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Lichens in relation to management issues in the Sierra Nevada national parks

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Abstract: The central and southern Sierra Nevada are subjected to high levels of ozone, high and increasing nitrogen deposition, and unknown quantities of pesticides such as organophosphates from agricultural emissions in the Central Valley. Fire regimes have changed greatly over time, from relatively frequent fire historically, to fire exclusion, to its reintroduction as prescribed fire. Parts of the Sierra parks have been grazed by livestock, and some of this persists today. On top of these factors, climate is likely to change rapidly.

Although a large literature exists on human impacts on lichens, almost nothing is known on this topic in the Sierra Nevada specifically. We are largely ignorant of the biodiversity, ecology, and ecological roles of lichens in the Sierra Nevada Park system (the “Sierra parks”: Sequoia and Kings Canyon National Park, Yosemite National Park, and Devils Postpile National Monument). This paper synthesizes existing data, written reports and other information about lichens in and near the Sierra Nevada parks, as a first step toward developing better baseline data and assessing lichen populations or communities as potential indicators of ecosystem change.

Lichens are diverse in their ecosystem roles and functional significance. Organizing the hundreds of lichen species present in the Sierra parks into functional groups helps us to understand, interpret, inventory, and monitor the diversity of lichens. We therefore divided lichens of the Sierra parks into the following functional groups: forage lichens, nitrogen fixers, acidophiles, wolf lichens, crustose lichens on rock, crustose lichens on bark and wood, biotic soil crusts, aquatic, other green algal macrolichens, and pin lichens (calicioids).

Management issues that relate to lichens include biodiversity, air quality, water quality, fire, grazing, and the possibility of draining Hetch Hetchy Reservoir. Existing lichen data from the west slope of the Sierra Nevada, of relevance to the management of Sierra parks include: extensive lichen community data from the Forest Inventory and Analysis program (FIA), a few floristic studies focused on the parks, photo points on prescribed fire transects, lichen biomass estimates from four locations, elemental analysis of lichens from a small number of locations, lichen communities in relation to various nitrogen species in Kings River watershed, the Western Airborne Contaminants Assessment Project, *Bryoria fremontii* studies at Teakettle Experimental Forest, and herbarium databases.

We recommend the following short list for future inventory and monitoring work: population status and trend of *Bryoria fremontii*, macrolichen community monitoring, revise and update the inventory of lichen biodiversity, and preliminary surveys of lichens in neglected habitats.

Key words: air quality, aquatic lichens, biodiversity, *Bryoria fremontii*, California, calicioid fungi, crustose lichens, forage lichens, functional groups, grazing, *Letharia*, lichens, monitoring, national parks, nitrophiles, pin lichens, Sierra Nevada, wolf lichens.

Introduction: National Parks were established with the dual purposes of protecting natural and cultural resources and providing for public enjoyment of those resources "by such means as will leave them unimpaired for the enjoyment of future generations" (National Park Service, National Park Service Organic Act of 1916: 16 U.S.C. 1ff., 39 Stat. 535). Sierra Nevada parks are also largely designated Wilderness, providing a strong mandate through The Wilderness Act of 1964 (Public Law 88-577: 16 U.S.C. 1131-1136) to preserve natural ecosystems and the processes that maintain them. Research that focuses on detecting, understanding, and managing human-influenced negative impacts to natural ecosystems has revealed deficiencies in our biological and ecological knowledge of National Parks (Cole and Landers 1996; Lubchenco et al. 1991).

National Park Service (NPS) Management Policies (NPS 2001a) and recent legislation (National Parks Omnibus Management Act of 1998) require that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the NPS mission of conserving parks unimpaired. The resulting NPS Inventory and Monitoring program strives to fill in knowledge gaps in baseline data about natural resources in parks and to design and implement long-term monitoring of vital signs. Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (NPS 2006). The program should provide scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems (NPS 2006).

One of the main objectives of the biological inventory portion of this program was to document the occurrence of at least 90 percent of vertebrates and vascular plants currently estimated to occur in each of the network parks, through existing verifiable data and field surveys (NPS 2004). The inventory component of the program addressed only vascular plants and vertebrate taxa, thereby excluding nonvascular plants and lichens from treatment in the funded inventories in the Sierra Nevada Network (NPS 2001b, NPS 2004).

Despite this decision, lichens are a conspicuous part of ecosystems in the Sierra Nevada, a part that may provide valuable vital signs for evaluating the condition and trend in those ecosystems. Lichens are vulnerable to air pollution, especially acidifying sulfur and nitrogen compounds, fertilizing nitrogen compounds, and other anthropogenic disturbance. The central and southern Sierra Nevada are subjected to high levels of ozone, high and increasing nitrogen deposition, and unknown quantities of pesticides such as organophosphates from agricultural emissions in the Central Valley. Fire regimes have changed greatly over time, from relatively frequent fire historically, to fire exclusion, to re-establishment of fire in some areas through management-ignited burns or lightning-caused fires that are closely monitored. Parts of the Sierra parks have been grazed by livestock, and some of this persists today. On top of these factors, climate is likely to change rapidly.

Although a large literature exists on human impacts on lichens, almost nothing is known on this topic in the Sierra Nevada specifically. We are largely ignorant of the biodiversity, ecology, and ecological roles of lichens in the Sierra Nevada Park Network (henceforth “Sierra parks,” including Sequoia and Kings Canyon National Parks, Yosemite National Park, and Devils Postpile National Monument. The purpose of this project is, therefore, to synthesize existing data, written reports, and other information about lichens in and near the Sierra Nevada parks, as a first step toward developing better baseline data and assessing lichen populations or communities as potential indicators of ecosystem change.

Our specific objectives are to:

1. Summarize current knowledge regarding distribution and abundance of lichens in the Sierra Nevada region, and for the Sierra Nevada parks.
2. Identify spatial gaps in existing baseline macrolichen data which should be targets of future inventory efforts and identify institutions with Sierra Nevada park lichen collections that should be searched.
3. Synthesize the available information on the role of lichens in Sierra Nevada ecosystems.
4. Identify management issues in relation to lichens.
5. Identify areas and taxa most likely to be sensitive to air pollution.
6. Synthesize any existing inventory and monitoring data that may be available for the Sierra Nevada.
7. Suggest lichen monitoring strategies for Sierra Nevada parks that address both broad-scale and targeted monitoring of sensitive species and habitats.

Although our focus is the Sierra Nevada, many of the environmental problems in the Sierra are present to varying degrees in other areas, including the Pacific Northwest. Many of the management issues in the Sierra National Parks are issues in other national parks. For example, Mount Rainier National Park, like Sequoia National Park, lies downwind of large urban and agricultural areas. Functional groups of lichens can be applied broadly to other areas, although the prevalence of particular groups will vary by region. For example, the Pacific Northwest west of the Cascades has high biomass of nitrogen fixing lichens, while east of the Cascades, biotic soil crusts are particularly important. We therefore hope that this summary will have broad utility, not to just the Sierra Nevada, but also to other areas, including the Pacific Northwest of North America.

Functional Groups of Lichens

Lichens are diverse in their ecosystem roles and functional significance. Lichens inhabit many different substrates, habitats, and climatic zones.

Organizing the hundreds of lichen species present in the Sierra parks into functional groups helps us to understand, interpret, inventory, and monitor the diversity of lichens. We therefore define functional groups of lichens of the Sierra parks and explain their significance to park management issues (Table 1). Species may belong to more than one functional group. For example, *Collema tenax* is a nitrogen-fixing species occurring in the biotic soil crusts; thus it belongs to the nitrogen fixers and the biotic soil crusts.

Forage lichens: Forage lichens (Table 1) are pendulous, hairlike species. They are eaten by a wide range of mammals. They were also eaten by Native Americans (references in McCune 2002 and Brodo and Hawksworth 1977). In the Sierra parks, the most important representative of this group by far is *Bryoria fremontii*. This species forms dark brown beards, usually on conifer branches. *Bryoria fremontii* is notable among forage lichens in its palatability. Unlike most forage lichens, it virtually lacks the secondary chemicals that commonly serve in lichens as defensive substances against herbivory. Abundant in the Pacific Northwest and the northern Rocky Mountains, and achieving a biomass of up to 1 T/ha dry weight, this species becomes increasingly rare southward in the Sierra, apparently becoming more and more restricted to particular habitats.

Bryoria can be an essential winter food source for some species. Winters in the Sierra Nevada can be harsh and food scarce. Within certain habitats of the Sierra parks, the northern flying squirrel (*Glaucomys sabrinus*) and Douglas squirrel (*Tamiasciurus douglasii*) probably depend on *Bryoria* for winter and spring forage. Rambo (2004) postulated that through these prey species, *Bryoria* has indirect effects on four Forest Service-listed Sensitive Species in the Sierra: the California spotted owl, northern goshawk, pine marten, and American fisher.

The range of the flying squirrel extends south into the moist forests of the Yosemite Valley (Schoenherr 1992), and becomes uncommon in the southern Sierra Nevada. During winter and spring in the Pacific Northwest, the stomach contents of the northern flying squirrel have been found to contain up to 93% lichen material by volume (Maser et al. 1985). The distribution of the northern flying squirrel may parallel the distribution and abundance of *Bryoria* in the Sierra Nevada (Rambo 2004).

Mule deer (or black-tailed deer, *Odocoileus hemionus*) also rely on *Bryoria* litterfall in winter (Ward 1999). Although we found no published information on lichen use by deer in the Sierra, on Vancouver Island the rumen of black-tailed deer has been found to contain 26% lichens by volume during winter months (Stevenson and Rochelle 1984).

