LICHENS AND AIR QUALITY
IN WILDERNESS AREAS IN CALIFORNIA:
A SERIES OF BASELINE STUDIES

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INTRODUCTION

Numerous studies in various parts of the world have established that lichens are useful bioindicators of air pollution, as reviewed by Nash & Wirth (1988). Most of these studies have been either field studies around major urban centers or known point sources of specific pollutants. A wide variety of approaches, many of which combine data on lichen distribution with data on actual measurements of pollutant concentrations in the air and in the lichens themselves, have been used. Many studies have been experimental in nature, using fumigation or transplants.

In areas where extensive and detailed historical records are available, as in Europe and a few parts of North America, re-studying those areas has often shown changes in the lichen flora that can be correlated with changes in pollution levels. In most parts of the United States, such historical records are not available. However, an increasing number of studies have begun to collect baseline field data in National Parks and other non-urban areas for the purpose of being able to follow future changes in air quality in those areas. The present studies are part of a series of baseline studies on lichens and air quality in Class I Wildernesses in California that are managed by the U.S. Forest Service Region 5.

BACKGROUND

Only a few previous studies have focused on lichens in California. Floristic studies have been made for Sequoia and Kings Canyon National Parks (Smith, 1980), The San Joaquin Experimental Forest (Hebert & Meyer, 1984), Sequoia National Park (Wetmore, 1985) and the Eastern Brook Lakes Watershed (Ryan & Nash, in prep.). Some general impressions on the present occurrence of lichens particularly foliose and fruticose kinds) in California is available from the recently published popular treatment by Hale & Cole (1989). The earliest lichen collections in California were made by Bolander and others in the middle to late 1800’s (Tuckerman, 1882). Detailed floristic treatments and keys were published for southern California by Hasse (1913) and for the Santa Cruz Peninsula by Herre (1910), and a catalog of the lichens of the state (with an extensive bibliography) was published by Tucker & Jordan (1979). However, little published information on the past distribution and relative abundance of species in most areas of the state is available for comparisons.

Thus the primary purpose of the present series of investigations into lichens in California wildernesses is to provide baseline data that can be used for future monitoring of air quality. In the case of the San Gabriel Wilderness, some general conclusions about pollution impacts that have already occurred have been made. Data and conclusions for the individual wildernesses are presented in a series of separate reports; the present report presents information applicable to more than one wilderness, and makes some comparisons among the wildernesses.

COMPARISON OF STUDY AREAS

The locations of the wildernesses investigated in this study are shown in Fig. 1. In order to compare the lichen vegetation of the different wildernesses, a brief comparison of the environmental conditions found in these wildernesses is needed.

Substrates and Habitats for Lichens

All of the rocks in the Wilderness areas studied are siliceous, and most are granitic or other types of metamorphic rocks, although volcanic rocks occur in a few parts of the Emigrant Wilderness, and ultramafic (serpentine) rocks are found in the Marble Mountain Wilderness.

The vascular vegetation, including the dominant trees or shrubs that are available as substrates for lichens, varies considerably among the wildernesses. Pines (*Pinus*) and Firs (*Abies*) occur in all of them, and Oaks (*Quercus*) occur in all but the Desolation Wilderness. Junipers (*Juniperus*) are an important substrate in the Desolation Wilderness, while Alders (*Alnus*) are important tree species in parts of the Marble Mountain Wilderness. Chaparral shrubs dominate parts of the southern wildernesses.

These differences in vascular vegetation partly reflect other differences among the wildernesses, especially in temperature and moisture conditions, which in turn are affected by the elevation and geographical locations. The northernmost wilderness (Marble Mountain) experiences the coldest average temperatures and highest annual precipitation of the wildernesses investigated in this study. The San Gabriel and Agua Tibia wildernesses, located in the southern end of the state and occurring partly at fairly low elevations (down to about 500 m) are warmer than the other wildernesses studied, and, in contrast to the wildernesses in the Sierras (Desolation and Emigrant), receive less annual precipitation but more of it in the form of rain (or fog) rather than snow. The Sierran wildernesses occur primarily above 2000 m, whereas the others occur mainly or entirely below 2000 m.

Exposure to Pollution

The San Gabriel Wilderness, located close to the Los Angeles urban area, obviously experiences the high levels of pollution. Air pollution impacts in most of the other wildernesses are most likely to be chronic low-level effects of acid precipitation and oxidant pollution originating primarily from major urban centers mostly on the California coast. Some localized effects from the cities and roads can also be expected.

