REGIONAL COPPER-NICKEL STUDY:

LICHENS AS AIR POLLUTION INDICATORS

MINNESOTA ENVIRONMENTAL QUALITY BOARD
REGIONAL COPPER-NICKEL STUDY

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ABSTRACT

The literature is reviewed concerning the use of lichens as air pollution indicators. There is a decrease in the frequency, coverage, and vitality of lichens as one approaches a large city or industrial complex. Lichens are more sensitive than most other plants to sulfur dioxide and contamination by heavy metal accumulation. By determining species presence and abundance, zones correlated to pollution levels can be quickly mapped. Species do not respond consistently from one region to another, so zonal scales relating species presence to pollution levels cannot be generalized. Lichens have only rarely been correlated to known sulfur dioxide concentrations because of the lack of available physico-chemical measurements. Lichens are most valuable as indicators of pollution patterns and toxicity levels on a regional scale. The known sensitivity of lichens make them excellent bioassay organisms for monitoring the impact of atmospheric pollutants at very low-levels.

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are to characterize the region in its pre-copper-nickel development state: 1) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 2) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 3) to conceptualize alternative degrees of regional copper-nickel development; and 4) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

LICHENS AS AIR POLLUTION INDICATORS

INTRODUCTION

During the last several decades there has been considerable interest in the use of lichens as indicators of atmospheric pollution. It has been observed that there is a decrease in the frequency, coverage, and vitality of lichens as one approaches a large city or industrial complex (Mrose 1941; Skye 1968; Gilbert 1970; Ferry et al. 1973; Westman 1975). Extensive literature pertinent to this subject is available.

Lichens are particularly sensitive to the presence of sulfur dioxide in the atmosphere (Mrose 1941; Skye 1968). They also serve as indicators of heavy metal accumulation (Nieboer et al. 1972; Stiennes and Krog 1977) and hydrogen fluoride and fluorine pollution (Hawksworth 1971). This report is mainly concerned with the air pollutant sulfur dioxide and contamination by heavy metal accumulation.

The harmful effect of sulfur dioxide on plants is well documented. It has been shown that relatively high concentrations of sulfur dioxide disrupt the plasma membrane within cells and cause plasmolysis (Skye 1968). Lichens, bryophytes, and fungi have proved to be the most sensitive plants to atmospheric pollution. Absolute levels of tolerance are still lacking for most species of lichens. Those studies which have related sulfur dioxide levels to individual lichen species have found lichens to be valuable indicators when mean sulfur dioxide levels range between 30-170 $\mu g/m^3$, and most sensitive in the range of 30-70 $\mu g/m^3$ (Hawksworth 1973). More work needs to be done correlating pollutant levels to the sensitivities of individual species. There are many variables which affect the impacts of air pollutants on lichens (e.g. prevailing atmospheric conditions and level and duration of pollutant concentration).

That lichens are more sensitive to the presence of sulfur dioxide than other plants can be explained in part by their unique living conditions. According to Smith (1964), "the fact that they live in barren habitats has meant that they have evolved highly efficient mechanisms for nutrient absorption (and) slow rates of growth so as not to outstrip their nutrient supplies." Thus, the efficiency with which lichens store food produces an organism with enormous potential for accumulating pollutants from both the atmosphere and dilute rain-water solutions. At the same time the organism has little potential for recovery following contamination, because unlike most plants the growth pattern of lichens does not include a mechanism for releasing contaminants (e.g. deciduous leaves, annual die-back to the root system, etc.).

What is a Lichen?

A lichen is composed of an alga and a fungus that live together in a symbiotic relationship. These two organisms form a thallus whose morphology, anatomy, and physiology are quite distinct from those of either organism when grown separately in culture. The majority of the plant body is made up of fungal hyphae which enclose a thin layer of alga located just beneath the surface. Lichens are found in diverse habitats from rocky ocean shores to mountain tops, from hot deserts to the polar regions, and from tree leaves to tree trunks (Hawksworth and Rose 1976). Within these habitats, most species are clearly specific to a particular ecological niche. Lichens grow on various substrates including rocks, soil, other plants, and man-made materials like cement, asbestos, and glass. They are not parasitic upon the substrate but use it as a surface for attachment. Microclimatic variables and the chemical composition of the substrate are important limiting factors influencing the distribution of lichens. On a single tree one can find a combination of many different species depending on such variables as acidity of the bark, exposure to wind, and shadiness. There are three major life-form types of lichens. The most inconspicuous life-form is crustose (flat, scaly, and crust-like). Crustose lichens are often difficult to see and blend well with their substrate. Foliose lichens are leaf-like in appearance. The third life-form is fruticose (erect shrubby or beard-like, pendant species).