Lichens likely have dietary significance for many other animals in the Sierra, for example, the California snail (*Monadenia hillebrandi mariposa*; Szlavecz 1986), collembolans, springtails, and various other invertebrates. Many invertebrates are crucial to the diet of migratory birds (Pettersson et al. 1995).

Aside from food, many species use lichens for nest materials. At least 19 species of birds and a handful of animals that reside in the Sierra parks use lichens as nest material. Northern flying squirrels and Douglas squirrels use *Bryoria* for nest material, in addition to eating it (Hayward and Rosentreter 1994, Rambo 2004).

Considering the importance of *Bryoria fremontii* as a forage species in western North America, studies of factors affecting its local distribution and abundance are surprisingly rare and widely scattered (e.g. Lehmkuhl 2004, Ward 1999). The only study we know of in the Sierra Nevada is an as-yet-unpublished study in Teakettle Experimental Forest (Rambo 2004).

Table 1. Functional groups of lichens occurring in the Sierra parks. The estimated number of species in the Sierra parks is very approximate, included only to give a rough order-of-magnitude. These values are based on professional judgement and the literature (nomenclature: Tucker and Ryan 2006; cetrarioid lichens follow McCune and Geiser 1997).

Functional group	Example species	Estimated no. species	Key management issues
Forage	*Bryoria fremontii* (only one prominent species)	10	air quality fire
Nitrogen fixers	*Collema nigrescens* *Leptogium lichenoides* *L. palmatum* *Peltigera degenii* *P. kristinssonii*	50	air quality
Nitrophiles	*Candelaria concolor* *Phaeophyscia orbicularis* *Physcia tenella* *Physconia perisidiosa* *Xanthomendoza fulva* *Xanthoria polycarpa*	100	air quality
Acidophiles	*Evernia prunastri* *Hypogymnia physodes* *Cetraria chlorophylla* *Hypocenomyce scalaris*	100	air quality
Wolf lichens	*Letharia columbiana* *Letharia vulpina*	2	air quality fire
Crustose lichens on rock	*Aspicilia* spp. *Candelariella vitellina* *Lecidea* spp. *Rhizocarpon* spp.	200	air quality aesthetics biodiversity
Crustose lichens on bark and wood	*Buellia erubescens* *Lecanora orizibana* *Lecidella euphorea* *Rinodina pyrina* *Xylographa vitiligo*	200	air quality biodiversity
Biotic soil crusts	*Endocarpon pusillum* *Placynthiella uliginosa*	50	biodiversity grazing
Aquatics	*Leptogium rivale* *Peltigera hydrothyria* *Staurothele fissa* *Verrucaria* spp.	20	water quality
Other green algal macrolichens	*Cetraria platyphylla* *Cladonia fimbriata* *Hypogymnia imshaugii* *Parmelia hygrophila* *Platismatia glauca*	150	air quality biodiversity fire
Pin lichens (calicioids)	*Calicium viride* *Chaenotheca furfuracea* *Cyphelium inquinans* *Mycocalicium sequoiae*	30	air quality biodiversity fire

Unfortunately we could find no historical quantitative data on *Bryoria fremontii* in the Sierra. Pinelli and Jordan (1978) did, however, report it as “common” in Calaveras Big Trees State Park.

Bryoria fremontii dieback is suspected to have occurred over the last few decades in Sequoia National Park, based on casual observation (N. Stephenson, pers. comm., 2005). The most obvious threats to *Bryoria* are from various air pollutants. Future climate change may become an exacerbating factor because the Sierra are at the south end of the range of *Bryoria*. Disappearance of *Bryoria* may affect populations of northern flying squirrels, Douglas squirrels, mule deer, and various birds, invertebrates, and mammals linked to these species through the food web.

Nitrogen fixers: All lichens that contain cyanobacteria as a symbiotic partner fix nitrogen, converting atmospheric nitrogen into forms usable by plants and animals. Cyanobacterial lichens (cyanolichens, for short) are most prominent in cool, oceanic climates, but they are also easy to find in the Sierra parks (Table 1).

Rotting logs, mossy boulders, hardwood tree trunks, and tree bases are the usual substrates for cyanolichens in the Sierra parks. The most prominent genus is *Peltigera*, which occurs frequently on all of those substrates. Other smaller genera are also readily found, such as *Fuscopannaria, Collema*, and *Leptogium*.

Cyanolichens can contribute a significant amount of fixed nitrogen in cool oceanic forests (Antoine 2001, 2004). However, the drier, warmer, less oceanic climate of the Sierra tends to disfavor cyanolichens. The amount of fixed nitrogen contributed by lichens in the Sierra parks is, therefore, likely very small compared to atmospheric inputs. Perhaps the greatest importance of cyanolichens in the Sierra parks is that they represent a sector of the biodiversity that is surely one of the most vulnerable components of the Sierra ecosystems, in the face of high anthropogenic nitrogen inputs and climate change. In general, nitrogen fixers are considered susceptible to both acidic and nitrogenous pollutants. It is very likely, therefore, that nitrogen fixers have already declined in the more polluted areas of the Sierra parks.

Nitrophiles: Certain lichens thrive in nitrogen-rich environments; these are called nitrophiles or nitrophytes (Table 1; more listed in Jovan and McCune 2005). Nitrogen inputs in the United States have doubled since 1961 due mainly to agricultural application of nitrogen fertilizers and human emissions from fossil fuels, power plants, and industry (Howarth et al. 2002). Sequoia, Kings Canyon, and Yosemite are downwind from one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, tons of fertilizers are applied to crops upwind of the Sierra Nevada parks. Agricultural fertilizers and feedlots emit much ammonia (NH_3) into the atmosphere. Some of this is deposited directly on surfaces, while some is oxidized, and some combines with nitric acid (HNO_3) to form ammonium nitrate particulates (NH_4NO_3). Both wet and dry deposition are expected, but in the dry climate of California, much of the nitrogen deposition is dry. Both forms are presumed to influence epiphytes.

Deposition of ammonia on bark increases its pH (decreases acidity), which is thought to affect lichen communities (Van Herk 1999). A common change in nitrogen-rich environments is for acidophilic lichens to disappear, while weedy nitrophiles colonize or increase in abundance. These nitrophiles include the lichens *Xanthoria* and *Physcia*, as well as free-living green algae (James et al. 1977, Benfield, 1994, Ruoss 1999). In contrast, acidophiles include naturally occurring lichens on acidic-barked trees, especially conifers, as well as species that respond positively to acidic pollutants, such as sulfuric acid and nitric acid. Deposition of nitrogen as nitric acid (HNO_3) is, therefore, likely to have different effects from deposition of nitrogen in the form of ammonia and ammonium nitrate.

Nitrophilous lichens have likely increased within the Sierra Nevada (Jovan and McCune 2006). It is possible to map ammonia pollution using nitrophilous lichen epiphytes (Van Herk 1999, Jovan and McCune 2005, 2006). In the greater Central Valley of California, including surrounding foothills, Jovan and McCune (2005) developed a multivariate lichen community model that represents the degree of development of nitrophilous lichen communities and, indirectly, deposition of reduced forms of nitrogen (NH_3 and NH_4^+). A second model represents lichen community relationships to climate and nitrogen deposition in the Sierra Nevada (Jovan and McCune 2006). These models can be used to score lichen community plots collected with the FIA protocol (see below). Changes in scores through time can be used to assess trends in nitrophily of the lichen community.

Acidophiles: Acidic nitrogen compounds, particularly HNO_3, may influence lichen species composition by promoting a set of species known as acidophiles or acidophytes (van Herk 1999, van Herk et al. 2003). Potential acidophiles that are widespread in California include *Cetraria chlorophylla, Evernia prunastri, Hypocenomyce scalaris, Hypogymnia physodes, H. tubulosa, Parmelia saxatilis, Parmeliopsis ambigua, Placynthiella icmalea, Platismatia glauca, Trapeliopsis flexuosa, T. granulosa,* and *Usnea* spp.

Acidophiles may be responding to changes in bark pH, increased nitrogen (as NO_3^-) in bark or precipitation, or changes in other epiphytes (algae, moss, lichens, etc.; van Herk et al. 2003). Some acidophiles are stimulated by anthropogenic acids, while others occur in naturally acidic environments that are nutrient-poor (e.g. conifer bark in high elevation forests). The two sets of species overlap somewhat—in other words, some, but not all, natural acidophiles tolerate acidic pollutants. For example, many of the fruticose genera typically on conifers (*Alectoria, Bryoria, Letharia*) are acidophiles thought not to tolerate acidic pollutants (Geiser and Neitlich 2007, p. 212).

Wolf lichens: The most conspicuous and abundant lichens in the Sierra parks are the fluorescent chartreuse *Letharia* species (wolf lichens; Table 1). Although nearly absent at the lowest elevations, with increasing elevation the conifer trunks and branches become coated with a stunning abundance of bright yellow, fruticose *Letharia vulpina* and *L. columbiana*. Shaw and Acker (2002) estimated biomass of *Letharia* between 5-20 kg/ha for four stands in Sequoia and Kings Canyon National Parks. Casual observation suggests much higher biomass of *Letharia* than this in certain areas. Shaw and Acker estimated that *Letharia* contributed approximately 50-95% of the total macrolichen biomass in these stands.

Species delimitation in *Letharia* is in some doubt (Kroken and Taylor 2001a, b; see also Altermann 2004 and 2005), but has not yet been resolved. For now we apply the traditional separation of the sorediate species *L. vulpina* from the esorediate species *L. columbiana.*

We chose to segregate *Letharia* into its own functional group to highlight its conspicuousness and abundance in the Sierra parks, along with some distinctive features that set it apart from other green-algal macrolichens:

- it is the only tufted, fruticose lichen in the Sierra parks that is abundant;
- it contains secondary metabolites that are toxic to many herbivores and microbes, strongly absorb UV-A, UV-B, and UV-C radiation, and fluoresce visible light (Stephenson and Rundel 1979, Rikkinen 1995); and

- it forms the bulk of the lichen biomass in the sequoia groves (Shaw and Acker 2002) and many other Sierran forests.