METHODS

The methods used in this study are based on those in the October 17, 1988 draft Lichen Monitoring Protocol for U.S. Forest Service Region 5, with some modifications as described below. Due to time limitations, no transplant experiments were attempted, and most of the emphasis in the field work during the 1989 field season was on the floristic survey.

Floristic Survey

A total of over 3000 lichen specimens were collected in various localities within and adjacent to the the wildernesses. Many more specimens were also collected from other areas of California during the summer and fall of 1989. Within each wilderness, efforts were made to sample as wide a range of elevations and habitat types as feasible, and to represent different major parts of the area. The specimens will be deposited in the herbarium at Arizona State University (ASU); whenever possible, sufficient material was collected so that duplicates can be sent to the individual Forest Service offices. The collections made from the San Gabriel Wilderness by M. Neel are also being deposited at ASU.

The nomenclature of the lichen species listed in the reports generally follows that of Egan (1987). Although considerable time and effort has been expended in identification of the taxa, and the species lists presented at this time are probably 80 to 90% complete, some of the determinations are necessarily somewhat tentative, due to the lack of adequate keys, descriptions, and authentic comparison material for many of the genera. In particular, the common and species-rich crustose genera, especially *Aspicilia*, *Lecanora*, and *Lecidea*, and few of the common macrolichen genera, especially *Bryoria*, *Cladonia* and *Physcia*, are quite challenging. Following the common practice in lichenological work, expression "cf." has been used to indicate identifications that are very tentative. However, for the purposes of these studies, emphasis must be placed on taxa that can be identified (at least to genus) with relative ease.

Semi-technical keys to the lichens of each wilderness, emphasizing field recognition characters are being prepared, to facilitate identification of at least the more conspicuous and distinctive taxa that are potentially most useful for pollution monitoring; these keys will be made available separately to Forest Service personnel in the future, as feasible.

Long Term Monitoring

Only a very limited number of permanent plots were established during the summer of 1989, mostly in the Desolation and Emigrant Wldernesses. These plots were of two kinds, as described below. Recommendations for future establishment of plots are made in this report and in the individual reports.

1. Transects on Trees. Only the "short transects", using the "dotiometer" described in the protocol were established in 1989.

2. Quadrats on Rock. It was found that a camera with a 28 mm lens provided the appropriate size field of view when the "quadpod" was used. The quadpod set-up was not entirely satisfactory, and several improvements are now being incorporated into it (Bob Doty, pers. comm.).

A separate critique of the existing protocol, with suggestions for improvements based on the experience of trying to use it in these studies has been submitted to the Region 5 office of the Forest Service.

The original data sheets and photographs are deposited at the offices of the Forests responsible for the particular Wilderness areas.

Element Analyses

A very limited number of samples of various lichens (mostly Letharia spp.) were collected from one or more localities in each wilderness, and have been sent to Dr. Phil Rundel at UCLA or element analysis. The results of these analyses will be presented in a supplemental report after they become available.

Laboratory Work

Specimens from the floristic survey were curated in paper packets, examined with a dissecting microscope and, when necessary, with a compound microscope, for identification. For some genera (e.g., Xanthoparmelia), secondary chemical constituents were analyzed by thin-layer chromatography.

RESULTS AND DISCUSSION

Species Composition of Lichens in the Various wildernesses

Aside from taxonomical uncertainties, comparisons of the lichen floras of the different wilderness is hampered by differences in the inclusion of species from areas adjacent to but outside of the boundaries, the size of the wildernesses and the thoroughness of the explorations made for lichens. Thus the species list for the San Gabriel Wilderness is inflated, while the lists for the others are probably underestimates, due to the inaccessibility of many areas. However, keeping these problems in mind, it is still possible to make rough comparisons of the minimum total species richness of the lichen floras in the wildernesses and the relative composition in terms of major growth forms and predominant taxa (note: in these comparisons, squamulose species are treated as crustose; species of the crustose genera *Aspicilia*, *Lecanora*, and *Lecidea* sensu lato are numerous in all of the Wildernesses).

Marble Mountain wilderness: 170+ species (15+ fruticose -- mostly species of *Cladonia* and *Bryoria*; 55+ foliose--mostly species of *Melanelia*, *Parmelia*, *Peltigera* and *Physcia*; 100+ crustose-- especially rich in species of *Caloplaca* and *Rhizocarpon*).

San Gabriel Wilderness: 155+ species" (9+ fruticose--mostly Cladonia spp.; 50+ foliose--mostly species of *Physcia* sensu lato, *Umbilicaria* and *Xanthoparmelia*; 94+ crustose--especially rich in species of *Acarospora*, *Caloplaca* and *Rhizocarpon*).