Lichens are small, slow-growing plants (in some cases they reach ages of up to 4500 years old)(James 1973). Mature crustose lichens rarely grow more than a centimeter per year (Smith 1973). The inability of lichens to retain moisture contributes to their slow-growth pattern. Lichens, however, are very efficient in accumulating substances from dilute solutions which allows them to utilize low concentrations of nutrients.

Solute accumulation in lichens occurs by two distinct mechanisms: active uptake and passive binding on cell walls. Active uptake is accompanied by enhanced respiration and directly relates to temperature change. Passive binding is temperature-independent and functions equally well in living or dead thalli. Experimental results of Smith (1962) and Farrar (1973) show that absorption is indeed significantly higher in lichens than other vascular plants. The phenomena that explain this greater efficiency are still poorly understood. Smith (1975) proposed some hypotheses: perhaps fungal hyphae have a higher efficiency of uptake because of a greater membrane surface area; or, perhaps because they may have more transport sites per unit area of membrane; or, perhaps in lichens the transport systems work more rapidly than in other plants.

Passive binding explains the accumulation of cations on cell walls. Tuominen and Jaakkola (1973) reviewed the mechanism of binding and concluded that it involved some type of cation-exchange process. The lack of a protective waterproof cuticle on lichens aids these uptake systems by permitting them to respond quickly to changes in available moisture and allows them to take in water and dissolved substances over the whole thallus surface. The slow-growth habit, efficient uptake system, and lack of protective covering are important in understanding the sensitivity of lichens to pollutants.

In Minnesota lichens grow most actively during the spring and autumn (Wetmore, personal communication). It is during these seasons that lichens are most susceptible to pollutant injury. The symptoms of pollutant injury can be detected by systematic and regular observation of the lichen thallus. Lichen species respond differently to pollutants (e.g. curling of margins, chlorosis of the thallus, discoloring of lobes, whitening of thallus followed by necrosis, or decreased annual growth)(Skye 1968).

HISTORICAL BACKGROUND

Lichens and Sulfur Dioxide

Over one hundred years ago, Nylander (1866) proposed that the paucity of lichens in the city of Paris was due to air pollution. Recently, more extensive studies, including work by Barkman (1958), Skye (1965, 1968), Gilbert (1970), and Westman (1975) have produced evidence supporting this view. For many years this explanation was countered by workers (e.g. Rydzak 1968; and Klement 1956) who suggested that the absence of lichens was due to the lower humidity level in urban areas. This idea, which had its greatest support in the 1950s, lost favor as actual levels of air pollution became known and sulfur dioxide concentrations were correlated with lichen distribution. Although both explanations may in part be relevant, the accumulated evidence indicates that atmospheric pollution is the most important environmental factor determining the distribution of lichens in urban and industrial areas (Saunders 1970).

The relationship between lichen distribution and sulfur dioxide concentrations was first demonstrated in a paper by Mrose (1941) in an attempt to determine why Usnea (a fruticose lichen) was absent from the forests in an industrial area in Germany. In the several decades since this study, there have been four basic approaches to understanding the relationship between lichen distribution and sulfur dioxide pollution. First, single species were mapped according to their distribution (Mrose 1941); second, lichens were transplanted and then carefully monitored; third, the tolerance of particular species was assessed by a calculated index of atmospheric purity (IAP) (LeBlanc and DeSloover 1970); and fourth, generalized zones of lichen distribution were established based on vitality and species numbers (Laundon 1967; Skye 1968; Gilbert 1970; and Hoffman 1974).