The fluorescent yellow pigment in *Letharia* is primarily vulpinic acid, known to be toxic to mammals and invertebrates (Slansky 1979, Richardson 1988). The concentration of secondary lichen substances in *Letharia* can be 3-9% of dry weight, and over 90% of this is vulpinic acid (Geyer 1985).

Despite the reported toxicity of *Letharia*, a few studies have reported northern flying squirrels eating *Letharia* (Hall 1991, Zabel and Waters 1997). On the other hand, Rosentreter et al. (1997) found no evidence of *Letharia* in flying squirrel diets. The importance of this as a food source to mammals is likely conditioned by the availability of other lichens. If *Bryoria fremontii* and other palatable lichens are sparse, then *Letharia* may be a more important food resource. This presumes, however, that mammals have or can acquire tolerance to vulpinic acid.

Despite the conspicuousness and abundance of this genus in western North America, virtually nothing is known about its ecological roles at the ecosystem level. These understudied lichens may be significant in diets, habitat, and nutrient cycling. We also do not know how these lichens respond to ozone, fires, an increase in nitrogen, or to other pollutants.

Crustose lichens on rock: Crustose lichens adhere so tightly to the substrate that they appear to be painted on. They lack a lower cortex and rhizines. Crustose lichens form conspicuous, diverse, colorful mosaics on rocks in the Sierra Nevada (Table 1). Crustose lichens are also ubiquitous on bark and dead wood (see the next species group).

Crustose lichens promote rock weathering (Syers and Iskandar 1973), some are nitrogen fixers, and many provide food and shelter for certain invertebrates. All of these functions are likely in the Sierra parks. In addition, and perhaps most importantly from a visitor's perspective, crustose lichens are an important aesthetic component of the many prominent rock outcrops in the Sierra Nevada. From a distance crustose lichens often create banding and dark zones along drainage tracks. Close up, crustose lichens form an intricate multicolored patchwork, often completely covering the rock surface.

Lichen communities paint the tremendous rockscapes in Yosemite and Sequoia National Parks, even at a distance. Visitors seldom appreciate this phenomenon for what it is. But even without knowing the underlying cause, most visitors appreciate the elegant vertical striping on the massive granitic faces of Yosemite and Sequoia Parks. Early inhabitants of Yosemite Valley appreciated this too. According to a film shown in the Yosemite Visitor Center, the Native American name for Half Dome means "Face of a Young Woman Stained with Tears."

Vertical stains on rocks in Yosemite show at least five different kinds of banding, each slightly different in color. One of the most common stains appears black from a distance, but is dark brown up close. These bands typically have abundant *Lecidea atrobrunnea*, *Dimelaena thysanota*, and dark gray *Rhizocarpon* species. Other stripes, with a grayer tone, have *Aspicilia* species and *Koerberia sonomensis*. Some darkened areas are covered with very complex, intricate communities of many species. Stripes that are very dark brown up close appear to be dominated by *Staurothele areolata* and perhaps other *Staurothele* and *Verrucaria* species. The blackest stripes appear to be dominated by cyanobacteria, perhaps *Nostoc*. Last, in some areas the stripes are dominated by mosses.

The landscape-level effect of rock lichens is perhaps most apparent along Hetch Hetchy Reservoir, where the elimination of rock lichens by inundation has created a striking contrast with the lichen covered rocks. This results in a horizontal banded pattern that is obvious at low water. This situation is discussed further under "Management Issues."

Although crustose lichens certainly respond to air pollutants, their low profile is thought to make them less sensitive to degradation in air quality than more three-dimensional growth forms of lichens. Nevertheless, many species of crustose lichens respond to nitrogenous and/or acidic pollutants. Pollutant effects are most likely to be seen in exposed landscape positions. For example, casual inspection of Moro Rock in Sequoia National Park in 2005 found abundant nitrophilic crusts (such as the yellow genus *Candelariella*) on the upper surfaces of the outcrop. In a natural ecosystem, nitrophilic crusts would be expected on rock primarily on bird perches, drainage cracks, or other sites with an unusually high nutrient load.

Crustose lichens on rock are the basis for lichenometry – dating rock surfaces by analysis of the slow radial growth of selected species of lichens. Lichenometry has a long history in the Sierra Nevada (Curry 1969; Bull 2000, 2003, 2004), where lichens were used to date glacial landforms and seismic rockfall events.

Crustose lichens on bark and wood: Crustose lichens are abundant in the Sierra parks on bark, wood, and cones (Table 1). Crustose lichens on bare wood form a distinctive subgroup, notable for their reliance on coarse woody debris, but for simplicity we have combined them with those species occurring on bark.

Much of the diversity of lichens in old-growth sequoia groves is present as crustose lichens on bark, wood, and cones. The macrolichen flora on these trees is relatively species-poor, as compared to conifers in more oceanic climates. Sequoia bark itself is relatively poor as a substrate for epiphytes, but associated tree species are often heavily clothed with lichens.

Several microhabitats within old conifer forests deserve specific attention, as each of these microhabitats hosts a distinctive set of species. The very old trees in the Sierra parks have likely resulted in refugia for numerous rare species in these microhabitats.

- Dead, barkless wood distributed throughout the canopy forms a hard, stable substrate that tends to accumulate a distinctive set of species (McCune et al. 2000).
- Sequoia cones high in the tree crowns are a persistent, stable surface that develops high cover of lichens, especially certain crustose species (S. Sillett, pers. comm.).
- Sheltered sides of leaning trees, particularly on humid sites, support numerous calicioid lichens (pin lichens; see below) and associated crustose species. These species tend to occur on surfaces that seldom receive direct precipitation.

Air pollutants threaten the natural lichen flora of these and other bark and wood substrates. Another potential threat to a subset of these species is that prescribed underburning may diminish populations of lichens restricted to sheltered lower trunks. Because ground fires are a natural part of the sequoia groves, and many other habitats in the park, any deleterious effects on lichens must be considered in a different light than impacts of poor air quality.

Biotic Soil Crusts: Lichens are one component of biological soil crusts, referred to here as biotic soil crusts (Table 1). These are also known as cryptogamic, microbiotic, cryptobiotic, or microphytic crusts. These living crusts, not to be confused with non-living physical soil crust, contain lichens, bryophytes, green algae, fungi, cyanobacteria, and other bacteria (West 1990, Belnap and Lange 2001). Biotic soil crusts are found in arid and semi-arid landscapes.

Distribution is determined in part by elevation, moisture, vascular plant cover, percent rock cover, soil depth, soil chemistry, and soil texture.

Biotic soil crusts play important and essential roles in their ecosystems including; carbon and nitrogen fixation, alteration of albedo, stimulation of plant growth, promoting native seed germination, capture of nutrient-rich dust, deterring establishment of non-native grasses, effects on soil water, and stabilizing soil surfaces (Eldridge and Greene 1994, Belnap 1995; Belnap and Eldridge 2001; Belnap et al. 2001a). In one case, disturbance of cyanobacterial crusts resulted in erosion of 35 times more sediment by winds and overland flow (Belnap and Eldridge 2001) than with the biotic crust intact. This and other influences of the crust depend on species composition within the crust, as well as climate, substrate, and vascular vegetation.

Biotic soil crusts are sensitive to soil disturbances such as human foot traffic, rodent burrowing, livestock grazing, and ORV use (Belnap 1995, Belnap and Eldridge 2001). These disturbances can pulverize, bury, or otherwise physically destroy the crust.

Our knowledge of biotic soil crusts in the Sierra Nevada is primitive compared to that of the hot deserts, Colorado Plateau, and the Columbia Plateau. Traditional soil crusts are likely to be important only at the drier fringe of the Sierra parks, at low elevations (for example, the calcareous knobs and hills near the Ash Mountain entrance to Sequoia NP). They may also be present on the occasional small inclusion of calcareous bedrock (often marble, generally mapped as metasedimentary rock) in other areas of the Sierra. Two examples at higher elevations are the vicinity of Bigelow Lake near the northern boundary of Yosemite NP and around Benson Lake in the Tuolumne drainage of Yosemite. On the coarse granitic soils that are common in the Sierra parks, the fern ally, *Selaginella,* appears to be a very important soil stabilizer, but lichen and bryophyte crusts are not prominent. Approaching the upper treeline, a second kind of biotic crust is expected, with different lichen species than at lower elevations (such as *Placynthiella uliginosa* and *Trapeliopsis granulosa*), and more cover by bryophytes and dwarf vascular plants.

Biotic crusts probably occupy a small proportion of the landscape in the Sierra parks. They are so important where they occur, and they are so poorly known in the Sierra, that preliminary studies of their extent and species composition are needed.

Aquatic lichens: A small number of lichen species live on rock in aquatic and semi-aquatic environments (Tables 1 and 2). Aquatic lichens are particularly prominent on streamside and lakeside rock outcrops and boulders in the mountains. Their abundance, location, and diversity are essentially unknown in the Sierra parks.

Peltigera hydrothyria (formerly *Hydrothyria venosa*) grows on rocks in streams where it is submerged throughout most of the year. This species favors small spring-fed streams without marked seasonal fluctuations (McCune and Geiser 1997). *Peltigera hydrothyria* is rare throughout its western range (Glavich and Geiser 2004). In southern California it appears to be restricted to the western slopes of the Sierra Nevada. Pinelli and Jordan (1978) reported it as “locally abundant and submerged in streams” from Calaveras Big Trees State Park. We found no evaluations of its abundance in the Sierra parks, although a state-wide evaluation of its distribution is expected soon from the California Lichen Society’s conservation committee.