Emigrant Wilderness: 90+ species (7 fruticose; 30+ foliose-- mostly species of *Physcia* and *Umbilicaria*; 53+ crustose--rich in species of *Caloplaca* and *Rhizocarpon*).

Desolation Wilderness: 90+ species (6+ fruticose; 20+ foliose-- mostly *Umbilicaria* spp.; 64+ crustose--rich in *Rhizocarpon* *spp*.).

Agua Tibia Wilderness: 90+ species (6 fruticose; 40+ foliose-- mostly species of *Physcia* sensu lato and *Xanthoparmelia*; 44 crustose--rich in *Caloplaca* spp.).

Distribution of Major Lichen Taxa Among the Wildernesses

As discussed below, many of the same lichen species were found in all of the wildernesses studied, but other taxa were more restricted in distribution.

Species on bark or wood

Probably the greatest variation among the lichen floras of the different wildernesses was in the corticolous or 1ignicolous species, especially the macrolichens (foliose and fruticose taxa).

Only a few taxa on bark or wood, such as Hypogymnia imshaugii and Letharia spp., occurred in all the wildernesses, but were more abundant and better developed in the northern ones. A greater diversity of Hypogymnia species occurred in the Marble Mountain Wilderness than in the others.

Bryoria abbreviata was found in the three northern wildernesses, but only the Marble Mountain wilderness had a rich and abundant flora of Bryoria species. with the exception of a single thallus found in the Desolation Wilderness, the genus Usnea was found only in the Marble Mountain wilderness. Quite a few other macrolichens were found in the Marble Mountain Wilderness but not in the others: Alectoria spp., Esslingeriana idahoensis, Lobaria linita, Nephroma spp., and Pseudocyphellaria spp. The genus Tuckermannopsis was also best developed in the Marble Mountain Wilderness. All of these are taxa that are best developed from northern California to the Pacific Northwest, and their absence from the southern wildernesses is not surprizing.

Species of Melanelia occurred in all the wildernesses, but M. glabra and M. subolivacea were dominant lichens only in the two southern ones. Likewise, species of Physcia sensu lato were best developed on trees in the San Gabriel and Agua Tibia wildernesses, and Candelaria concolor was found only in those two wildernesses, where it was fairly frequent.

Evernia prunastri and Platismatia glauca were found only In the Marble Mountain and Agua Tibia wildernesses, but were not common in either. Ahtiana sphaerosporella, a species with northwestern affinities, was found only in the Desolation Wilderness.

Comparisons among the crustose lichens on bark or wood are hampered at present by difficulties in identification of species, but it can be stated that, as might be expected, species of the large genera Lecanora, and Lecidea sensu lato were common on trees in all the wildernesses, while other genera, such as Calicium, Cyphelium, and Ochrolechia were more restricted in distribution.

Species on soil or moss

Of the terricolous or muscicolous species, the Cladonia chlorophaea complex, Lepraria spp., and Leptogium californicum occurred in all the wildernesses, while Leptochidium albociliatum and Peltigera rufescens occurred in all but one. The genus Peltigera was more diversely represented in the Marble Mountain, San Gabriel and Agua Tibia wildernesses than in the Sierran sites, while Cladonia was perhaps best represented in the Marble Mountain Wilderness. Trapeliopsis wallrothii was found only in the San Gabriel wilderness, although it was also abundant in areas adjacent to the Marble Mountain Wilderness.

Species on rock

A large portion of the species found on rock occurred in all or almost all of the wildernesses. This includes the crustose taxa Aspicilia caesiocinerea and related species, Candelariella spp., the Lecidea atrobrunnea complex, Rhizocarpon bolanderi, the U. geographicum complex, and the foliose species Umbilicaria phaea.

Acarospora chlorophana, Dermatocarpon miniarum, Lecanora polytropa and L. sierrae were found in all but the Agua Tibia Wilderness. Lecanora semitensis was found in all but the San Gabriel Wilderness.

The fruticose genus Pseudephebe, the foliose genus Umbilicaria (other than U. phaea}, and the crustose species Dimelaena thysanota were best represented in the San Gabriel Wilderness and the two Sierran wildernesses, while Xanthoparmelia was abundant and diverse only in the southernmost two wildernesses. The foliose genus Parmelia (sensu stricto) was best developed in the Marble Mountain Wilderness.

Bellmerea spp. were found only in the three northern wildernesses. Lecanora "pseudomellea" was found only in the two Sierran Wildernesses, while tbe true L. mellea occurred in the two southern wildernesses and at low elevation sites outside the Emigrant and Marble Mountain wildernesses.