The first method is effective but does not give the breadth of information that a more generalized study of more species provides. The second approach involves too many variables that cannot be controlled. Lichens are so specific to a particular microhabitat that it is difficult to imagine being able to consistently replicate the habitat from which the lichen was transplanted. It would be unfair to conclude that a lichen's waning vitality was due to pollution when it might well be an artifact of transplantation.

The third approach, the index of atmospheric purity (IAP), was developed by LeBlanc and DeSloover (1970). The IAP was calculated by the number of species present, their coverage and frequency, and their specific tolerance to pollutants. Field methods used by LeBlanc and DeSloover included careful scrutiny of the base and trunk of each tree up to two meters. The extent of coverage and the frequency of occurrence of each species was recorded according to an arbitrary five point scale. The selection of trees and the location of stations were carefully and purposefully chosen (i.e. one species of tree was sampled and all individuals grew in similar microhabitats). To facilitate the manipulation of a great deal of data, they developed a mathematical formula that assessed the richness of vegetation.

> For any one station IAP = $\Sigma_n^1 (Q \cdot f)/10$, where n is the number of species present at a station, Q is the ecological index of each species, and f is the value given in our coverage scale. The sum of $Q \cdot f$ is divided by 10 to provide a small manageable figure. The ecological index (Q) of a species was established by adding together the number of species of epiphytes escorting it at a station and then taking the average of the sums for all the stations where that species was present (LeBlanc and DeSloover 1970).

Once the IAP's from all the stations were determined, they were plotted on a map, and those having an index within a particular range were linked together. The map then illustrated zones of varying levels of species richness. These zones, if correlated with air pollution measurements, are a valid and important means for estimating long-range effects of pollution on epiphytic vegetation. The index should be low in areas where there has been contamination over a long period of time and high in areas of relative purity.

The fourth approach has been most widely used in the last decade. Cities and industrial complexes around the world have been mapped and species distribution zones established. The criteria used in establishing zones are best demonstrated by the work of Laundon (1967) and Skye (1968). Laundon (1967) divided London into four zones; central, inner urban, suburban, and green belt. Only Lecanora dispersa, a crustose lichen, was identified from the central ring. This species was also characteristic of Sernander's (1926) so-called "lichen desert" and was the only lichen recorded in Brodo's (1966) central zone in his study of Long Island, New York. Laundon found 32 species (52 percent of the lichen flora of the London area) within the inner urban zone and a further increase to 57 species (92 percent) within the suburban zone. Skye (1968) recognizes five zones surrounding the city of Stockholm. He defines these zones by the frequency, and combination and number of lichens within them. These zones are central, inner transitional, central transitional, outer transitional, and normal. These zonation studies and others consistently establish a positive correlation between decreasing levels of sulfur dioxide and numbers of species present.

Jones (1952) and more recent authors (Fenton 1964; and Westman 1975) have established that there are variable sensitivities to air pollution exhibited by the different life-forms of lichens. This pattern corresponds to the distribution of lichens as mapped in the zonation studies of cities and industrial areas. Jones (1952) studied life-form distribution on a transect from Birmingham to Stratford-on-Avon, England. He found crustose lichens to be most tolerant (e.g. Lecanora conizaeoides), foliose lichens (e.g. Hypogymnia physodes) less tolerant, and fruticose lichens (e.g. Usnea spp.) least tolerant. Fenton (1964) discovered a similar trend in his studies in Northern Ireland. He found that no lichen could tolerate a mean annual sulfur dioxide concentration of greater than 78 $\mu g/m^3$. The first species to occur outside the "lichen desert zone" was Lecanora conizaeoides, a crustose lichen. Foliose lichens do not appear until the concentrations have dropped to 25-40 $\mu g/m^3$ and fruticose lichens do not appear until the air is nearly pure. These values would reflect more accurately the real response of lichens to pollutants if more variables had been monitored.

This trend of increasing resistance to air pollutants as related to life-form type is valid in mapping percent cover and aids in the construction of toxicity zones. However, it should not be viewed as an absolute measure, for not all crustose lichens are more tolerant than all foliose and fruticose species. Some crustose species (e.g. Dimerella spp., Gyalecta spp.) are very sensitive to air pollution (Hawksworth 1971). Maps showing zonation patterns of lichens around cities are informative but do not reflect the complexities of many regions. More recently, maps have been drawn incorporating sociability, vigor-vitality, and individual species sensitivities to different levels of sulfur dioxide. Gilbert (1970)(see Appendix A) and Hawksworth and Rose (1970)(see Appendix B) have constructed scales for England and Wales which relate species populations to actual levels of sulfur dioxide ($\mu g/m^3$). Hoffman (1974) made semiquantitative measurements of sociability and vigor-vitality of lichen species and then computed an Index of Atmospheric Purity (a modified form of the IAP of LeBlanc and DeSloover 1970).