Another aquatic lichen, *Leptogium rivale*, thought to be more common than *P. hydrothyria*, can be found on siliceous rock in or near water (Glavich and Geiser 2004; McCune and Geiser 1997). This species appears to be restricted to streams with low sediment and unpolluted water.

Table 2. Aquatic lichens in the Sierra Nevada parks. Herbarium acronyms are in upper case. Obligate aquatics are shown in bold face. The others can occur in seepage tracks and other areas with periodic inundation. "MIN" is the University of Minnesota Herbarium; "OSC" is the Oregon State University Herbarium.

Species	Locations
Dermatocarpon bachmannii Anders	Sequoia National Park (MIN). Primarily in seepage tracks, according to Heidmarsson and Breuss in Nash et al. (2004).
Dermatocarpon luridum (With.) J. R. Laundon	Not confirmed for Sierra parks but known from Arizona (op. cit.); many western N Am records are misidentifications of *D. meiophyllizum* Glavich and Geiser (2004).
Dermatocarpon meiophyllizum Vainio	Known from Sierra Nevada (Glavich and Geiser 2004); likely but not yet reported from Sierra parks
Dermatocarpon miniatum (L.) W. Mann	Historically this name was applied very broadly so that most records are in doubt. Kings Canyon National Park (Smith 1980) Sequoia National Park (Wetmore 1985, Wetmore 1986, MIN, Smith 1980) Yosemite National Park (Imshaug 1957, Hasse 1913, MIN)
Dermatocarpon reticulatum H. Magn	Kings Canyon National Park (Wetmore 1986, MIN) Sequoia National Park (Wetmore 1986, MIN, Wetmore 1985) Yosemite National Park (MIN).
Leptogium rivale Tuck.	Yosemite National Park (Sierk 1964)
Peltigera hydrothyria (J. L. Russell) Miadlikowska & Lutzoni = *Hydrothyria venosa* J. L. Russell	Sequoia National Park (MIN, OSC) Yosemite National Park (Weber 1971a)
Staurothele fissa (Taylor) Zwackh.	Very likely but not reported.
Verrucaria spp.	Very likely but not reported.

Scientists have recently described new species and range extensions of aquatic lichen species in western North America. For example, *Dermatocarpon meiophyllizum* has recently been found in North America (Glavich and Geiser 2004). Two of their sites were from the Sierra Nevada (*Ryan 24666d; Ryan 12611a* (ASU)). *Dermatocarpon bachmannii* was only recently reported from North America, but is known in Sequoia NP (Table 2).

Some Sierra Nevada streams may contain elevated pollutants such as pesticides and nutrients (see *Water Quality* below). Aquatic lichens may decline or otherwise be affected by these pollutants. So little is documented about aquatic lichens in the Sierra parks that their decline or disappearance may go unnoticed. More extensive surveys are needed to learn which species of aquatic lichens occur in the park, their habitats, and their abundance. We would expect to find populations of *Peltigera hydrothyria, Leptogium rivale*, and *Dermatocarpon* species, all near the edges of their ranges and therefore vulnerable to changes in climate, hydrology, and water chemistry.

Surveys should take place in the most likely habitats, such as cool mountain brooks and streams without marked seasonal variations. Streams cutting through outcrops and boulder fields are also likely to be good habitats for aquatic lichens.

Other green algal macrolichens: Specific ecosystem functions are poorly understood for many lichens, especially the green-algal macrolichens in groups other than those described above. Certainly these species are important as shelter and food for invertebrates and vertebrates. Uses of green algal macrolichens include forage, nest material, water, and camouflage (Carey et al. 1999; Hayward and Rosentreter 1994; Maser et al. 1985, Szlavecz 1986, Ward 1999).

These lichens also influence nutrient cycling by accumulating nutrients in different patterns and amounts than vascular vegetation (Boucher and Nash 1990). Preliminary data suggest that throughfall chemistry is affected by epiphytic lichens, and the throughfall under trees with canopy lichens is enriched in Cl^-, Na^+, K^+, Ca^{+2}, Mg^{+2}, organic nitrogen, total nitrogen, total phosphorus (Knops and Nash 1996).

Because of the diversity of lichens in the “other green-algal macrolichens” group, and their somewhat ambiguous ecosystem roles, perhaps monitoring this group is most important from the standpoint of biodiversity.

Pin lichens: Pin lichens (also known as calicioid lichens) have a crustose thallus and minute stalked fruiting bodies resembling the head of a pin. Some calicioid species are nonlichenized, but historically all calicioid species have been treated by lichenologists rather than mycologists. Many pin lichens are considered to be old forest indicators in humid climates. Pin lichens reported before 2003 from the Sierra parks include *Calicium adaequatum, C. corynellum, C. glaucellum, C. viride*, and several *Chaenotheca* species. Some closely related species are nonlichenized, such as *Mycocalicium subtile*, reported from Sequoia National Park. The type locality of one nonlichenized calicioid fungus, *Mycocalicium sequoiae*, is from Sequoia National Park (Bonar 1971). This species grows only on hardened resin of sequoia.

Pin lichens are easiest to find on the sheltered sides of old leaning trees and old snags on humid sites. Good habitat for pin lichens diminishes in extent as one moves south in the western states into increasingly dry climates. Occurrences of pin lichens in the Sierra therefore hold special interest, as these populations are likely to be near the southern end of their range. Like many populations at the southern end of their ranges, the persistence of pin lichens in the Sierra parks is dubious in the face of climate change.

In the first critical study of calicioid species from the Sierra Nevada, Rikkinen (2003) reported on four sites on the west slope of the Sierra Nevada (Tables 3 and 4), one in Calaveras Big Tree State Park (his site G5), and three in Stanislaus National Forest, Tuolumne County (G6a, G6b, G6c). Even though he visited few sites in this area, his data provide the best glimpse of calicioid lichens so far (Tables 3 and 4). Note that he found the most species in mesic old forests with diverse tree species, and the fewest on a dry serpentine ridge. Rikkinen (2003) summarized his Sierra findings: "Species diversities in the driest forests were generally low and many open woodlands east of the Sierra-Cascade Crest were totally devoid of calicioids. Mixed conifer forests at mid elevations on the western slopes of the Sierra Nevada seemed to be rich in calicioid species, but these forests were sampled too sparsely to permit real comparisons with the Oregonian forest types."

Table 3. Calicioid species reported by Rikkinen (2003) from the west slope of the Sierra Nevada. Each species is followed by codes for sites where it was found. See Table 4 for site codes.

Calicioid species
Calicium glaucellum (G5)
Calicium salicinum (G5)
Calicium viride (G5, G6a, G6c)
Chaenotheca furfuracea (G5)
Chaenotheca cf. *nitidula* (G6a)
Chaenotheca phaeocephala (G5)
Chaenotheca trichialis (G5)
Chaenotheca xyloxena (G6c)
Chaenothecopsis cf. *vainioana* (G6c)
Cyphelium inquinans (G5, G6a, G6c)
Cyphelium karelicum (G6c)
Cyphelium pinicola (G6b)
Mycocalicium sequoiae (G5)
Mycocalicium subtile (G5, G6c)
Phaeocalicium sp. 1 (G6a, G6c)
Thelomma occidentale (G6b)

Management Issues

This section discusses current management issues in the Sierra parks that are related to the distribution and abundance of lichens. Our definition of "management issue" is a current or potential problem for which resource managers and state and federal governments have at least partial control.

Biodiversity

Biodiversity is important for both utilitarian (anthropocentric) and ecosystem functional (intrinsic) values. Lichens are important contributors to ecosystem function (see functional group section above) and to interpretation of human impacts on ecosystems. Although for most lichens we are ignorant of these values, caution is warranted in our approach to conserving of lichen biodiversity. "Destroying species is like tearing pages out of an unread book, written in a language humans barely know how to read, about the place where they live" (Rolston 1985).

Table 4. Site characteristics corresponding to species list in Table 3. *S* = the number of calicioid species reported by Rikkinen (2003).

Site	County	Elev., m	Dominant trees	*S*
5	Calaveras	950	*Abies concolor, Calocedrus decurrens, Pinus lambertiana, P. ponderosa, Sequoiadendron giganteum*	9
6a	Tuolumne	1600	*Abies concolor, Pinus contorta, P. jeffreyi, P. lambertiana, Calocedrus decurrens*	4
6b	Tuolumne	1700	*Pinus jeffreyi, Calocedrus decurrens* (on serpentine ridge)	2
6c	Tuolumne	1500	*Pinus jeffreyi, P. contorta, Abies concolor*	7

The biodiversity of lichens, especially crustose lichens, is still not well known. New species of crustose lichens are still being described at a fairly rapid rate, such as the many new species described for southwestern North America in the *Lichen Flora of the Greater Sonoran Desert Region* (Nash et al. 2002, 2004). Similarly, we have minimal ecological information on the autecology of many species of lichens, apart from substrate preferences. A cautious, conservative approach would suggest monitoring and protecting lichens, including crustose lichens, at least until we understand more about them and their roles in the surrounding ecosystems.

Air quality

In California, various environmental and anthropogenic factors combine to create an air quality problem. The Sierra parks are subjected to pesticides, nitrogen-based and sulfur-based pollutants, and elevated levels of ozone. Sequoia and Kings Canyon have some of the worst air quality in national parks of the United States (Peterson and Arbaugh 1992, Cahill et al. 1996, Ayers and Oakes 2002).

Many lichens are extremely vulnerable to air pollution, especially acidifying sulfur and nitrogen compounds, and fertilizing compounds. Lichens lack a waxy cuticle and absorb nutrients and pollutants from wet and dry atmospheric deposition. Lichen communities in polluted environments typically have low diversity, though the abundance of some pollution-tolerant species may be relatively high.