Abundance and Condition of Lichens in the wildernesses
Definite differences in the abundance, evenness of the species diversity, and types of distribution patterns of the lichens were found among the wildernesses.

In the most of the wildernesses, coniferous or other softwood trees were frequently either covered heavily and almost exclusively by Letharia spp., or else fairly barren of lichens, especially at the higher elevations where oaks or other hardwoods were present, the lichen flora was usually more diverse, but fairly uniform over large areas of the wilderness. In the San Gabriel Wilderness, conifers were quite frequently barren of lichens, and oaks were either barren or, in more protected sites, dominated by *Melanelia* spp. By contrast, in the Marble Mountain Wilderness, both softwood and hardwood trees usually had heavy and diverse lichen coverage, which varied considerably in composition depending on the kind of trees and the habitat conditions in different parts of the wilderness.

In all of the wildernesses, the lichen vegetation on soil or moss was rather spottily distributed and dependent on the availability of suitable (usually moist) microhabitat conditions, which were fairly rare except in the Marble Mountain Wilderness.

The vegetation on rocks was much more widespread in occurrence, usually with relatively few species dominant in a given area, but with various richer assemblages of taxa in particular habitats. In the Sierran and southern wildernesses, the lichen vegetation was best developed on the relatively few large outcrops in moist or shaded habitats, whereas in the Marble Mountain wilderness, the rocks in more exposed sites had the most luxuriant and diversified floras.

With the exception of atypical specimens of a few taxa (especially *Hypogymnia* *imshaugii*) in the Agua Tibia and Sierran wildernesses, obvious signs of damage or degeneration or reduced abundance or fertility that might be attributable to air pollution were observed only in the San Gabriel Wilderness, as described in that report.

The total lichen flora found in the San Gabriel Wilderness and vicinity in this study and that of Neel (1987) is rather large and diverse in comparison to that found in most of the other wildernesses we examined in 1989 (other than Marble Mountain). This may be partly a reflection of the greater thoroughness with which this wilderness was surveyed, and of the inclusion of a number of species from adjacent areas.

Several of the sites in the San Gabriel Wilderness, along the edge of the Wilderness (especially 5, 24 and 25) or near the wilderness (especially 3 and 8) exhibited well developed lichen vegetation (fairly high cover and diversity). However, as in most of the other wildernesses examined, much of this diversity and cover consists of crustose species, and species on rocks rather than trees.

Although several of the sites in the San Gabriel Wilderness did have a relatively high diversity and cover of lichens on bark, this was mostly on hardwood trees (especially Oaks), which throughout much of California have a richer lichen flora than conifers (which are frequently either mostly barren or covered mainly by a few dominant taxa, often *Letharia* spp.). Much of the San Gabriel W1ilderness is at fairly low elevations, where oaks are among the dominant trees. In contrast, the wildernesses in the Sierra Nevada and Klamath Mountains are mostly at high elevations, where conifers predominate, and the lichen flora on bark was often found to be richer at lower elevations outside those wildernesses.

Contrasting with the "rich" sites in the San Gabriel wilderness and vicinity are the numerous sites where even the lichen vegetation on rocks was impoverished or absent. The poor development of the lichens in dry, exposed sites, or the restriction of most lichens at some sites to certain habitats, may partly reflect a situation due to "natural" causes, but there are other possible explanations. Habitats that are more “sheltered” against heat and drought may also be less exposed to air pollution. Also, if the lichens are being stressed by air pollution, they may survive better in habitats that are more optimal for their growth, rather that in “marginal” habitats where they might otherwise be able to grow.

Beyond these comments on diversity and cover, it must be remembered that even in those sites in the San Gabriel wilderness where the lichen vegetation appears to be well developed, obvious signs of deterioration in the condition of the lichens were observed. It must also be emphasized that comparison of the present lichen vegetation with historical information indicates definite losses of diversity and decreases in the abundance and healthiness of the lichens in the general area around the San Gabriel Wilderness.

CONCLUSIONS

Although many of the same species or genera of lichens occur in all of the wildernesses examined, there are major differences in the lichen vegetation among the different wildernesses, many of which can be attributed to differences in natural environmental factors. Definite evidence of the effects of air pollution on the lichens is presently seen only in the San Gabriel Wilderness. The data presented in this study will allow future monitoring of the lichens in relation to air quality in all of the wildernesses studied.

Recommendations for Future Long-Term Monitoring

Specific suggestions for future long-term monitoring are given in each of the separate reports. In general, plots should be established wherever suitable quantities of relatively easy-to-recognize species occur. Although it is desirable to use species of known sensitivity, the present lack of sufficient information on many species makes this difficult in many cases. A preliminary listing of the pollution sensitivities of species found in one or more of the wilderness areas is given in Appendix A.

