo & Hawks.

Rare on exposed quartzite at Blair Mountain (2 collections).

Pseudephebe pubescens (L.) Choisy

Rare on quartzite at Crater Lake (1 collection).

Psora decipiens (Hedw.) Hoffm.

Widespread on open soil among outcrops, probably best developed in limestone areas (3 collections: Indian Camp Pass). This and the following Psoras are soil consolidators.

Psora luridella (Tuck.) Fink

Rare on soil at higher elevations (2 collections). Both specimens contained gyrophoric acid.

Psora nipponica (Zahlbr.) Schneid.

On soil between boulders at Trappers Lake (1 collection).

Psora rubiformis (Ach.) Hook.

On soil at granitic outcrops (1 collection at South Fork). The specimen contains gyrophoric acid and is quite pruinose.

Psora russellii (Tuck.) Schneid.

Common on all soil types among boulders in open outcrops (12 collections: South Fork and Indian Camp Pass).

Psoroma hypnorum (Vahl) Gray

Rare on mosses and humus in spruce forests (3 collections: Wall Lake trail and Stillwater-Derby Peak trail).

Rhizocarpon disporum (Naeg.) Mull. Arg.

Common on volcanic and granitic rocks and sandstone in more sheltered ledges and erratics (14 collections: Meadow Lake). This is the commonest gray Rhizocarpon and contains stictic with or without norstictic acids.

Rhizocarpon geographicum (L.) DC.

Very common on volcanic and granitic rocks and sandstone at higher elevations (16 collections). This lichen has the common name "Map Lichen" and is the most conspicuous crustose lichen in the Flat Tops because of its bright yellow color.

Rhizocarpon grande (Flk.) Arn.

Common only a granitic outcrops 4 collection in South Fork area). The material contains gyrophoric acid.

Rhizoplaca chrysoleuca (Sm.) Zopf

Rather rare (except above Chinese Wall) on volcanic and granitic outcrops (6 collections). This species (and R. melanophthalma next) grow on the most exposed ledges and outcrops.

Rhizoplaca melanophthalma (Ram.) Leuck.

Very common on exposed volcanic and granitic outcrops and sandstone at higher elevations (19 collections). All specimens were tested and contained psoromic acid and usnic acid.

Rinodina archaea (Ach.) Arn.

Rare on spruce twigs and dead wood in spruce forests (2 collections: Crater Lake and South Fork). Probably a widespread species but often overlooked.

Rinodina conradi Koerb.

Rare on mosses, detritus, and soil (3 collections: South Fork and Wall Lake trail).

Rinodina mniaraea (Ach.) Koerb.

On humus over soil at Trappers Lake (1 collection).

Rinodina turfacea (Wahl.) Koerb.

On detritus at high elevations (1 collection).

Sarcogyne regularis Koerb.

Common on limestone outcrops (2 collections: South Fork).

Sporastatia testudinaria (Ach.) Mass.

Rare on exposed volcanic and granitic rocks, sandstone and quartzite (5 collections).

Staurothele clopima (Wahl.) Th. Fr.

Extremely common on all rock types everywhere (18 collections: all limestone areas and Meadow Lake). This makes up the brown crusts so common in the Flat Tops area.

Stereocaulon glareosum (Sav.) Magn.

Rather rare on soil between boulders and near snow melt sites at high elevations (4 collections).

Thamnolia subuliformis (Ehrh.) Culb.

On soil among grasses on exposed ridges near Derby Peak (1 collection). This conspicuous fruticose lichen is grazed by caribou in the arctic and there are signs of grazing by elk or deer here.

Toninia massata (Tuck.) Herre

Rare on soil at South Fork (1 collection).

Tremolecia nivalis (Ach.) Hert.

Rather rare on exposed volcanic and granitic outcrops and sandstone (4 collections).

Umbilicaria hyperborea (Ach.) Hoffm.

Locally common on granitic boulders at South Fork (3 collections). This species was not collected on volcanic rocks.

Umbilicaria torrefacta (Lightf.) Schrad.

Rare on granitic boulders at South Fork (1 collection).

Umbilicaria virginis Schaer.

Common on exposed volcanic and granitic rocks and sandstone at higher elevations (10 collections). This is the most common umbilicate lichen and is being explored as an indicator species.

Usnea sp.

Rather rare to abundantly developed on spruce trees at all limestone and forest trail sites except Indian Camp Pass and Little Trappers area (8 collections). Two specimens contained barbatic acid and the remainder salazinic acid. They are all sorediate, members of the U. comosa group. Usnea is very pollution sensitive and is being used as an indicator species at forested sites.

Xanthoparmelia chlorochroa (Tuck.) Hale

Locally common on soil in limestone areas (1 collection: Indian Camp Pass).

Xanthoparmelia conspersa (Ach.) Hale

Rare on volcanic and granitic outcrops in exposed habitats (2 collections). This is the typical species with a black lower surface and stictic and norstictic acids.

Xanthoparmelia cumberlandia (Gyel.) Hale

Very common on all rock types except limestone from high elevations to lower forested sites (25 collections: Wall Lake trail and Meadow Lake). All specimens were tested for the presence of stictic and norstictic acids. This is the most important indicator species in the Flat Tops and is the prime sample material for elemental analyses.

Xanthoparmelia lineola (Berry) Hale

Rare on volcanic rock and sandstone (2 collections: Wall Lake and South Fork). This species contains salazinic acid; otherwise it resembles X. cumberlandia.

Xanthoparmelia mexicana (Gyel.) Hale

Locally common on granite at South Fork (1 collection). This isidiate species contains salazinic acid.