Air pollution can also affect the growth form and reproductive traits of lichens. For example, *Evernia prunastri* develops a compact, shrubby, dwarfed growth form, with heavy production of soredia (asexual reproductive propagules) in sites with chronically poor air quality. *Platismatia glauca* will likewise have a compact growth form when stressed. In such cases it often heavily produces soredia and isidia. Direct injury from air pollutants often shows as patchy bleaching or reddening of the upper surface.

Lichens have many attractive qualities as passive monitors of ecosystem health, as affected by air pollutants. Lichens are potentially long lived, are visible at any time of the year, accumulate pollutants throughout the year, and have wide geographical ranges, which allow comparisons with other parts of the region and world.

Only a handful of full meteorological and air quality monitoring stations exist in the Sierra National Parks. They are located along the lower Kaweah River and at Lookout Point in Sequoia National Park, and at Turtleback Dome and Yosemite Village in Yosemite National Park. Due to the scarcity of monitors, we know relatively little about fine-scale distribution of air pollution within these parks. Microclimates associated with narrow drainages, steep leeward slopes, and other sheltered areas may offer some localized topographic relief from some air pollutants (e.g., Benfield 1994, Lovett et al. 1997, Weathers et al. 2000). These sheltered areas could harbor pollution-sensitive lichens. Areas with poor ventilation and high vehicular traffic may have lower abundance of sensitive lichens species; for example, *Bryoria fremontii* appears to be very scarce in Yosemite Valley. *Bryoria fremontii* is among the most sensitive species in the Sierran forests, so the importance of clean air for maintaining *Bryoria* in the Sierra Nevada and its status in food webs (see above) is clear.

Sulfur dioxide: Sulfur dioxide (SO_2) is well known to have detrimental effects on lichen communities. Fossil fuel combustion, vehicle exhaust, paper manufacturing, and other industries produce SO_2. In many parts of the U.S. sulfur dioxide is not the threat it once was to lichen communities, due to decreasing emissions in recent years. Although levels of SO_2 toxic to lichens are found in Los Angeles and other urban areas, SO_2 occurs in relatively low concentrations in more remote areas in California (Jovan and

McCune 2005). We do not, therefore, believe SO_2 to have a major influence on lichen communities of the Sierra Nevada.

Nitrogen: Inputs of fixed nitrogen into ecosystems of the United States have doubled since 1961 due mainly to agricultural application of nitrogen fertilizers, combustion of fossil fuels, and industry (Howarth et al. 2002). In the Sierra Nevada nitrogen deposition has become a major concern (Fenn et al. 2003).

Nitrogen deposition occurs in three main forms HNO_3, NH_3, and NO_x, of which ammonia (NH_3) pollution is the best understood in regards to lichens (see above under "Nitrophiles"). California lacks consistent and thorough ammonia deposition monitoring. Ammonium nitrate (NH_4NO_3) is a major component of the fine particulate matter deposited in the park (Esperanza and van Mantgem in Mutch et al. 2004), and is likely active in altering the lichen communities of the Sierra parks. In Sequoia National Park, ammonia and ammonium are the dominant N pollutants in summer, indicating strong influence of agricultural emissions (Bytnerowicz et al. 2002).

Ammonia (NH_3) deposition has been documented to cause a shift in lichen communities (van Dobben and ter Braak 1999, Wolseley and Pryor 1999) through increased bark pH (van Dobben and de Bakker 1996). Nitrophilous lichens are prominent in the Sierra Nevada (Jovan and McCune 2006). Nitrogen content of *Letharia* is unusually high in the Sequoia-Kings Canyon area (Jovan and Carlberg 2007).

Ammonia pollution can feasibly be mapped using nitrophilic lichen epiphytes (Van Herk 1999, Jovan and McCune 2005, 2006) or nitrogen content of selected target lichen species (Jovan and Carlberg 2007). In California, Jovan and McCune (2005, 2006) developed multivariate lichen community models to represent effects of nitrogen enrichment on lichen communities, one model for the greater Central Valley, and one model for the west slope of the Sierra Nevada. They found lichen communities in plots located in Kings Canyon, Sequoia and Yosemite National Parks showed some of the highest scores along a gradient of nitrogen enrichment in the Sierra Nevada.

Ozone: Tropospheric ozone (O_3) pollution is widespread in California, occurring in both urban and rural areas, and causing injury to both wild and crop plants (Duriscoe and Stolte 1992, Miller 1973, 1996, Peterson and Arbaugh 1992, Stolte et al. 1992). Ozone is a photochemical pollutant formed when nitrogen oxides (NO_x) and hydrocarbons react with oxygen and sunlight. Although effects of ozone on vascular plants are well known, it does not appear to have a strong effect on lichens under natural conditions in temperate climates (McCune 1988, Lorenzini et al. 2003, Ruoss and Vonarburg 1995). Nevertheless, ozone fumigations of lichens in laboratories have shown negative effects on nitrogen fixation and photosynthesis (Nash and Sigal 1979, Ross and Nash 1983, Sigal and Johnston 1986, Scheidegger and Schroeter 1995). Although some authors have attributed lichen injury in southern California to ozone (Nash and Sigal 1980, Sigal and Nash 1983), it is difficult to pin the blame on ozone alone for several reasons. Visual symptoms of ozone injury to lichens are not clearly distinct from other pollutants. Other pollutants, such as nitric acid (HNO_3), may be distributed similarly to ozone. Many other pollutants participate in the poor air of southern California.

A key question likely to determine the impact of ozone on lichens under natural conditions is the degree to which high ozone levels occur when lichens are moist, and therefore physiologically active. In Switzerland, ozone levels are strongly negatively correlated with moisture content of lichens, such that lichens are essentially always physiologically inactive when ozone levels are high (Ruoss and Vonarburg 1995). Whether this is also true in southern California is unknown. In the Sierra Nevada, ozone pollution is most severe during sunny, dry, hot weather, primarily during the summer months, suggesting minimal impact. However, it is possible that ozone transport over a prolonged period may result in high ozone levels during humid conditions in the mountains, as humidity rises at night.

We made a preliminary evaluation of this question for Sequoia National Park, to better assess the likelihood of ozone injury to lichens. We obtained hourly ozone and humidity data for three years from three sites, choosing the sites and years to give maximum overlap. Data were obtained from the National Park Service Gaseous Pollutant Monitoring Program (Air Resource Specialists, http://12.45.109.6/). We tabulated ozone exceedances under high relative humidities (RH > 90%; Table 5), when lichens are likely to be physiologically active and therefore subject to ozone injury. These values were then compared to ozone exceedances without regard to RH.

Lower Kaweah is the highest station and tends to have the highest humidities of the three stations (Table 5). Although Lower Kaweah station has lower ozone levels than Lookout Point in general, more of those hours have ozone > 45 ppb when RH > 90%. At Lookout Point, ozone exceeds 45 ppb almost 60% of the time, while these levels of ozone are very rare (0.08% of hours) with RH > 90%. Lower Kaweah thus appears to have the highest likelihood of ozone damage to lichens of the three sites. Assuming these stations are representative of their elevations, we would most likely see ozone injury to lichens at relatively high elevations. Yet all sites had so few hours with elevated ozone levels under humid conditions that one could argue that lichens avoid high ozone levels while they are physiologically active.

Table 5. Summary of hourly ozone values at three stations in Sequoia National Park, based on data from 2002-2004. Ozone concentrations exceeding selected values are shown for hours with relative humidity (RH) > 90%, and for all hours, regardless of relative humidity. Lichens are presumed to be physiologically active at RH > 90%. Note the relatively low ozone concentrations under humid conditions.

	Ash Mountain		Lookout Point		Lower Kaweah	
Elevation, m:	457		1225		1890	
Total O_3 hrs:	7183		6458		6984	
% hrs with RH > 90%:	3.2%		6.9%		17.7%	
O_3 (ppb)	% hrs above O_3 level with RH> 90%	% hrs above O_3 level at any RH	% hrs above O_3 level with RH> 90%	% hrs above O_3 level at any RH	% hrs above O_3 level with RH> 90%	% hrs above O_3 level at any RH
> 45	0	45.96	0.08	58.97	1.02	47.27
> 65	0	22.39	0	26.60	0	17.07
> 85	0	5.64	0	6.36	0	2.29
> 105	0	0.16	0	0.03	0	0.06

Acid deposition: Acid deposition is the generic term to include wet and dry deposition of acidic forms of mainly nitrogen and sulfur compounds. Acidic derivatives of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are the principle acidifying agents. In the Sierra Nevada, relatively low emissions of SO_2 make sulfuric acid less likely to be a problem than nitric acid.

Concerns about acid deposition are often focused on the eastern North America, but in the Sierra, the lakes have shown sensitivity to even low levels of acid deposition due to thin topsoils, granitic subsurface layers, sparse vegetation, steep slopes, and a dry climate. Liquid water in the Sierra Nevada comes during late summer rains and spring snowmelts, delivering acidic pulses of water to lakes and creeks (Melack and Sickman 1995, Melack et al. 1998, Mutch et al. 2004, Stohlgren and Parsons 1987).

We have essentially no information on the influence of acidic deposition on lichens in the Sierra Nevada. Is the widespread abundance of nitrophiles in the Sierra a result of nitric acid, ammonium nitrate, or other ammonium compounds? Studies of bark pH would provide suggestive evidence. Co-locating lichen community sampling and passive monitoring of various species of nitrogen would be even more direct and informative.