Further recommendations for establishment of plots are given in the separate critique of the protocol. In addition to establishing more plots and sampling more lichens for element analyses in the various wildernesses, transplant experiments are highly recommended. Lichens from the San Gabriel Wilderness can be transplanted to the other, presumably less polluted, wildernesses, and vice-versa, keeping in mind the need to keep the natural features of the habitat similar. Transplants between the Agua Tibia Wilderness and the others may provide information on recovery after fire. Transplants between the Marble Mountain Wilderness and the two wildernesses in the Sierras may also yield interesting results.

It must be remembered that all of these monitoring programs are long-range projects, which may not yield usable results for quite a few years, due to the slow growth of most lichen species (especially crustose ones), but the results are potentially quite valuable.

Ecological/Economic Significance of the Lichens

The significance of the past and potential decrease in the abundance and diversity of lichens in the San Gabriel Wilderness and surrounding areas can be considered from several perspectives. From the economic perspective, the lichens found in the California wildernesses have few direct uses by man, and no major applications at present. The two *Letharia* species are sometimes used in crafts and in dyeing wool, and *Umbilicaria* species are also likely to be used as a source of dyes; both of these genera are common in all of the wildernesses. *Lecanora sierrae*, common in several of the wildernesses, has been proposed as an aid for locating mining sites, since it turns from yellowish to deep blue-green in the presence of copper. Although many lichens are known to produce antibiotic substances, this has yet to be exploited to any significant degree, at least in the United States.

The application of lichens to various fields of science other than biology has also been limited, but a few taxa, especially the yellow *Rhizocarpon* species, have been used, in some parts of the Sierras, for lichenometry (dating of rock surfaces in relation to glaciation).

Another point of view is that of scientific (taxonomical) interest and concern for the preservation of biological diversity. Most of the lichen species presently identified from the wilderness areas are common over large areas of California or western North America in general. However, one distinctive species (*Rhizoplaca glaucophana*, found only at one site several miles outside the boundary of the San Gabriel Wilderness) is endemic to California and only known from a few scattered localities around the state. Several taxa in the Marble Mountain Wilderness (e.g., species of Lecanora, Parmeliella and Pseudocyphellaria) appear to be undescribed, or at least not previously known from North America, and others in nearby areas (e.g., Umbilicaria coccinea var. phaea) appear to be endemic to a narrow area in northern California. Vestergrenopsis elaeina, found in or near several of the wildernesses, *is* a primarily Arctic species that has apparently not been reported from California previously. Another species (Xanthoparmelia pertinax, found within the Agua Tibia and San Gabriel Wildernesses) has previously been known only from Australia, and has so far been found in North America only at a few localities in southern California during this study in 1989.

Another perspective is that of concern for the functioning of the ecosystem. The main ecological significance of lichens in the Wildernesses is likely to be in the production or stabilization of soil. However, various taxa contain a cyanobacterial photobiont and thus are potential. nitrogen fixers: members of the genera Collema, Leptochidium, Leptogium, Lobaria, Nephroma, Pannaria, Parmeliella, Placynthium, Polychidium, Pseudocyphellaria and Vestergronopsis. Except for Leptochidium, Leptogium and Peltigera, those "cyanolichens" were absent or fairly rare except in parts of the Marble Mountain Wilderness. Many lichens provide habitats or food for invertebrates; a few kinds, especially large fruticose taxa (e.g., Usnea and other genera found in the Marble Mountain Wilderness) may provide a food source for deer or other higher animals.

The last (and perhaps most crucial) way of looking at the significance of the lichens is by seeing them as indicators of the environmental conditions. Impoverishment and deterioration of the lichen vegetation provides a warning that other parts of the ecosystem may also be endangered.

Figure 1. Map of California showing the locations of the five wildernesses surveyed in 1989.

APPENDIX A:

POLLUTION SENSITIVITY

There is information on the pollution sensitivity of only a relatively limited number of the lichen taxa found in the Wildernesses. Many of the lichens in these wildernesses are saxicolous crustose taxa, on which few previous studies have been done. According to Hale (1982), saxicolous taxa, and crustose taxa in general, are likely to be fairly tolerant to pollution.

The notes below summarize what can presently be said about the pollution sensitivity of lichens in the wildernesses. With a few exceptions, the sensitivities attributed to these species are based on floristic studies which have not yet been confirmed by either transplant experiments or fumigation studies. Reports based on fumigation experiments are indicated by asterisks (*).