Xanthoparmelia taractica (Kremplh.) Hale

Rather rare on volcanic and granitic outcrops, mostly at higher elevations (6 collections). These specimens are more or less loosely attached and contain salazinic acid.

Xanthoparmelia wyomingica (Gyel.) Hale

Common on soil and adjacent rocks at high elevations (4 collections). All contain salazinic acid. This species comes close to X. chlorochroa, which occurs at lower elevation, and intergrades with X. taractica. Collections were made for elemental analysis.

Xanthoria candelaria (L.) Th. Fr.

Rare on sheltered volcanic rocks, over mosses on rocks, and on aspen in spruce forests (3 collections: South Fork and Stillwater-Derby Peak).

Xanthoria elegans (Link) Th. Fr.

Extremely common on exposed sandstone, volcanic and granitic rocks, and limestone and over mosses on rocks (22 collections). This brilliant orange lichen (together with Caloplaca trachyphylla) accounts for the orange-red tinge of the great vertical cliffs of the Flat Tops. It is a good indicator species but was difficult to collect in mass quantities.

Xanthoria polycarpa (Hoffm.) Rieb.

Common on twigs of oak, aspen, and spruce in forested areas (10 collections: all limestone areas and Marvine-Slide Lake).

Xanthoria sorediata (Vain.) Poelt

Common on volcanic and granitic outcrops and sandstone in talus slopes and at cliffs, usually on overhangs or other sheltered areas (19 collections).

Checklists of the Species at Each Site

The following checklists give the results of the inventories of the lichen flora at the major sites. Using these lists, one will be able to make a rapid resurvey at some future date and assess the extent of any changes in species composition.

The lists are not claimed to be absolutely complete inventories. They include what can be observed and collected in several hours of field work. Thus the number of species varies from 35 to 56 in the sites, indicating that the richness of the flora varies but also that some species were probably overlooked. No two lichenologists would come up with the same lists but any additions would be for very rare species, which might add as many as 10 more species at each site. For a pollution monitoring study, however, it is the disappearance of common indicator species which is more important, not rare, inconspiuous crustose species.

Checklist for Wall Lake (site no. 1; 56 species)

Acarospora chlorophana
A. fuscata

Aspicilia alphoplaca
A. caesiocinerea
A. calcarea

Caloplaca adnexa
C. arenaria
C. trachyphylla

Candelariella rosulans

Catapyrenium lachneum

Cladonia pyxidata

Dermatocarpon miniatum

Dimelaena oreina

Diploschistes scruposus

Lecanora badia
L. bicincta
L. cf. cladonioides
L. dispersa
L. frustulosa
L. muralis
L. mutabilis
L. novomexicana
L. polytropa
L. thomsonii
L. sp. #1
L. sp. #2

Lecidea armeniaca
L. atrobrunnea
L. syncarpa
L. tessellata

Lecidella stigmatea

Lepraria arctica

Massalongia carnosa

Melanelia substygia

Pachyspora verrucosa

Peltigera polydactyla

Phaeophyscia decolor
P. orbicularis

Phaeorrhiza nimbosa

Physcia cf. biziana
P. caesia
P. dubia

Physconia detersa
P. muscigena

Rhizocarpon disporum
R. geographicum

Rhizoplaca melanophthalma

Rinodina conradi

Sporastatia testudinaria

Staurothele clopima

Stereocaulon glareosum

Xanthoparmelia cumberlandia
X. lineola
X. taractica

Xanthoria elegans
X. sorediata

Checklist for Chinese Wall (site no. 2; 44 species)

Acarospora chlorophana
A. fuscata

Aspicilia alphoplaca
A. calcarea
A. gibbosa

Caloplaca adnexa
C. arenaria
C. jungermanniae
C. trachyphylla

Candelariella aurella

Dimelaena oreina

Endocarpon pulvinatum

Lecanora badia
L. bicincta
L. cf. cladonioides
L. frustulosa
L. muralis
L. novomexicana
L. thomsonii
L. sp. #2

Lecidea armeniaca
L. atrobrunnea
L. leucothallina
L. syncarpa
L. tessellata

Lecidella stigmatea

Lepraria sp.

Melanelia elegantula

Pachyospora verrucosa

Phaeophyscia decolor

Physcia cf. biziana
P. dubia

Physconia muscigena

Rhizocarpon disporum
R. geographicum

Rhizoplaca chrysoleuca
R. melanophthalma

Stereocaulon glareosum

Tremolecia nivalis

Umbilicaria virginis

Xanthoparmelia cumberlandia
X. taractica
X. wyomingica

Xanthoria elegans

Checklist for Trappers Lake talus (site no. 4; 41 species)

Aspicilia alphoplaca
A. calcarea
A. gibbosa

Caloplaca adnexa

Candelariella rosulans

Cladonia chlorophaea
C. coniocraea
C. gracilis
C. macrophyllodes

Dermatocarpon miniatum

Diploschistes scruposus

Lecanora bicincta
L. frustulosa
L. mutabilis
L. novomexicana
L. polytropa
L. thomsonii

Lecidea atrobrunnea
L. syncarpa
L. tessellata

Lecidella stigmatea

Lepraria arctica

Peltigera canina
P. degenii

Phaeophyscia orbicularis

Phaeorrhiza nimbosa

Physcia cf. biziana
P. caesia
P. dubia

Physconia detersa

Psora luridella
P. nipponica

Rhizocarpon disporum
R. geographicum

Rhizoplaca melanophthalma

Rinodina conradi
R. mniaraea

Staurothele clopima

Xanthoparmelia cumberlandia

Xanthoria elegans
X. sorediata

Checklist for Blair Mountain area (sites 5, 6; 47 species)