Pesticides: Pesticides are found in the Sierra parks, but we have no information on their importance to lichens. Sequoia, Kings Canyon and Yosemite are downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, tons of pesticides are applied to crops – 2 billion pounds of active ingredients were applied in California between 1991 and 2000 (Pesticide Action Network in Esperanza and van Mantgem 2004). In 2003, 63 million pounds of active pesticide ingredient including fifteen different fungicides/algicides (http://westernfarmpres.com/news/10-6-05-benefits-of-fungicide-use/) were applied in Fresno, Kern and Tulare Counties (California Department of Pesticide Regulation 2003), all upwind of Sierra Nevada parks. Pesticides volatilize or become suspended in the atmosphere as particulates, then drift into the parks on prevailing winds. Organophosphates have been found in precipitation up to an elevation of 1,920 meters in Sequoia (Zabik and Seiber 1993) and have been measured in plant foliage from low to high elevations (Aston and Seiber 1997).

Certain pesticides negatively affect numerous epiphytic lichens (Bartók 1999) and may cause lichens to peel from their attached substrate, turn reddish-brown, decolor, and stunt normal growth (Alstrup 1991). The mycobiont and photobiont of lichens may be particularly sensitive to fungicides and algicides, respectively. Dormant lichens that seemed unaffected by pesticides showed negative effects up to four months later when rains caused them to activate (Alstrup 1991). Even low doses of pesticides on lichens could conceivably decrease resistance to parasitism, herbivory, and competition.

Deposition and effects of pesticides on lichens in the Sierra parks are largely unknown. The proximity of the Sierra parks to agricultural areas suggests that non-target effects of pesticides on lichens in the parks are possible. Pesticides transported from the Central Valley are also present in lakes and streams and food webs of the Sierra parks (Datta et al. 1998, LeNoir et al. 1999). Effects of these pesticides on aquatic and semi-aquatic lichens are unknown.

Water quality

Atmospheric nitrogen deposition in park watersheds has steadily increased (Lynch et al. 1995). Increased nitrogen and phosphorous loading may cause aquatic eutrophication (Sickman et al. 2002, 2003; Fenn et al. 2003a, 2003b). Emerald Lake in Sequoia, once limited by nitrogen, is now phosphorous limited. The consequences of increased nitrogen deposition and retention on aquatic lichen communities are largely unknown. Casual observation suggests, however, that aquatic lichens are most abundant in and along shallow oligotrophic waters, and largely absent from eutrophic waters.

Lichens living in and along these oligotrophic waters may also be susceptible to episodic acidification. Episodic reduction in acid-neutralizing capacity occurs during snowmelt. Episodic acidification can be caused by “dirty” rainstorms of summer and fall (Melack and Sickman 1995, Melack et al. 1998, Mutch et al. 2004, Stohlgren and Parsons 1987).

Fire

The fire management programs in Sequoia and Kings Canyon and Yosemite National Parks are among the most extensive within the National Parks. Fires are important in restoring and maintaining natural conditions (Caprio and Swetnam 1995, Parsons 1981, Parsons and Nichols 1986; see bibliography of Caprio 2005). In the Sierra Nevada, naturally occurring fires promoted mosaics of different stand ages and diversity (Bonnicksen and Stone 1981, 1982; Parsons 1981, Vankat and Major 1978). In sequoia groves, patches of high intensity fire are needed to open large enough holes in the canopy for sequoias to successfully regenerate (Stephenson et al. 1991, Stephenson 1994). Park managers have used prescribed (or management-ignited) fires for more than 30 years in Sierra Nevada parks to reduce fuels and restore fire as a process in these fire-dependent systems.

Effects of fire on epiphytic lichen diversity and biomass may be influenced by stand age and density, seasons, weather, burn intensity, and flame length. Low intensity burns in open canopy areas are not likely to have negative effects on epiphytic lichen communities, whereas high intensity fires tend to create homogenously dense forest and a decline in lichen diversity and abundance (Lehmkuhl 2004). Both prescribed and lightning-caused fire are often highly variable within stands, with lightly burned spots providing refugia and source propagules for fire-sensitive lichen species. Wildfires in areas with heavy fuel buildups can result in continuous high intensity fires that completely destroy the epiphytic lichen community. In this case, lichen recolonization must occur from propagules arriving from outside the stand.

In sequoia groves, crown scorch height averages 9.1 m (Parsons and Nichols 1986), but is highly variable, ranging from zero to the treetops. The scorch level from which lichens can survive is unknown. The extent of lichen damage and death likely depends not only on the maximum microsite temperatures, but also the duration, as well has the hydration state of the lichen at the time of the fire. Because lichens become physiologically active when moist, fires may have a higher negative impact during wet months as opposed to dry months (Lehmkuhl 2004). In eastern Oregon, spring burning under humid conditions resulted in more mortality of *Bryoria fremontii* than did fall burns with higher scorch heights (R. Rosentreter, personal communication).

Knapp and Keeley (2006) examined the effects of spring versus fall burning in old mixed-conifer forests in Sequoia National Park, but lichens were not included. Perhaps the photographic record of that study is good enough to provide information on lichen effects. If, indeed, lichens are more sensitive to fire when moist, then the more typical fall fire season (for Sierra Nevada) would be more favorable for lichens than spring burning. The spring burns were being evaluated because air quality issues restrict burning less than in fall. On the other hand, “Burning areas with high fuel loads in early season when fuels are moister may lead to patterns of heterogeneity in fire effects that more closely approximate the expected patchiness of historical fires” (Knapp and Keeley 2006). As discussed above, this patchiness could promote the recolonization of burned areas by lichens.

A few lichens respond positively to charred substrates, particularly the small squamulose genus *Hypocenomyce*. Charred bark and wood, particularly on lower trunks, can develop extensive colonies of *Hypocenomyce* that can persist for many decades after a fire.

Fire affects not only epiphytic lichens but potentially also aquatic lichens and biotic crusts. Hot ground fires are known to kill or damage biotic crusts (Johansen et al. 1993), and other ground- and shrub-dwelling lichens (Rosso and Rosentreter 1999). Crustose lichens on rock can also be damaged by fire, particularly when the rocks are surrounded or overlain by fuels. Rock, however, has a high heat capacity, relative to other lichen substrates, moderating the temperature spike during a fire and resulting in higher survival of lichens (pers. obs.).

Considering the tremendous amount of research on fire ecology in the past 40 years, it is remarkable how little research is available for the effects of prescribed fires on lichen species. Wildfire will always be part of western forests, and prescribed fire is a common management tool, so research on lichens in relationship to fire is greatly needed. To assess the effects of prescribed fire on lichen canopy communities, both pre-burn and post-burn data are desirable.

Grazing

Recreational and administrative pack stock graze in Sequoia, Kings Canyon, and to a lesser extent in Yosemite. Pack stock graze in many Sierra Nevada meadows, and administrative pack stock grazing also occurs in the foothills of Sequoia National Park. Feral cows also wander the western boundary areas of Sequoia National Park in the East Fork, Middle Fork, and South Fork drainages of the Kaweah River, and in the Redwood Canyon area of Kings Canyon. These animals trample and devour riparian vegetation, ground lichens, and biotic soil crusts.

Heavy grazing affects many biotic crust species, the amount of disturbance depending in part on soil type (see various papers in Belnap and Lange 2001). We could find no information on biotic crusts in the park, apart from our casual observations (see above under "Biotic Crusts"), much less the effects of grazing on this component of the ecosystem in the Sierra parks. Grazing in montane meadows was summarized by S. Haultain in Mutch et al. (2004):

> "During the mid-1800s and into the early 1900s, most Sierran meadows were grazed, in some cases severely, by cattle and sheep. Many park meadows continue to be grazed by recreational pack stock, and this activity has a suite of known impacts to meadows such as soil compaction, erosion, trampling of vegetation, and changes in plant species composition (McClaren and Cole 1993). Recent research in Yosemite National Park suggests that even moderate levels of such grazing can have a measurable effect on meadow productivity (Cole et al. 2004)."

The presence and abundance of bryophytes and lichens in these montane meadows has apparently not been evaluated. Based on observations in other mountain systems, moist and wet meadows with lush vascular vegetation tend to have few lichens. In wet meadows, mosses can become a prominent part of the vegetation, including such wetland species as *Aulacomnium palustre*. Dry meadows have more potential for cryptogamic crust development. Of particular interest in the Sierra are the inclusions of calcareous bedrock, which may support regionally rare calciphilic lichen species, such as *Solorina spongiosa* in wet areas and numerous soil crust species in dry areas.

Hetch Hetchy Valley

The possibility of draining Hetch Hetchy Reservoir has been discussed for decades (National Park Service 1988, Restore Hetch Hetchy 2005). Lichen communities on bedrock of the valley walls were killed by submergence when the reservoir was created. Draining the reservoir would leave pale, exposed granite below the high water mark, contrasting with the darker lichen covered rocks above the level of the reservoir. Draining the reservoir would, therefore, form a conspicuous "bathtub ring" around the valley. This ring is apparent during low water, and would be even more obvious if the reservoir was completely drained. Draining the reservoir would initiate a primary succession on the re-exposed rock.

Given enough time, rock exposed after draining the reservoir would be recolonized by lichens, first subduing the contrast of the ring, eventually making it so subtle as to be indistinguishable by casual observation. The pace of these changes is unknown, but presumably it would depend on the local microsites. Seepage tracks are likely to quickly re-acquire semi-aquatic lichens. Cool exposures and relatively moist, sheltered areas are likely to have a faster rate of succession. Because the chemical environment during colonization of the bare rock differs from that at the time of lichen establishment on the higher rocks, it is likely that the rocks below the waterline will support lichen communities that differ from those above the line for a very long time; certainly for decades, possibly for centuries.