The sensitivity ratings are used below only as rough indications of the relative sensitivities expected. Although some of the cited authors, including Wetmore, have correlated their rating systems to particular concentrations of pollutants, the criteria and conditions used in the various studies are quite variable. Some authors, such as Hale (1982), did not explain the basis for their ratings. It should also be noted that sensitivity is frequently inferred on the basis of patterns observed in the field. Even where these patterns correspond to known pollutant gradients, the factors to which an apparently sensitive species responds cannot be known absolutely. Transplant experiments and much more extensive fumigation work with different air pollutants and the species found in this study are necessary.

Sensitivity to Sulphur Dioxide

The major focus of most previous lichen/pollution studies has been on sulphur dioxide. The sensitivities of the following species are rated according to the system of Wetmore (1985): S = sensitive, I = intermediate, T = tolerant.

S   *Acarospora chlorophana*--Hale (1982).
T   *Aspicilia caesiocinerea*--Hale (1982).
S   *Bryoria capillaris*--Follman (1973).
I   *Bryoria fuscescens*--Wetmore (1985, 1987); Hawksworth & Rose (1970); Wirth & Turk (1975*).
S   *Bryoria glabra*--Skorepa & Vitt (1976).
S   *Bryoria trichooes* subsp. *americana*--LeBlanc & Rao (1975).
T   *Buellia punctata*--Wetmore (1985, 1987, 1988); Gilbert (1973); Johnsen & Sochting (1973), DeSloover & LeBlanc (1968), DeWit (1916), Windler (1977).

I   _Calicium_ _viride_--Wetmore (1985). Somewhat tolerant (Zone 2) according to Hawksworth & Rose (1970).

S-I   _Caloplaca_ _cerina_--Wetmore (1985, 1987, 1988); Hawksworth & Rose (1970); LeBlanc & Rao (1975).

S-I   _Candelaria_ _concolor_--Wetmore (1985, 1987, 1988); Hawksworth & Rose (1970), Skye (1968*).

I   _Candelariella_ _vitellina_--Wetmore (1985, 1987, 1988); DeSloover & LeBlanc (1968). Some reports (e.g., Follman, 1973; LeBlanc & Rao, 1975) treat this species among the more tolerant ones; other reports (e.g., Seitz, 1972) treat it as a relatively sensitive species.

I?   _Chrysothrix_ _candelaris_--Somewhat tolerant according to Hawksworth & Rose (1970), but Skye (1968) found . it only in the "normal zone".

S-I   _Cladonia_ _fimbriata_--Wetmore (1985, 1987, 1988). LeBlanc & Rao (1975) placed this species in the most sensitive of their five sensitivity ranks.

I-S   _Evernia_ _prunastri_--Intermediate according to Wetmore (1985); DeSloover & LeBlanc (1968); and Baddeley, et al. (1973*). Hawksworth & Rose (1970) placed this species in Zone 2 (second most tolerant of their five ranks), but Wirth & Turk (1975*) gave this species the fumigation rank of 8 (most sensitive of the species they tested). Skye (1968*) and DeWit (1976) also treated it as sensitive.

S   _Flavopunctelia_ _flaventior_--Windler (1977).

I-T   _Hypocenomyce_ _scalaris_--Intermediate according to Wetmore (1985, 1987) and Seitz (1972). However, Hawksworth & Rose (1970) placed this species in Zone 2, the second most tolerant of their five ranks, and Skye (1968) reported that this species was restricted to the inner (most polluted) zone.

T   _Lecanora_ _muralis_--Wetmore (1985, 1987).

I   _Lecanora_ _saligna_--Wetmore (1985, 1987,1988). LeBlanc & Rao (1975) placed this species in the most tolerant of their five ranks.

T   _Lecidea_ _atrobrunnea_--Hale (1982).

S   _Lecidella_ _euphorea_—Skye (1968).

T   _Lepraria_ _incana_--Hawksworth & Rose (1970), LeBlanc & Rao (1975), Skye (1968), DeWit (1975), and many other reports.

T   _Letharia_ _vulpina_--Wetmore (1985).

I   _Melanelia_ _exasperatula_--Skye (1968); DeSloover & Leblanc (1968); Hawksworth & Rose (1970); LeBlanc & Rao (1975).

I   _Melanelia_ _fuliginosa_--Wetmore (1987); DeSloover & LeBlanc (1968); Hawksworth & Rose (1970); Jurging (1971). Skye (1968*) suggested that this species may be somewhat sensitive.

S   _Melanelia_ _subaurifera_--Wetmore (1985, 1988), Skye (1968*).

S   _Nephroma_ _parile_--Skye (1968) .