Aspicilia caesiocinerea
A. calcarea
A. gibbosa

Caloplaca adnexa
C. arenaria
C. trachyphylla

Candelariella rosulans

Cladonia macrophyllodes
C. pyxidata

Dermatocarpon miniatum

Dimelaena oreina

Endocarpon pulvinatum

Lecanora frustulosa
L. muralis
L. novomexicana
L. polytropa
L. thomsonii
L. sp. #2

Lecidea atrobrunnea
L. auriculata
L. plana
L. syncarpa
L. tessellata

Lecidella stigmatea

Lepraria arctica

Peltigera canina

Phaeophyscia decolor
P. nigricans
P. orbicularis

Phaeorrhiza nimbosa

Physcia caesia
P. dubia

Physconia muscigena

Pseudephebe minuscula

Psora decipiens
P. luridella
P. russellii

Rhizocarpon geographicum

Rhizoplaca melanophthalma

Sporastatia testudinaria

Staurothele clopima

Stereocaulon glareosum

Tremolecia nivalis

Umbilicaria virginis

Xanthoparmelia cumberlandia

Xanthoria elegans
X. sorediata

Checklist for Crater Lake area (sites 7, 8; 39 species)

Aspicilia caesiocinerea
A. calcarea
A. gibbosa

Caloplaca adnexa
C. arenaria

Candelariella rosulans

Catapyrenium lachneum

Dermatocarpon miniatum

Dimelaena oreina

Endocarpon pulvinatum

Lecanora novomexicana
L. polytropa
L. varia

Lecidea atrobrunnea
L. plana
L. syncarpa
L. tessellata

Lecidella stigmatea

Melanelia disjuncta

Peltigera canina

Phaeophyscia decolor
P. nigricans
P. orbicularis

Physcia cf. biziana
P. caesia
P. dubia

Physconia muscigena

Polysporina simplex

Pseudephebe pubescens

Rhizocarpon disporum
R. geographicum

Rhizoplaca melanophthalma

Rinodina archaea

Sporastatia testudinaria

Staurothele clopima

Umbilicaria virginis

Xanthoparmelia cumberlandia

Xanthoria elegans
X. sorediata

Checklist for South Fork area (site no. 16; 47 species)

Acarospora chlorophana
A. fuscata

Aspicilia alphoplaca
A. caesiocinerea
A. calcarea
A. gibbosa

Caloplaca adnexa
C. arenaria
C. saxicola

Candelariella rosulans

Catapyrenium lachneum

Dermatocarpon reticulatum

Dimelaena oreina

Lecanora frustulosa
L. novomexicana
L. thomsonii
L. sp. #2

Lecidea atrobrunnea
L. plana
L. fessellata

Lecidella stigmatea

Melanelia substygia

Peltigera canina

Peltula euploca

Phaeophyscia orbicularis
P. sciastra

Physcia cf. biziana
P. caesia
P. phaea

Psora rubiformis
P. russellii

Rhizocarpon disporum
R. geographicum
R. grande

Rhizoplaca chrysoleuca
R. melanophthalma

Staurothele clopima

Toninia massata

Umbilicaria hyperborea
U. torrefacta
U. virginis

Xanthoparmelia conspersa
X. cumberlandia
X. mexicaaa
X. taractica

Xanthoria elegans
X. sorediata

Checklist for Indian Camp Pass (site no. 17; 35 species)

Acarospora chlorophana
A. fuscata

Aspicilia alphoplaca
A. caesiocinerea
A. calcarea
A. gibbosa

Caloplaca adnexa
C. arenaria
C. trachyphylla

Candelariella rosulans

Dermatocarpon miniatum

Lecanora frustulosa
L. muralis
L. novomexicana
L. polytropa

Lecidea atrobrunnea
L. syncarpa
L. tessellata

Lecidella stigmatea

Lepraria finkii

Melanelia elegantula

Physcia cf. biziana
P. caesia
P. dubia

Physconia detersa

Rhizocarpon geographicum

Rhizoplaca chrysoleuca
R. melanophthalma

Tremolecia nivalis

Umbilicaria virginis

Xanthoparmelia conspersa
X. cumberlandia
X. wyomingica

Xanthoria elegans
X. sorediata

Checklist for Stillwater Reservoir-Derby Peak (site no. 20; 48 species)

Acarospora chlorophana

Aspicilia alphoplaca
A. caesiocinerea
A. gibbosa

Caloplaca adnexa
C. jungermanniae
C. trachyphylla

Candelariella rosulans

Catapyrenium lachneum

Cladonia pyxidata

Dermatocarpon miniatum

Dimelaena oreina

Lecanora badia
L. bicincta
L. cf. cladonioides
L. frustulosa
L. muralis
L. mutabilis
L. novomexicana
L. thomsonii
L. sp. #2

Lecidea armeniaca
L. atrobrunnea
L. tessellata

Lecidella stigmatea

Lepraria arctica

Ochrolechia upsaliensis

Phaeophyscia nigricans
P. orbicularis

Phaeorrhiza nimbosa

Physcia dubia

Physconia muscigena

Psora decipiens

Rhizocarpon geographicum

Rhizoplaca chrysoleuca
R. melanophthalma

Rinodina turfacea

Sporastatia testudinaria

Stereocaulon glareosum

Thamnolia subuliformis

Tremolecia nivalis

Umbilicaria virginis

Xanthoparmelia cumberlandia
X. taractica
X. wyomingica

Xanthoria candelaria
X. elegans

Checklist for limestone areas (sites no. 18, 19; 35 species)

Caloplaca adnexa
C. saxicola
C. trachyphylla

Candelariella rosulans

Catapyrenium lachneum

Cladonia cariosa
C. chlorophaea
C. coniocraea
C. macrophyllodes
C. pyxidata

Collema polycarpon
C. tenax

Dermatocarpon miniatum

Diploschistes scruposus

Lecanora muralis
L. sp. #1

Lecidea plana

Lecidella stigmatea

Lepraria sp.