The value of lichens as air pollution indicators would be increased if absolute concentrations of sulfur dioxide could be determined from the lichen thallus. However, sulfur dioxide toxicity and lichen metabolism are still poorly understood. Tomassini et al. (1976) analyzed sulfur content in lichens by X-ray fluorescence but found their technique suffered "the inherent weakness (poor reproducibility and limited accuracy) of most plant sulfur analyses." The relevance of solution studies (Saunders 1966; and Gilbert 1968) to field observation cannot be ascertained at present because of the numerous environmental factors acting upon the movement of sulfur dioxide.

Lichens and Heavy Metals

Within the last decade it has been shown that lichens are good indicators of heavy metal pollution. Lichens are capable of accumulating metals from their substrate and surrounding environment in levels far beyond their needs (Nieboer et al. 1972; James 1973; Tomassini et al. 1976; and Steinnes and Krog 1977). Both Nieboer (1972) and Tomassini et al. (1976), using different analysis techniques, found a positive correlation between metal content and proximity to a pollution source. Analyses for metal levels has usually been determined by atomic absorption spectrophotometry. More recently, Tomassini et al. (1976) have developed a technique whereby metal levels in lichens are analyzed by X-ray fluorescence. This technique proved to be faster and demonstrated better sensitivity and reproducibility than methods used previously. In addition, the samples are not consumed in the analysis and can be stored for future reference. Steinnes and Krog (1977) compared the content of heavy metals in naturally occurring specimens and in transplant specimens of the lichen Hypogymnia physodes by neutron activation analysis. The mercury level was significantly higher in the transplant specimens than in the naturally occurring specimens in an area surrounding an industrial complex. There was no significant increase in the concentration levels of arsenic and selenium.

Tyler (1976) discusses some of the problems inherent with the use of lichens as indicators of heavy metal accumulation. Even though lichens are capable of accumulating large amounts of heavy metals, they are also very sensitive to gaseous pollutants. Thus, in some situations, sufficient numbers for analysis are lacking. An additional disadvantage is the inability to establish a time-scale because of the difficulty in separating the biomass of one year's growth from another. However, if lichens are present, the X-ray fluorescence method promises to be a very accurate indicator of heavy metal accumulation. If lichens are not present, the transplant method discussed by Steinnes and Krog (1977) appears to be a valid means for determining the presence of heavy metals.

Lichen Studies in Minnesota

Two long-term studies using lichens as air pollution indicators are being conducted in Minnesota. The Northern States Power Company, at its Allen S. King Generating Plant in Oak Park Heights, has been collecting data on the vitality of certain lichen species since 1967. The lichens show no reported symptoms of air pollution damage (Grether 1975). Lichen plots are marked on 20 hardwood trees in the environs of the King Plant and 10 in a control area near Fair Haven, Minnesota (see species list, Appendix C and D). Photographic slides taken of each plot are projected on graph paper and percentage of change is computed annually.

The second study began during the summer of 1976 in the area surrounding Minnesota Power and Light Company's Boswell Station in Cohasset. It is hoped that this study will be continued on a long-term basis.

Observations on the epiphytic (growing on trees) lichen flora were made at each of the 35 vegetation study plots and representative individuals of each tree species supporting foliose lichens were evaluated (MPCA 1977). The selection of study plots was based on wind patterns which helped define the boundaries of the area to be impacted by the power plant. The study evaluated the condition of about 3500 individual lichens of the species, *Physica aipolia*, *Parmelia coperata*, and *Parmelia sulcata*. The study found that, "The emissions of the Clay Boswell Station essentially killed almost all sensitive lichens within 1 mile (1.61km) northeast and south of the station and within 3 miles (4.83km) west and southeast of the station" (MPCA 1977).