S   _Ochrolechia_ _androgyna_--Wetmore (1987).

I-T   _Parmelia_ _saxatilis_--Intermediate according to Wetmore

(1985, 1987). Some authors, including Hawksworth & Rose (1970), Seitz (1972), and Baddeley, et al. (1977*), regarded this species as moderately tolerant. Others, such as DeSloover & LeBlanc (1968), Wirth & Turk (1975*) and DeWit (1976) place this species somewhat closer to the sensitive end of the spectrum.

I? *Parmelia sulcata*--Intermediate to tolerant according to Wetmore (1985,1987, 1988); Hawksworth & Rose (1970), Johnsen & Sochting (1973), Wirth & Turk (1975*). LeBlanc & Rao (1975) treated this as a tolerant species. On the other hand, workers suggesting that it is fairly sensitive include Pisut (l962), Skye (1968*), DeWit (1976), Windler (1977) and Taylor & Bell (1983).

I *Parmeliopsis ambigua*--Intermediate according to Wetmore (1985, 1987). Hawksworth & Rose (1970) and LeBlanc & Rao (1975) place this species somewhat closer to the tolerant end of the spectrum, and Wetmore (1988) suggested that it may even be increasing in abundance in polluted areas. On the other hand, DeSloover & LeBlanc gave it a fairly high "toxiphoby" rating (9 or 10, with 12 being the most sensitive).

I *Parmeliopsis hyperopta*--Wetmore (1987).

T? *Peltigera canina*--Likely to be "least sensitive" according to Hale (1981), but found only in the "normal zone" according to Skye (1968).

I *Phaeophyscia orbicularis*--Intermediate according to Wetmore (1987), De Sloover & LeBlanc (1968), Johnsen & Sochting (1973). However, Pisut (1962), Seitz (1972) and Leblanc & Rao (1975) treated it as a fairly sensitive species.

S *Phlyctis argena*--Skye (1968*), DeWit (1976).

I *Physcia adscendens*--Wetmore (1985, 1988), DeSloover & LeBlanc (1968), Johnsen & Sochting (1973), Le Blanc & Rao (1975), Marti (1983*). Hawksworth & Rose (1970) put in in zone 2 (somewhat tolerant), while Seitz (1972) reported it from the "outer, less polluted zone."

I *Physcia aipolia*--Intermediate according to Wetmore (1985, 1987) and Hawksworth & Rose (1970), but DeSloover & LeBlanc (1968) and LeBlanc & Rao (1975) considered it somewhat sensitive.

I-S *Physcia caesia*--DeSloover & LeBlanc (1968).

T *Physcia dubia*--Wetmore (1985), Johnsen & Sochting (1973).

I *Physcia stellaris*--Wetmore (1985, 1987, 1988) , DeSloover & LeBlanc (1968), LeBlanc & Rao (1975), Marti (1983). Skye (1968) found it only in the "normal zone".

I *Physcia tenella*--Intermediate according to Wetmore (1985) and DeSloover & LeBlanc (1968). Seitz (1972) and DeWit (1976) treated it as a somewhat sensitive species; Hawksworth & Rose (1970) placed it in zone 2 (somewhat tolerant).

S *Physconia detersa*--LeBlanc & Rao (1975). Most North American reports on "*Physcia grisea*" are probably based on *P. detersa*.

S *Physconia distorta*--Johnsen & Sochting (1973).

S *Physconia enteroxantha*--Skye (1968*).

I Platismatia glauca--Intermediate according to Wetmore (1985). DeSloover & LeBlanc (1968) and Jurging (1971) treat this as a fairly sensitive species, but Skye (1968), Hawksworth & Rose (1970) and Baddeley, et al. (1973*) treat it as moderately tolerant.

T Rhizocarpon geographicum--Ranft (1971) ("a widespread smoke species").

S Rhizoplaca chrysoleuca--Hale (1982).

S Rhizoplaca melanophthalma--Hale (1982).

I Trapeliopsis granulosa--De wit (1976).

S Tuckermannopsis chlorophylla--Wetmore (1985), Ranft (1971), DeSloover & LeBlanc (1968).

I Umbilicaria polyphylla--Ranft (1971).

S-I Usnea filipendula--Wetmore (1987); DeSLoover & LeBlanc (1968), Hawksworth & Rose (1970), Marti (1983*).

S Xanthoparmelia cumberlandia--Hale (1981).

I Xanthoria candelaria--Wetmore (1985); DeSloover & LeBlanc (1968). Hawksworth & Rose (1970) placed this species in Zone 2 (somewhat tolerant).