Melanelia elegantula

Phaeophyscia orbicularis

Phaeorrhiza nimbosa

Physcia caesia
P. dubia

Physconia detersa
P. muscigena

Polysporina simplex

Psora decipiens
P. russellii

Rinodina archaea

Sarcogyne pruinosa

Staurothele clopima

Xanthoparmelia chlorochroa

Checklist for forested trails (sites no. 3, 10, 11, 12, 15, 19, 21; 36 species)

Bryoria fuscescens

Buellia parasema

Caloplaca holocarpa

Cladonia cariosa
C. carneola
C. chlorophaea
C. coniocraea
C. cyanipes
C. fimbriata
C. gracilis
C. pyxidata

Evernia divaricata

Foraminella ambigua
F. hyperopta

Hypocenomyce scalaris

Lecanora subfusca
L. varia

Lecidella elaeochroma

Lepraria finkii
L. so.

Melanelia elegantula
M. exasperatula
M. subolivacea

Phaeophyscia ciliata
P. chloantha
P. orbicularis

Physcia adscendens
P. aipolia
P. biziana
P. dubia
P. stellaris

Physconia detersa

Psoroma hypnorum

Rinodina conradi

Usnea sp.

Xanthoria polycarpa

Most commonly collected species (608 collections)

Lecidea atrobrunnea (50)
Lecanora novomexicana (38)
Physcia dubia (31)
Candelariella rosulans (27)
Lecidea syncarpa (27)
Aspicilia caesiocinerea (26)
Xanthoparmelia cumberlandia (25)
Lecidella stigmatea (24)
Aspicilia gibbosa (22)
Xanthoria elegans (22)
Physcia orbicularis (20)
Caloplaca adnexa (20)
Rhizoplaca chrysoleuca (19)
Xanthoria sorediata (19)
Lecanora muralis (18)
Staurothele clopima (18)
Aspicilia calcarea (17)
Rhizocarpon geographicum (16)
Dermatocarpon miniatum (14)
Physcia caesia (14)
Rhizocarpon disporum (14)
Lecidea tessellata (13)
Peltigera canina (13)
Lecanora frustulosa (13)
Psora russellii (12)
Phaeorrhiza nimbosa (12)
Lecidella elaeochroma (12)
Cladonia coniocraea (11)
Dimelaena oreina (11)
Umbilicaria virginis (10)
Acarospora fuscata (10)
Lecidea plana (10)

Establishment of Permanent Lichen Study Plots

The purpose of establishing lichen study plots is to provide permanently marked reference sites which can be photographed and studied at intervals. They represent a sample of the lichen communities, obviously not a statistically significant sample but nonetheless one which can provide some quantification of the changes. For example, by comparing later photographs with these originals, one can measure growth rates of the various lichen species and get a better idea of changes in species coverage and community composition which may be ultimately correlated with pollution stress.

Each quadrat is demarcated by four drilled corner holes to form a 20 X 25 cm ($8\frac{1}{2}$ X 11") area on the rock. After taking color photographs, species in the quadrat were tabulated and small samples collected adjacent to the quadrat for later identification of the species with sporing or chemical tests.

A total of 12 quadrats was set up, 7 in the Trappers Lake area, 3 at Blair Mountain-Crater Lake, and 2 in South Fork Canyon. A description of each quadrat and its location are given on the following pages. Photographic prints are assembled in the Appendix.

Two additional quadrats were established in the Mt. Zirkel Wilderness Area and data on these are included here.

Quadrat 1

Location: Trappers Lake area (site no. 4), Garfield County, talus above boat docks on NE side of Trappers Lake, first large rock on left (about 1.2 m high) on entering talus area, 2 m off the trail from a small cairn at trail edge. Elevation 9650 ft.

Orientation: About 60° sloping flat surface near top of rock, facing NW.

Species composition:

Aspicilia calcarea
Caloplaca adnexa
Lecanora novomexicana (psoromic acid +)
Lecidea atrobrunnea (confluentic acid with or without hyposalazinic acid +)
Lecidea tessellata (sterile)
Lecidella stigmatea
Physcia dubia (in cracks)
Rhizocarpon disporum
Rhizocarpon geographicum

Quadrat 2

Location: Trappers Lake area (site no. 4), Garfield County, talus above boat docks at NE side of Trappers Lake, small boulder (about 80 cm high) 4.8 m and N65°E from Quadrat 1 (about 6.8 m from cairn at trail edge). Elevation 9650 ft.

Orientation: 80° flat slope, lower part of rock near ground level, N facing.

Species composition:

Aspicilia caesiocinerea
Caloplaca adnexa
Candelariella rosulans
Lecanora novomexicana
Lecidea syncarpa (norstictic acid +)
Rhizocarpon geographicum
Xanthoparmelia cumberlandia (norstictic and stictic acids +)

Quadrat 3

Location: Trappers Lake area (site no. 4), Garfield County, talus above boat docks on NE side of Trappers Lake, a large jutting boulder (about 1.2 m high) about 16 paces (13.5 m) from cairn near Quadrat 1 and 7.6 m to the right from trail edge going N50°W. Elevation 9650 ft.