Can the rate of lichen succession be accelerated, so that the bathtub ring is quickly erased? The answer is unknown, but we do know that attempts to stimulate lichen growth, such as watering and fertilizing, are generally counterproductive. Most lichens require frequent cycles of wetting and drying, do not tolerate high nutrient levels, and are among the most difficult organisms to culture. It is unlikely, therefore, that attempts to stimulate lichen growth would be successful, and such attempts might inhibit lichen growth. Localized trials of various methods for accelerating lichen colonization could, however, prove informative, if not for the benefit of restoration of Hetch Hetchy Valley, at least for other reservoirs slated for draining.

Existing Lichen Data

FIA lichen community data: Describing gradients in lichen community composition contributes towards an ecological understanding of lichen species, communities, and ecosystem health (McCune 2000; Jovan and McCune 2004, 2005, 2006). The principle of lichen indication of forest health was the basis of the inclusion of lichen communities as an indicator in the national Forest Health Monitoring (FHM) program, now conducted under the auspices of the Forest Inventory and Analysis program (FIA).

Lichen data are available from 1998-2003, in various subsets of the sampling grid used for the FIA program, along with off-grid plots sampled by Jovan and McCune (2005, 2006; Fig. 1). Of these plots, only 6 on-frame plots and 3 off-frame plots have fallen within the Sierra parks (Table 6). At this time an analysis of trends in the FIA data is not possible; this awaits application of a lichen community gradient model recently developed by Jovan and McCune (2006) to data sets that are not yet complete.

A successful and practical protocol for monitoring epiphytic macrolichen diversity and abundance is used by the Forest Inventory and Analysis program (FIA; methods in McCune et al. 1997). This protocol for recording epiphytic macrolichens has been applied to thousands of plots nationwide (McCune 2000). Similar surveys can also be added for crustose, terricolous, and aquatic lichens.

Vegetation in the Sierra Nevada differentiates along both an elevation gradient and a topographic moisture gradient (Urban et al. 2000, 2002). Lichen communities also differentiate along these gradients in the Sierra Nevada, and therefore probably differ with respect to vegetation type (Jovan and McCune 2006).

Figure 1. Lichen community plots sampled in the Sierra Nevada from 2000-2003. Small solid dots are "fuzzed coordinates" for on-frame plots sampled for the FIA program. Fuzzed coordinates have a small random number added to protect landowner privacy. Large dots are off-frame plots sampled for development of gradient models. Fine lines mark ecoregion boundaries and the California-Nevada state line.

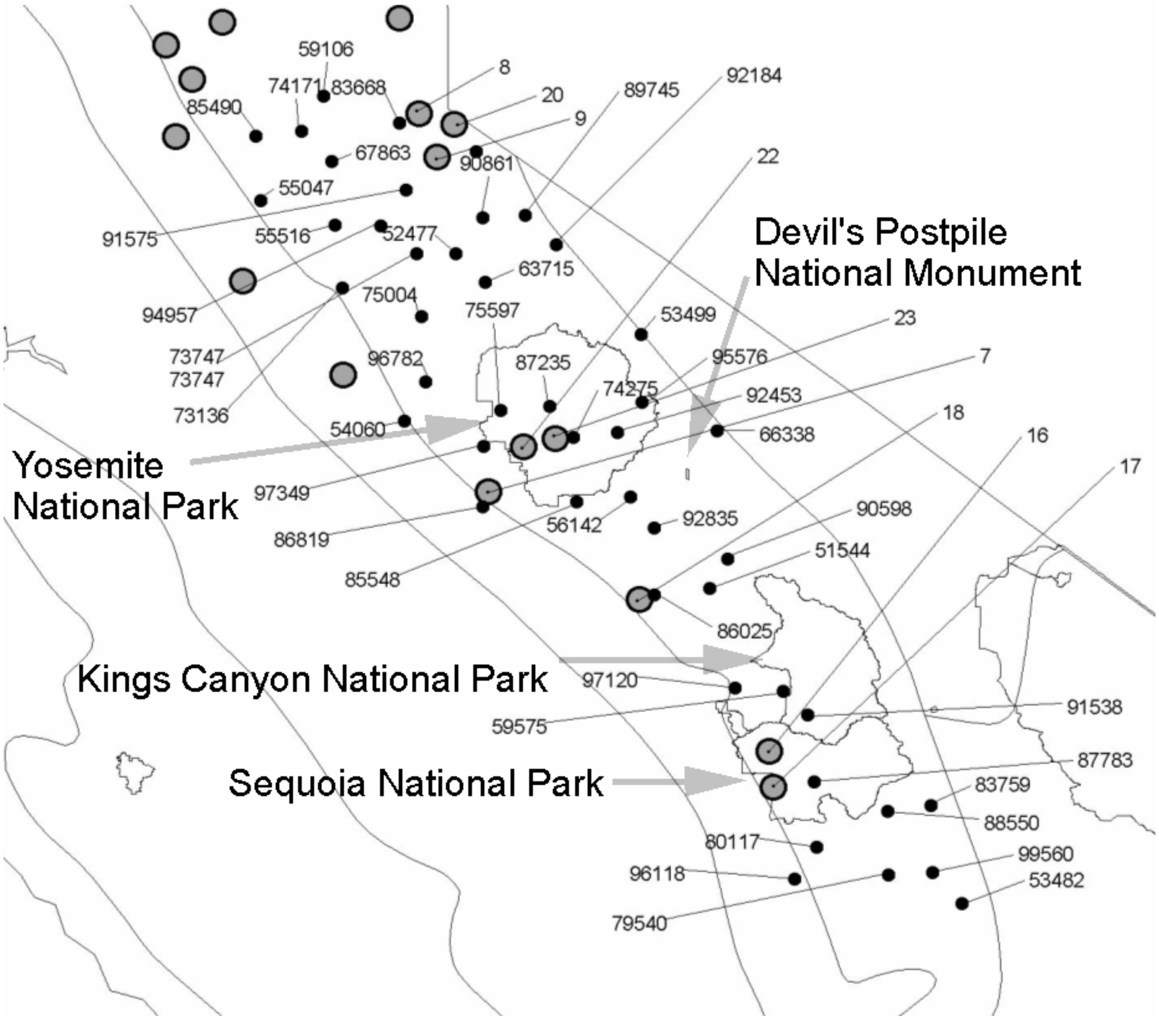

Table 6. Approximate number of FIA lichen community plots falling within the Sierra Parks. The FIA program does not reveal exact plot locations to protect landowner privacy, so these numbers are approximate. On-frame plots are part of the regular formal sampling pattern of FIA; off-frame plots are temporary plots added by Jovan and McCune (2005, 2006) for development of gradient models.

	Number of plots	
Park unit	On-frame	Off-frame
Devils Postpile	0	0
Kings Canyon	1	0
Sequoia	1	1
Yosemite	4	2

Table 7. Frequencies of macrolichen species occurring in FIA plots in the Sierra Nevada, including only those plots between 36° and 40° N latitude that were sampled between 1998 and 2003. Several species were present in the database but are considered doubtful records, such as *Hypogymnia metaphysodes* and *Physcia leptalea*. Some species in the list are not yet known from south of Yosemite. Records that were not identifiable to genus are excluded.

Species	On frame (46 plots)	Off frame (9 plots)
Ahtiana sphaerosporella	12	3
Candelaria concolor	16	6
Cetraria merrillii	13	7
Cetraria orbata	7	0
Cetraria pallidula	1	0
Cetraria platyphylla	5	1
Cetrelia cetrarioides	1	0
Collema furfuraceum	4	1
Collema nigrescens	2	0
Esslingeriana idahoensis	2	1
Evernia prunastri	7	2
Flavopunctelia flaventior	3	0
Hypocenomyce scalaris	1	0
Hypogymnia enteromorpha	1	0
Hypogymnia imshaugii	18	9
Hypogymnia inactiva	1	0
Hypogymnia metaphysodes	2	0
Hypogymnia physodes	1	0
Leptochidium albociliatum	1	0
Leptogium lichenoides	3	0
Leptogium pseudofurfuraceum	1	0
Letharia columbiana	20	8
Letharia vulpina	29	8
Melanelixia glabra	11	3
Melanelixia subargentifera	0	2
Melanohalea elegantula	6	4
Melanohalea exasperatula	3	1
Melanohalea subelegantula	3	0
Melanohalea subolivacea	17	7
Nephroma helveticum	1	0
Nodobryoria abbreviata	12	0
Nodobryoria oregana	1	0
Normandina pulchella	2	0
Parmelia hygrophila	0	1
Parmelia sulcata	6	6
Parmelina quercina	6	1

Table 7, cont.

Species	On frame (46 plots)	Off frame (9 plots)
Peltigera collina	3	0
Phaeophyscia ciliata	1	1
Phaeophyscia orbicularis	3	2
Physcia adscendens	6	4
Physcia aipolia	6	1
Physcia biziana	3	2
Physcia dimidiata	2	0
Physcia dubia	0	0
Physcia leptalea	1	0
Physcia stellaris	2	6
Physcia tenella	8	6
Physconia americana	4	4
Physconia enteroxantha	6	6
Physconia fallax	0	2
Physconia isidiigera	5	4
Physconia perisidiosa	11	6
Platismatia glauca	5	1
Pseudocyphellaria anomala	1	0
Pseudocyphellaria anthraspis	2	0
Tholurna dissimilis	1	0
Usnea diplotypus	1	0
Usnea hirta	1	0
Usnea pacificana	1	0
Usnea subfloridana	1	0
Vulpicida canadensis	2	1
Xanthomendoza fallax	1	2
Xanthomendoza fulva	3	4
Xanthomendoza hasseana	5	6
Xanthomendoza oregana	7	4
Xanthoria parietina	2	0
Xanthoria polycarpa	4	5

Elevation is one of the strongest factors influencing forest community patterns in the southern Sierra Nevada (Parker 1982, Vankat 1982, Rundel et al. 1977, Jovan and McCune 2006). Hardwood forests predominate at lower elevations, grading into essentially pure conifers at higher elevations. Epiphytic lichen diversity and abundance generally tend to decrease with increasing elevation in the Sierra (Jovan and McCune 2006), at least partly in concert with the decreasing hardwood component. Conifer forests host a different blend of lichen species compared to hardwood forests. Jovan and McCune (2006) found that a small contingent of non-nitrophilous species, such as *Ahtiana sphaerosporella*, *Letharia vulpina*, *L. columbiana*, and *Cetraria merrillii*, usually dominate high-elevation conifer forests. Hardwood forests in the Sierra Nevada support diverse lichen communities. Pockets of hardwood forests in a matrix of conifer forest can be hotspots for lichen diversity (Neitlich and McCune 1997).