CONCLUSION

Plant growth and development are directly related to ambient air and water quality. Pollutants in large enough concentrations can suppress and kill plant life. The known sensitivity of lichens to sulfur dioxide and their ability to accumulate heavy metals make them important pollution indicators. By determining species present and their abundance, zones correlated to pollution levels can be quickly mapped. Species do not respond consistently from one region to another, so zonal scales relating species presence to pollution levels cannot be generalized. Lichens have only rarely been correlated to known sulfur dioxide concentrations because of the lack of physio-chemical measurements. However, Hawksworth and Rose (1970) feel that estimates based on epiphytic vegetation are probably more significant indicators of air pollution than quantitative chemical measurements made at a particular time. Because of the slow-growth and long-lived habit of lichens, the existing lichen communities in an area can be considered to be more or less in equilibrium with their environment. The literature provides a clear estimate of both the potential for and the limitations involved in using lichens as pollution indicators.

Table 1. *Biological indicators of SO_2 air pollution*

Annual average concentration of SO_2	Lichens: Acid stonework	Lichens: Boles of vertical deciduous trees	Lichens: Old asbestos roofs or calc. stonework	Bryophtes: Dry, mortared acid stonework	Bryophtes: Boles of vertical deciduous trees	Bryophtes: Old asbestos roofs or calc. stonework
> *c.* 170 µg/m³	None; the alga *Pleurococcus viridis* may be present		*Lecanorion dispersae*, two to four (five) spp.	*Funaria hygrometrica Tortula muralis* p.n. five to six spp., short turf growth forms predominate; usually on old mortar	None	Variable cover of *Ceratodon–Bryum argenteum* p.n.
c. 125 µg/m³	*Conizaeoidion* 5–40% cover, especially on gently sloping horizontal surfaces	*Conizaeoidion* 5–20% cover, especially on buttresses and the upper side of slightly leaning trunks	*Lecanorion dispersae* joined by low cover of two to three foliose or lobate spp. especially on ridge and edges of roof	As above	None	Patches of *Bryum capillare–Tortula muralis* p.n. start to appear
c. 60–65 µg/m³	*Conizaeoidion* joined by *Parmelia* and white often sterile crustaceous spp.; *Acarospora fuscata* often present	*Conizaeoidion* abundant	*Xanthorion*, foliose and lobate spp. becoming abundant all over roof	The above assemblage plus? *Barbula* sp.; predominant growth form now small or large cushion; no pleurocarps	None	*Grimmia pulvinata* appears in small amounts; usually sterile
c. 45 µg/m³	Diversity increasing, *Lecanora conizaeoides* decreasing	*Conizaeoidion* very abundant; thallus thick, continuous and luxuriant	*Xanthorion*, *c.* twelve spp. present	First apperance of many common wall top bryophtes; *Grimmia* spp. *Hypnum cupressiforme*, *Camptothecium sericeum*	None	Patches of *Orthotrichum–Grimmia pulvinata* p.n., start to appear; *c.* six spp.; short turf and small cushion growth forms only
40 µg/m³	Several foliose lichens; *Cladonia* spp. may be common; many lichens with well-developed fruit bodies	*Lecanora conizaeoides* still abundant but at least two foliose (or *Pertusaria*) spp. at breast height; *Buellia puncata* usually present	*Xanthorion*, increasing diversity	Increasing diversity, cover and luxuriance	*Dicranoweisia cirrata Hypnum cupressiforme* on buttresses and the upper side of leaning trunks	First appearance of pleurocarps
Relatively pure air	Diversity increasing; luxuriance increasing; *Lecanora conizaeoides* rare or absent	Fruticose lichens well developed; members of the Graphidales and Caliciaceae often present; *Lecanora conizaeoides* rare–absent	*Xanthorion*, up to twenty spp./roof	Diversity increasing to include leafy liverworts and tall turfs	*Tortulion laevipilae*, pleurocarps, liverworts and *Orthotrichum* spp. on trunks at breast height	*c.* Twelve spp. on gently sloping roofs; luxuriant growth forms including large cushions