Orientation: Nearly vertical face on N end of rock, facing east.

Species composition:

Aspicilia calcarea
Candelariella rosulans
Lecanora muralis
Lecanora novomexicana
Lecidea atrobrunnea (not tested)
Lecidella stigmatea
Rhizocarpon disporum
Rhizoplaca melanophthalma
Xanthoria elegans

Quadrat 4

Location: Trappers Lake area (site no. 2), Garfield County, main sample outcrop on the Tops, east of Chinese Wall, N end, 4.0 m from cairn at N end, about 2 m up on vertical cliff, end of flat face. Elevation 11,200 ft.

Orientation: Vertical, flat, N facing section.

Species composition:

Aspicilia sp.
Lecanora indet.
Lecanora novomexicana (psoromic acid +)
Lecanora thomsonii (psoromic acid +)
Lecanora bicincta
Phaeophyscia decolor
Phaeophyscia orbicularis
Physcia dubia
Rhizoplaca melanophthalma
Umbilicaria virginis
Xanthoria elegans

Quadrat 5

Location: Trappers Lake area (site no. 2), Garfield County, Main sample outcrop on Tops east of Chinese Wall,10 m S of cairn on north end, first vertical face at ground level. Elevation 11,200 ft.

Orientation: Flat, nearly vertical NW facing plot near ground level.

Species composition:

Aspicilia gibbosa (norstictic acid +)
Candelariella aurella
Lecanora badia
Lecanora bicincta
Lecanora novomexicana
Lecidea atrobrunnea (not tested)
Rhizocarpon geographicum
Xanthoparmelia cumberlandia (norstictic and stictic acids +)

Quadrat 6

Location: Trappers Lake area (site no. 2), Garfield County, main sampling outcrop on Tops east of Chinese Wall, S end, 12.4 m NNW of cairn at south end. Elevation 11,200 ft.

Orientation: Nearly vertical, flat face, N facing.

Species composition:

Acarospora chlorophana

Candelariella aurella

Lecanora novomexicana (psoromic acid +)

Lecanora thomsonii (psoromic acid +)

Physcia dubia

Sporastatia testudinaria

Quadrat 7

Location: Trappers Lake area (site no. 2), Garfield County, main sample outcrop on Tops east of Chinese Wall, flat area on top of south end of site, overlooking and about 8 m E of main cliff drop off, marked with a metal tent stake. Elevation 11,200 ft.

Orientation: In middle to flat slab flush with ground.

Species composition:

Aspicilia calcarea
Caloplaca adnexa
Candelariella rosulans
Lecanora muralis (terpenes +)
Lecanora novomexicana
Lecidea syncarpa (norstictic acid +)
Lecidea tessellata
Lecidella stigmatea
Rhizocarpon grande (TLC-)
Xanthoparmelia taractica (salazinic acid +)
Xanthoria elegans

Quadrat 8

Location: Blair Mountain, Garfield County, on Forest Road 604, 14.1 miles from Meadow Creek Campground, in the saddle about 1500 feet north of southernmost rise ("Limestone 11375"), the first sandstone ledge on the left (going south), 100 oaces ENE from road going east, overlooking Elk Lakes. Elevation about 11200 ft.

Orientation: Quadrat on nearly level ledge surface.

Species composition:

Caloplaca adnexa

Lecanora novomexicana (psoromic acid +)

Lecidea syncarpa (2 specimens tested, norstictic acid)

Rhizocarpon geographicum

Quadrat 9

Location: Blair Mountain area, about .5 mi down on the trail from rim to Crater Lake, first major talus transected by the steep path, a large 80 X 130 cm quartzite boulder on upper side just off trail. Elevation 10700 ft.

Orientation: Upper right quadrant of rock, SE facing with a 45° slope.

Species composition:

Aspicilia caesiocinerea (TLC-)

Lecanora novomexicana (2 specimens, psoromic acid +)

Lecidea atrobrunnea (confluentic acid group +)

Rhizocarpon geographicum

Quadrat 10

Location: Blair Mountain area, Garfield County, about .1 mi down from rim on trail to Crater Lake, first major sandstone ledge on right going down. Elevation about 11000 ft.

Orientation: West end of ledge, flat surface at end.

Species composition:

Aspicilia caesiocinerea (TLC-)

Candelariella rosulans

Lecidea plana

Lecidella stigmatea

Xanthoparmelia cumberlandia

Xanthoria elegans

Quadrat 11

Location: South Fork of White River (site no. 16), Rio Blanco County, first major granite outcrop coming upslope with small cairn on right and large quadrat rock on left, 5.5 m from trail edge. Elevation 7700 ft.

Orientation: Nearly flat surface of 2 X 2 m boulder, 95 cm from S edge and 135 cm from W edge.

Species composition:

Aspicilia caesiocinerea (TLC-)
Caloplaca adnexa
Candelariella rosulans
Lecanora novomexicana (psoromic acid +)
Lecidea atrobrunnea (no test)
Rhizocarpon geographicum
Xanthoparmelia taractica (salazinic acid +)

Quadrat 12

Location: South Fork of White River (site no. 16), Rio Blanco County, first major outcrop about 1.1 mi from Wilderness Boundary (near South Fork Campground), 64 paces (ca 55 m) up the trail (going east) from Quadrat 11, 8 m to the left from trail. Elevation 7700 ft.