S Xanthoria elegans--Hale (1981).

S-I Xanthoria fallax--Wetmore (1985, 1987, 1988); DeSloover & LeBlanc (1968). Both Marti (1983*) and LeBlanc & Rao (1975) placed this species in the most sensitive of their five ranks, and Skye (1968*) also considered it sensitive.

I Xanthoria polycarpa--Intermediate according to Wetmore (1985, 1987, 1988); Skye (1968); and Hawksworth & Rose (1970). However, LeBlanc & Rao ranked this species as 5 (most sensitive), and DeSloover & LeB1anc gave it a toxiphoby of 7 (fairly sensitive).

Sensitivity to Oxidants

The sensitivities of the following species to oxidants are ranked according to a modification of the system of Sigal & Nash (1983): S= very sensitive, S-I = sensitive, I-T = moderately tolerant, T = tolerant.

S Alectoria sarmentosa--Sigal & Nash (1983).

S Bryoria abbreviata--Sigal & Nash (1983).

S Bryoria fremontii--Siga1 & Nash (1983).

S Calicium viride--Siga1 & Nash (1983).

S-I Cladonia spp.--Sigal & Nash (1983).

S Collema nigrescens--Sigal & Nash (1983).

S Evernia prunastri--Siga1 & Nash (1983).

I-T Hypogymnia imshaugii--Sigal & Nash (1983) and Nash & Sigal (1979*, 1980*), all as “H. enteromorpha”.

S-I Leptogium ca1ifornicum--Sigal & Nash (1983).

T Letharia vulpina--Nash & Sigal (1980*); Siga1 & Nash (1983).

I-T Melane1ia elegantula--Sigal & Nash (1983).

I-T *Melanelia glabra*--Sigal & Nash (1983).
I-T *Me1ane1ia subolivacea*--Nash & Sigal (1980*); Siga1 & Nash (1983).
S *Parmelia sulcata*--Nash & Sigal (1979*, 1980*); Siga1 & Nash (1983).
S *Parmelina quercina*--Sigal & Nash (1983).
S *Peltigera canina*--Sigal & Nash (1983).
S-I *Peltigera rufescens*--Sigal & Nash (1983).
S *Phaeophyscia ciliata*--Sigal & Nash (1983) .
S *Phaeophyscia orbicu1aris*--Sigal & Nash (1983).
T *Physcia biziana*--Sigal & Nash (1983).
T *Physcia tenella*--Sigal & Nash (1983).
S *P1atismatia glauca*--Sigal & Nash (1983).
S *Pseudocyphellaria anthraspis*--Sigal & Nash (1983).
S *Rhizoplaca chrysoleuca*--Nash (1976) (NO2).
S *Tuckermannopsis canadensis*--Sigal & Nash (1983).
S-I *Tuckermannopsis merrillii*--Sigal & Nash (1983).
S *Usnea* spp.--Siga1 & Nash (1983).
S *Xanthoria candelaria*--Sigal & Nash (1983).
T *Xanthoria fa1lax*--Sigal & Nash (1983).
T-I *Xanthoria polycarpa*--Sigal & Nash (1983).

Sensitivity to Fluorides

T = tolerant, S = sensitive, I = intermediate.

T *Candelariella vitellina*--Perkins & Mi1lar (1987).
S *Lecanora polytropa*--Perkins & Millar (1987).
I *Melanelia fuliginosa*--Perkins & Millar (1987) .
I *Parmelia omphalodes*--Perkins & Millar (1987).
S *Parmelia sulcata*--Perkins & Millar (1987).
S *Rhizocarpon geographicum*--Martin & Jacquard (1968).

Other Species Likely to be Sensitive to Various Pollutants

Based on their growth forms or the known sensitivities of other members of the genus, several other species can be expected to be at least moderately sensitive to various pollutants:

Ahtiana sphaerosporella

Esslingeriana idahoensis

Lobaria linita--Other species of this genus are among the most sensitive lichens known, in relation to sulfur dioxide.

Nephroma spp.

Pseudephebe spp.--Observations made during the present study show that although P. minuscula is still abundant at one site in the San Gabriel Wilderness, thalli of this species there are damaged, presumably due to Oxidant pollution.

Pseudocyphellaria spp.--Closely related to Lobaria (see above), and similar in containing blue-green algae and having "breathing pores".

Umbilicaria spp.--According to Ranft (1971), U. cylindrica and U. polyphylla are "sligtly sensitive" to SO2' and according to Sigal (in Lawrey, 1984), U. mammulata showed necrosis when treated with simulated acid rain. Likely to be sensitive because of the foliose growth form.