APPENDIX B

Table 1. QUALITATIVE SCALE FOR THE ESTIMATION OF AIR POLLUTION IN ENGLAND AND WALES USING LICHENS EPIPHYTIC ON NON-EUTROPHIATED BARK

Zone		SO_2 ($\mu g/m^3$)
0	Epiphytes absent	?
1	*Pleurococcus viridis* s.l. present but confined to the base	>170
2	*Pleurococcus viridis* s.l. extends up the trunk: *Lecanora conizaeoides* present but confined to the bases	About 150
3	*Lecanora conizaeoides* extends up the trunk; *Lepraria incana* becomes frequent on the bases	About 125
4	*Hypogymnia physodes* and/or *Parmelia saxatilis*, or *P. sulcata* appear on the bases but do not extend up the trunks. *Lecidea scalaris*, *Lecanora expallens* and *Chaenotheca ferruginea*, often present	About 70
5	*Hypogymnia physodes* or *P. saxatalis* extends up the trunk to 2·5 m or more; *P. glabratula*, *P. subrudecta*, *Parmeliopsis ambigua* and *Lecanora chlarotera* appear; *Calicium viride*, *Lepraria candelaris*, *Pertusaria amara* may occur; *Ramalina farinacea* and *Evernia prunastri* if present largely confined to the bases; *Platismatia glauca* may be present on horizontal branches	About 60
6	*P. caperata* present at least on the base; rich in species of *Pertusaria* (e.g., *P. albescens*, *P. hymenea*) and *Parmelia* (e.g., *P. revoluta* (except in NE), *P. tiliacea*, *P. exasperatula* (in N)); *Graphis elegans* appearing; *Pseudevernia furfuracea* and *Alectoria fuscescens* present in upland areas	About 50
7	*Parmelia caperata*, *P. revoluta* (except in NE), *P. tiliacea*, *P. exasperatula* (in N) extend up the trunk; *Usnea subfloridana*, *Pertusaria hemisphaerica*, *Rinodina roboris* (in S) and *Arthonia impolita* (in E) appear	About 40
8	*Usnea ceratina*, *Parmelia perlata* or *P. reticulata* (S and W) appear; *Rinodina roboris* extends up the trunk (in S); *Normandina pulchella* and *U. rubiginea* (in S) usually present	About 35
9	*Lobaria pulmonaria*, *L. amplissima*, *Pachyphiale cornea*, *Dimerella lutea*, or *Usnea florida* present; if these absent crustose flora well developed with often more than 25 species on larger well lit trees	Under 30
10	*L. amplissima*, *L. scrobiculata*, *Sticta limbata*, *Pannaria* spp., *Usnea articulata*, *U. filipendula* or *Teloschistes flavicans* present to locally abundant	"Pure"

See text for explanation.

Table 2. COMMUNITIES PRESENT ON EUTROPHIATED BARK AND THE ZONES IN TABLE 1 TO WHICH THEY CORRESPOND

Zone	
0	Epiphytes absent
1	*Pleurococcus viridis* s.l. extends up the trunk
2	*Lecanora conizaeoides* abundant; *L. expallens* occurs occasionally on the bases
3	*Lecanora expallens* and *Buellia punctata* abundant; *B. canescens* appears
4	*Buellia canescens* common; *Physcia adscendens* and *Xanthoria parietina* appear on the bases; *Physcia tribacia* appears in S
5	*Physconia grisea*, *P. farrea*, *Buellia alboatra*, *Physcia orbicularis*, *P. tenella*, *Ramalina farinacea*, *Haematomma coccineum* var. *porphyrium*, *Schismatomma decolorans*, *Xanthoria candelaria*, *Opegrapha varia* and *O. vulgata* appear; *Buellia canescens* and *X. parietina* common; *Parmelia acetabulum* appears in E
6	*Pertusaria albescens*, *Physconia pulverulenta*, *Physciopsis adglutinata*, *Arthopyrenia alba*, *Caloplaca luteoalba*, *Xanthoria polycarpa*, and *Lecania cyrtella* appear; *Physconia grisea*, *Physcia orbicularis*, *Opegrapha varia* and *O. vulgata* become abundant
7	*Physcia aipolia*, *Anaptychia ciliaris*, *Bacidia rubella*, *Ramalina fastigiata*, *Candelaria concolor* and *Arthopyrenia biformis* appear
8	*Physcia aipolia* abundant; *Anaptychia ciliaris* occurs in fruit; *Parmelia perlata*, *P. reticulata* (in S and W), *Gyalecta flotowii*, *Ramalina obtusata*, *R. pollinaria*, and *Desmaziera evernioides* appear
9	*Ramalina calicaris*, *R. fraxinea*, *R. subfarinacea*, *Physcia leptalea*, *Caloplaca aurantiaca*, and *C. cerina* appear
10	As 9

See text for explanation.