Orientation: near top center of large, slightly sloping WSW facing rock.

Species composition:

Candelariella rosulans

Lecanora novomexicana (psoromic acid +)

Rhizocarpon disporum (stictic acid +)

Rhizocarpon geographicum

Umbilicaria hyperborea

Xanthoparmelia taractica (salazinic acid +)

Mt. Zirkel. Quadrat 1

Location: Mt. Zirkel Wilderness Area, Routt County, road intersection at Buffalo Pass, going along trail about 50 m SW from Wilderness Area boundary marker, turning left and walking south along ridge about 250 m to last outcrop overlooking road. Elevation 10,300 ft.

Orientation: flat 45° N-facing slope on large boulder.

Species composition:

Aspicilia caesiocinerea (TLC-)

Rhizocarpon geographicum

Xanthoparmelia cumberlandia (stictic, norstictic acids+)

Mt. Zirkel. Quadrat 2

Location: Mt. Zirkel Wilderness Area, Routt County, on Forest Road 310 going to Fish Creek Reservoir, 3.3 mi from road intersections at Buffalo Pass, going south, first large outcrop on right, N side of small creek and pools in meadow, 10-20 m from road. Elevation about 10,000 ft.

Orientation: Top of main outcrop, flat.

Species composition:

Aspicilia caesiocinerea (TLC-)
Candelariella rosulans
Rimelaena oreina (gyrophoric acid+)
Lecidea atrobrunnea (confluentic acid+)
Physcia dubia
Rhizoplaca melanophthalma (psoromic, usnic acids+)
Umbilicaria hyperborea

Results of Elemental Assays

The purpose of elemental assays of lichens in the Flat Tops is to lay the foundation for baseline values which can be compared with future values. No comparable studies have been made in the Rocky Mountain area.

Six common species were used: Rhizoplaca chrysoleuca and R. melanophthalma, very similar crustose-umbilicate lichens, Umbilicaria hirsuta, a large umbilicate lichen, Usnea sp., a fruticose lichen on spruce, and foliose Xanthoparmelia cumberlandia and X. wyomingica.

Samples of 5-10 g (a large handful) were taken at 12 sites around the Flat Tops, encompassing different elevations and rock types. About 1 g of the material from each sample was pulverized in a Wiley Mill, divided into two replicate samples, and sent for analysis at the Research-Extension Analytical Lab (REAL), Ohio Agricultural Research and Development Center, Wooster, OH. The results are summarized on the following pages with tables giving raw values and a summary for each species.

The following observations can be made on some of the more important elements:

Calcium is known to be accumulated by many lichens as calcium oxalate in high concentrations such as those shown by many samples from the Flat Tops. We are at a loss to explain the great range of values or the source of the calcium.

Iron content is strongly influenced by nearby iron-rich dust sources. It is the only element showing significant regional differences in the Flat Tops. For example, almost all Xanthoparmelia cumberlandia samples on iron-rich volcanic rocks contain more than 9000 µg/g, almost certainly derived from dust eroded and blown from the rock surface. Those in the Blair Mountain area, dominated by iron-poor quartzite and sandstone, contain 4000-5000 µg/g. Tree-growing Usnea sp., as expected, has the least amount, 378 µg/g.

Lead, the best studied heavy metal in lichen populations, has uniformly low values, close to baseline values reported in comparably unpolluted areas. Tree-growing Usnea sp. has the lowest value, 22 µg/g, but even the large, prostrate, rock-growing Xanthoparmelias do not accumulate significantly

larger amounts (51 μg/g), far less than the 800-1600 μg/g commonly measured in the same species in polluted areas.

Zinc, another widespread element associated with increasing pollution, also has low values, averaging 31-74 μg/g, in contrast to reports of 150 to 200 μg/g in polluted areas.

Sulfur dioxide has low values, .11-.16% S, near reported baseline values and much less than the .40% for lichens in polluted areas.

Several conclusions can be drawn from the overall values with respect to their value in biomonitoring air pollution in the Flat Tops:

1. The lichens seem to take up only very small quantities of elements from the rock substrate, whether volcanics, granites, or sandstone. The only exception is iron.

2. There seem to be no significant differences in elemental content with elevation, which varies from 7700 to 11,400 feet.

3. There seem to be no significant differences in values between the various sites, ranging from the extreme northeastern section to the southwestern corner. This may be interpreted to show that no particular area of the Flat Tops is being impacted more than any other.

4. Because of the uniformity at this time, any perturbations in pollution levels should be readily picked up as increases in elemental content of the indicator species in future surveys.

RESULTS OF ELEMENTAL ANALYSIS OF RHIZOPLACA CHRYSOLEUCA AND R. MELANOPHTHALMA (DATA COMBINED)

Three samples (6 replicates) collected at sites no. 5, 16, and 17. Values in µg/g.

Element	Average	Range
Al	2362	1530-3241
B	23	18-31
Ca	25164	18876-38403
Cu	24	19-29
Fe	1799	860-3284
K	2402	2228-2542
Mg	1006	552-1916
Mn	39	24-65
Na	125	53-277
P	765	646-894
Pb	36	25-46
Zn	31	23-38

RESULTS OF ELEMENTAL ANALYSIS FOR UMBILICARIA HIRSUTA

Two samples (4 in replicate) collected at sites no. 2 and 17.

Values in µg/g.