APPENDIX C

Table III

List Of The Lichens Involved In The Study Of The Effects Of The Allen S. King Generating Plant On The Environment

LOCATION & MARKER		HOST TREE	SPECIES OF LICHEN
Monitor #1	1	Pin Oak	Parmelia bolliana Müll. Arg.
Carlson Bros.	11	Elm	Physcia stellaris (L) Nyl.
Square Lake	10(20)	Bur Oak	Physcia grisea (Lam.) Zahlhr.
Monitor #4	4	Pin Oak	Parmelia bolliana Müll. Arg.
Monitor #5	5	Bur Oak	Physcia stellaris (L) Nyl.
Monitor #3	23	Bur Oak	Xanthoria fallax (Hepp) Arn.
Monitor #6	33	Pin Oak	Parmelia rudecta Ach.
Monitor #6	16	Pin Oak	Parmelia caperata (L) Ach.
Monitor #7	17	Elm	Physcia stellaris (L) Nyl.
Monitor #8	18	Pin Oak	Physcia stellaris (L) Nyl.
Monitor #9	19	Elm	Physcia stellaris (L) Nyl.
Monitor #1	28	Pin Oak	Physcia aipolia (Ehrh.) Hampe
Monitor #2	27	American Elm	Physcia stellaris (L) Nyl.
Monitor #3	29&30	Bur Oak	Parmelia bolliana Müll. Arg.
Monitor #4	31	Red Oak	Parmelia bolliana Müll. Arg.
Monitor #5	34	Bur Oak	Physcia millegrana (+ Xanthoria fallax (Hepp) Arn.)
Monitor #6	33	Pin Oak	Parmelia bolliana Müll. Arg. (+ Physcia millegrana) (+ Physcia aipolia) (+ Parmelia caperata)
Monitor #7	36	American Elm	Xanthoria fallax (Hepp) Arm. (+ Physcia orbicularis (Neck) Poetsch) (+ Physcia stellaris (l) Nyl.)
Monitor #8	32	Pin Oak	Physcia stellaris (L) Nyl.
Monitor #9	26	American Elm	Physcia stellaris (L) Nyl.
Afton Coulee Ridge	40	Basswood	Physcia stellaris (L) Nyl.

Table IV

List Of Lichen Species In Control Plots In Fair Haven Woods, Stearns County, Minnesota For Comparison With The King Study

MARKER	HOST TREE	SPECIES
8	Basswood	Xanthoria polycarpa (Ehrh.) Olij.
25 A	Basswood	Physcia aipolia (Ehrh.) Hampe
25 B	Basswood	Physcia orbicularis (Neck.) Poetsch
25 C	Basswood	Xanthoria polycarpa (Ehrh.) Olij.
37	Red Oak	Physcia stellaris (L) Nyl.
38 A	Basswood	Physcia orbicularis (Neck.) Poetsch
38 B	Basswood	Caloplaca cesina (Ehrh.) Th. Fr.
38C	Basswood	Xanthoria polycarpa (Ehrh.) Olij.
43	Cherry	Physcia stellaris (L) Nyl.
44 A	Basswood	Physcia ciliata (Hiffm.) Dr.
44 B	Basswood	Zanthoria fallax (Hepp) Arn.
45	Basswood	Parmelia bolliana Mull. Arg.
46	Basswood	Physcia stellaris (L.) Nyl.
47 A	Ash	Xanthoria fallax (Hepp) Arn. Candelaria concolor (Dichs) Arn.
47 B	Ash	Physcia orbicularis (Neck) Poetsch
48	Basswood	Physcia ciliata (Hoffm.) Dr. f. fibrillosa Thoms.

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