Element	Average	Range
Al	2924	1949-5194
B	32	24-46
Ca	1777	960-3561
Cu	63	56-75
Fe	1783 (avg. of 3 replicates; 4th over range (9000)	
K	3809	3760-3865
Mg	2147	1283-4358
Mn	66	38-137
Na	597	112-1826
P	1245	1073-1399
Pb	24	19-30
Zn	74	63-85

RESULTS OF ELEMENTAL ANALYSIS FOR USNEA SP.

Three sample (6 in replicate) collected at sites no. 3, 10, and a logged area near Cow Lake, east of Meadow Creek Lake. Values in µg/g.

Element	Average	Range
Al	944	720-1187
B	24	17-46
Ca	6812	5167-8757
Cu	16	8-28
Fe	378	252-879
K	3677	3340-3917
Mg	640	579-724
Mn	72	49-90
Na	103	96-128
P	1285	874-1592
Pb	22	14-28
Zn	34	29-48

RESULTS OF ELEMENTAL ANALYSIS OF XANTHOPARMELIA CUMBERLANDIA

Eleven samples (22 in replicate) collected at sites no. 1 (2 collections), 2, 3 (2 collections), 8, 13, 16, 17, 18, 20. Values in µg/g.

Element	Average	Range
Al	5176	3055-7031
B	41	27-62
Ca	23776	14454-31775
Cu	43	20-79
Fe	3492 (2 replicates; rest over range (9000))	
K	3327	2524-4090
Mg	2242	1430-4608
Mn	116	60-203
Na	207	125-742
P	1251	797-1560
Pb	51	27-119
Zn	56	43-74

RESULTS OF ELEMENTAL ANALYSIS OF XANTHOPARMELIA CUMBERLANDIA

Two samples (4 replicates) collected at Mt. Zirkel. Values in µg/g.

Element	Average	Range
Al 4519	4519	4012-5309
B	31	15-50
Ca	16629	9259-24220
Cu	37	26-47
Fe	2908 (3 samples; 4th over range (9000))	
K	3561	3165-3866
Mg	1472	1309-1544
Mn	90	82-108
Na	126	100-138
P	1250	928-1750
Pb	55	50-63
Zn	65	61-67

RESULTS OF ELEMENTAL ANALYSIS OF XANTHOPARMELIA WYOMINGICA

Two samples (4 replicates) collected at site no. 2 (2 collections).

Values in µg/g.

Element	Average	Range	
Al	3816	3299-4334	(one sample)
B	46	28-70	
Ca	31351	29622-35113	
Cu	22	18-27	
Fe	3730 (1 value; others over range (9000))		
K	2730	2656-2760	
Mg	2013	1320-2728	
Mn	87	52-117	
Na	130	114-154	
P	1114	1045-1215	
Pb	34	31-38	
Zn	42	31-53	

RESULTS OF SULFUR ANALYSIS

Five samples were selected for separate sulfur analysis. Values are give in %S for each replicate.

Xanthoparmelia cumberlandia:

Site no. 2	0.13, 0.16
Site no. 8	0.14, 0.15
Site no. 16	0.13, 0,13
Mt. Zirkel	0.11, 0.12

Usnea sp.:

Site no. 10	0.13, 0.15

Raw lab results for Xanthoparmelia wyomingica. Values in µg/g.

Site	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	Al	Pb	B
2	1060	2750	30173	1320	105	3730	31	52	18	3299	37	47
	1137	2656	29622	2193	138	OR	40	115	20	4334	38	70
2	1043	2755	35113	1811	116	OR	45	64	25	-	33	28
	1215	2760	30497	2728	154	OR	53	117	27	-	31	39

Raw lab results for Xanthoparmelia cumberlandia at Mt. Zirkel. Values in µg/g.

Site	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	Al	Pb	B	%S
1	1348	3866	24220	1508	138	2543	67	108	34	5309	63	28	-
	1750	3773	23219	1309	100	3012	61	88	26	4012	59	15	-
2	975	3440	9818	1528	129	3169	67	82	47	4434	50	33	0.12
	928	3165	9259	1344	138	OR	66	85	44	4322	50	50	0.11

Raw lab results for Xanthoparmelia cumberlandia. Values in µg/g.

Site	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	Al	Pb	B	%S
2	1219	3444	15688	1978	255	3919	65	79	62	4222	42	38	-
	1372	3246	17883	1530	171	3295	63	61	65	3055	41	41	-
2	992	3381	18600	2224	161	OR	60	95	50	4956	50	41	0.13
	1466	3471	21531	2033	126	OR	49	86	42	4150	48	33	0.16
3	1407	3673	14470	2385	188	OR	71	181	79	7013	40	53	-
	1270	3792	15460	1984	146	OR	71	178	59	6067	40	46	-
3	797	2753	28372	1901	136	OR	43	66	20	-	76	27	-
	924	2608	25852	1946	125	OR	62	60	23	-	119	27	-
1	1307	3700	28192	2035	129	OR	46	92	45	5197	50	49	-
	1188	3504	25209	2266	140	OR	51	114	47	4888	45	43	-
13	1427	3546	24296	2176	146	OR	65	84	36	5771	42	41	-
	1560	3532	23970	2393	164	OR	61	96	43	6064	42	52	-
20	1084	2715	24339	2956	260	OR	48	137	37	4784	38	54	-
	1233	3080	27822	3125	350	OR	48	175	35	5667	43	62	-
17	1515	2622	29039	4461	483	OR	49	190	26	-	40	45	-
	1408	2524	30132	4608	742	OR	49	203	28	-	27	34	-
19	1196	3496	16914	1430	137	4730	54	129	31	4990	76	32	-
	1170	3338	14454	1553	107	OR	53	137	43	5150	43	39	-
8	1487	4090	25674	1712	166	3327	74	112	62	5660	53	45	0.15
	1557	3742	31704	1565	157	3077	65	122	42	4955	54	35	0.14
16	955	3604	31775	1587	150	3843	54	84	43	5608	58	35	0.13
	996	3344	31711	1485	135	3721	52	78	39	4956	56	36	0.13

Raw lab results for Rhizoplaca melanophthalma (first two samples) and R. chrysoleuca. Values in µg/g

Site	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	Al	Pb	B
17	857	2449	18876	1916	277	3284	35	65	28	3241	25	31
	649	2316	19272	1483	163	2050	32	50	22	2833	25	24
5	646	2228	24347	552	53	1216	23	27	19	1530	39	18
	656	2377	22363	564	61	860	25	24	19	1590	41	24
16	890	2542	27728	766	96	1615	34	35	28	2399	42	23
	894	2504	38403	758	100	1774	38	33	29	2582	46	21

Raw lab results for Umbilicaria hirsuta. Values in µg/g.

Site	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	Al	Pb	B
2	1174	3760	1406	1419	145	1441	63	48	56	2336	27	30
	1399	3843	1182	1283	112	2581	85	38	75	1949	19	30
17	1334	3768	3561	4358	1825	OR	73	137	62	5194	30	46
	1073	3865	960	1531	305	1327	76	41	61	2218	22	24

Raw lab results for Usnea sp. Values in µg/g.

Site	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	Al	Pb	B	%S
Cow	1171	3340	5278	605	98	328	29	52	17	720	25	22	-
Lake	1175	3509	5167	600	99	257	31	49	20	721	25	17	-
10	874	3710	8757	703	128	271	48	74	28	1187	28	23	0.15
	1592	3888	8489	724	97	879	35	79	19	1149	28	17	0.13
3	1403	3917	6896	623	100	252	32	88	8	-	14	46	-
	1500	3702	6286	579	96	282	31	90	8	-	15	20	-

Indicator Species

Unfortunately we have no experimental data on the relative sensitivity of lichens in the Flat Tops to air pollution. Using information from related species in Europe and eastern North America, we can predict a sensitivity scale as follows:

Most sensitive species:

Usnea sp. (occurring on spruce at access points)
Evernia divaricata (occurring on spruce at access points)
Xanthoparmelia cumberlandia (on rocks throughout Flat Tops)
Umbilicaria hirsuta (on rocks at higher elevations)
Rhizoplaca chrysoleuca & R. melanophthalma (on rocks at higher elevations)
Lecanora novomexicana (on rocks throughout the Flat Tops)
Xanthoria elegans (on rocks throughout the Flat Tops)

Least sensitive species:

Aspicilia caesiocinerea (on rocks at all elevations)
Lecidea atrobrunnea (on rocks at all elevations)
Staurothele clopima (on rocks at all elevations)
Lecidea tessellata (on rocks at all elevations)
Peltigera canina (on soil everywhere)
Cladonia spp. (on soil everywhere)

Role of Lichens in the Ecosystem

Extremely little is known of the role of lichens in the ecosystem. Their role in recycling mineral elements, input of fixed nitrogen, etc., has been studied only recently, mostly in the Douglas-fir forests of Oregon and in the arctic, where in fact lichens make a significant contribution.

As an example, soil-inhabiting lichens which contain blue-green algae are able to fix atmospheric nitrogen. This fixed nitrogen is cycled into the ecosystem by leaching or decomposition of the lichens. In the Flat Tops Peltigera species that are known to fix nitrogen (see color photographs in Appendix) are common on soil in forest areas, less so at higher elevations. They must enrich the soil, how much we can only guess at this time.

Lichens are suspected of being an important source of food for invertebrates. At the Flat Tops a very common land snail, Oreohelix haydenii, was often observed grazing on lichens, and we can probably assume that lichens make up its primary food. Many insects and mites also infest lichens. Colonies of Thamnolia subuliformis at Derby Peak (see color photograph in the Appendix) seem to be clipped off by elk or deer, grazing animals that are known to utilize lichens as winter fodder in boreal zones.

4. RECOMMENDATIONS

Extremely few baseline studies, that is surveys made before pollution begins, have ever been made. There are no guidelines on how soon later surveys should be made. One can only make an educated guess at this time, taking into consideration the general climatic and air mass conditions at the Flat Tops, the estimated rate of natural changes in the lichen flora, and any known increase in pollution sources in the future.

If pollution remains at the present low level, one would not expect any measurable change in floristic composition, caused mainly by loss of sensitive species, over the next decade. If pollution increases significantly, changes in the flora would still take several years to detect. However, low-level pollution should appear as gradually increasing elemental content over a period of a few years. For example, while Xanthoparmelia cumberlandia in the Flat Tops now contains about 50 ppm lead, the same species at a similar elevation in Gothic, CO, less than 100 miles to the south, contains about 200 ppm. This significant difference may be related to the greater amount of acid rain in the Gothic area.

The following intervals for resurveys are recommended with the qualification that they be accelerated or extended depending on results of physical monitoring stations:

1. Elemental analyses: Every 3-5 years.

2. Permanent lichen study plot photographs: every 3-5 years. These are important as a quantitative backup to the floristic survey and will enable us to measure growth rates and natural changes in coverage and community structure.

3. Floristic inventory: every 10 years. Later surveys might be designed to add more exact data on frequency and coverage of the lichens.