At this time, we have very little information on the occurrence of rare lichen species in various vegetation zones and topographic positions. Landscape distribution of rare lichen species may be associated with special habitat types and fine scale microclimate variables (McCune et al. 1997; Neitlich and McCune 1997; Peterson and McCune 2003; Pykälä 2004; Martin 2005). These factors can include the presence of hardwood trees, canopy gaps, rock outcrops, drainages, and old-growth legacy trees.

Floristic studies: We could find only two comprehensive lichen floristic studies of the Sierra parks (Smith 1980; Wetmore 1985, 1986). Smith sampled 13 sites in Sequoia and Kings Canyon National Parks. He reported 40 macrolichen species, a small proportion of the actual macrolichen flora. Specimens are presumably housed at San Francisco State University herbarium (SFSU), although we have not verified this.

Wetmore (1985) collected from 35 localities in the Kaweah River drainage and reported 197 species, along with 41 unidentified species. Judy Blakeman collected at an additional seventeen localities, focussing on the Grant Grove section of Kings Canyon NP and Kern Canyon in Sequoia NP. These specimens were then identified by Wetmore (1986). Specimens are housed at the University of Minnesota herbarium (MIN). Combined, Wetmore's lists contained 207 species.

Imshaug (1957) reported on macrolichens from nine summits in the Sierra. Three of these are in Yosemite National Park (Mt. Dana, Mammoth Peak, and the ridge above Parker Pass). Elevations in Yosemite ranged from 3596-3977 m (11800-13050 ft). The macrolichen flora of these areas was not well developed, compared to the Rocky Mountains and the Pacific Northwest. Most of the typical alpine macrolichens, such as *Thamnolia* and *Coelocaulon*, were absent. Presumably the crustose lichen flora of Sierra alpine areas would be better developed than the macrolichen flora.

Two floristic studies of lichens were conducted in nearby areas outside the National Parks. Ryan and Nash (1991) listed over 100 lichen species from the eastern Brooks Lake watershed on the east slope of the Sierra in the Inyo National Forest. Most of these were crustose species on rock. Specimens were deposited in the Arizona State University herbarium (ASU) and the Sierra Nevada Aquatic Research Laboratory near Mammoth Lakes. Not far north of Yosemite NP, Pinelli and Jordan (1978) reported 85 species of lichens from Calaveras Big Trees State Park. They focused almost entirely on macrolichens. Specimens were deposited in the herbaria of the University of San Francisco (SAFU) and San Francisco State University (SFSU).

Floristic lichen inventories in the Sierra parks are now outdated. In recent decades, rapid advances in lichen systematics have clarified the lichen flora of western North America, with the result that many of the names in existing lichen taxonomic inventories in the Sierra parks represent unnaturally broad species concepts. In many cases these are incorrect applications of European species concepts to North American species. Crustose species are under-represented. In short, the existing information on lichens in Sierra parks has all of the usual problems encountered when trying to use older species lists.

Yosemite has only 95 lichen species recorded in the NPS lichen database. Clearly, this greatly underestimates the actual species number. As of 2005, Sequoia National Park shows 250 lichen species in the NPS lichen database; Kings Canyon lists only 107 (www.ies.wisc.edu/nplichen; July 2005). These two parks share a border, and have similar climates and habitats, so the overlap in species lists is probably greater than the current lists would suggest. On-line database searches found no collections from Devils Postpile National Monument, nor were any lichen records shown for it in the NPS lichen database.

Many lichen species newly described in recent years are likely to be found in the Sierra parks. Examples of such species already known from the parks include *Caloplaca stellata* (Wetmore and Kärnefelt 1998), *Hypocenomyce sierrae* (Timdal 2001), *Psora hyporubescens, Rinodina lignicola* (Sheard and Mayrhofer 2002), *Lecidea fuscoatrina* and *L. perlatolica* (Hertel and Printzen in Nash et al. 2004). The type locality of the recently described *Physconia californica* is from Sequoia NP on the North Fork of the Kaweah River (Esslinger 2000).

Careful study of the Sierra parks lichen floras would certainly bring many range extensions. So far these have accumulated haphazardly (e.g., Kolb and Spribille 2001, Rikkinen 2003) and rather slowly, because the lichen flora of the Sierra parks is not well represented in major herbaria other than MIN.

Photo points on prescribed fire transects: As part of the evaluation and monitoring of prescribed burning, photo points document the appearance of permanent transects through the burned areas. These transects have been installed at approximately 80 plots of varying ages (A. Caprio, pers. comm. 2005). The photos immediately precede the burn, then follow the burn at increasing intervals (before, immediately after, and 1, 2, 5, 10, and 20 years). This work has followed the protocol of the Fire Monitoring Handbook (National Park Service 2003a).

These photo points may provide a valuable, yet previously overlooked resource for monitoring the initial lichen response and recovery to prescribed burning. Examination of some sample photos from Sequoia National Park suggest that the photo quality will be sufficient to record changes in at least *Letharia vulpina* on trunks and branches near the photo point. Casual observations suggest that destruction of lichens on lower trunks and branches is highly variable. We know essentially nothing about the pace of recovery of *Letharia vulpina* following partial or complete destruction on bark.

Lichen biomass: Shaw and Acker (2002) reported canopy lichen biomass data from four conifer stands in Sequoia and Kings Canyon National Parks. The four locations are reference stands that have intensive sampling of stand structure, all between 2000 and 2200 m in elevation. Dominant trees include sugar pine, white fir, giant sequoia, and Jeffrey pine. Based on inference from lichen litter collections, they estimated biomass of the major macrolichen species. Totals ranged from 7-34 kg/ha (oven dry weight). The dominant macrolichens were *Letharia vulpina, Hypogymnia imshaugii*, and *L. columbiana*, in decreasing order of abundance. No stand-level estimates exist for biomass of epiphytic crustose lichens.

Elemental analysis: Elemental content of lichens is commonly used as a method of assessing atmospheric pollutants (Blett et al. 2003). Two sources of such data are available for the Sierra parks. Wetmore (1985) reported concentrations of 16 elements in *Letharia vulpina* and *Hypogymnia imshaugii* from 9 and 4 sites, respectively, in Sequoia National Park. An additional 4 sites were reported for each species by Wetmore (1986). Unfortunately, nitrogen was not among the elements evaluated.

Rhoades (1999) provided extensive comparison data for elemental content of these species. The best comparison data are available for *Letharia vulpina*, with elemental content data available for five wilderness areas in California, in addition to Sequoia and Kings Canyon National Parks. Excluding the San Gabriel wilderness near Los Angeles, which is alarmingly high in most elements, Sequoia National Park is similar to the other wilderness areas. Sequoia and Kings Canyon NPs emerged exceptionally high only in lead, and rather high in copper and nickel.

A third study measured nitrogen content of *Letharia*, as part of a larger study of the Sierra Nevada and Modoc Plateau (Jovan and Carlberg 2007). This sampling was done in conjunction with lichen plots for the FIA program (see above). They found high N content in *Letharia* collected near Kings Canyon and Sequoia Parks, in agreement with the elevated N from direct monitoring data (Bytnerowicz et al. 2002) and abundance of nitrophytic lichens (Jovan and McCune 2006).

Lichen communities and nitrogen species in Kings River watershed: Jovan collected lichen community data in plots co-located with direct monitoring of various forms of nitrogen (A. Bytnerowicz et al., unpublished). Analysis of these data is still in process. The outcome should help to clarify differential responses of lichen communities to different forms of nitrogen.

WACAP lichen data: Sequoia and Yosemite National Parks cooperated in the Western Airborne Contaminants Assessment Project (WACAP; National Park Service 2003b). This study was initiated by the National Park Service in 2002, in collaboration with the Environmental Protection Agency, the US Geological Survey, the USDA Forest Service and several universities. The purpose of the project is to determine the risk to ecosystems and food webs in western National Parks from the long-range transport of airborne contaminants, in particular, semi-volatile organic compounds (SOCs). These include various persistent organic pollutants such as PCBs and DDT. Some of these materials have physical properties that permit them to accumulate preferentially in colder areas of the environment. Thus high-latitude and high-elevation ecosystems may be at greater risk due to the accumulation of these toxins.

Sampling for the WACAP program in 2003 found both current-use and banned SOCs present throughout monitored indicators (lake water, snow, lichens, and other biological materials) in high-elevation ecosystems of the Sierra parks. "Very early data ... from last summer's sampling at Sequoia NP show current-use and banned SOCs are present in water, snow, and lichen at the two watersheds sampled. The initial sample analysis indicates that Sequoia NP likely has a broader range of these compounds than does Rocky Mountain NP" (Rocchio 2004). Data analysis and reporting are still in progress.

Aquatic lichen data: The US Forest Service has surveyed aquatic lichens on the west side of the Cascade crest, south to Mendocino National Forest and Shasta National Forest near McCloud (L. Geiser and D. Glavich, unpublished data). We know of no similar work to the south in the Sierra Nevada.

These aquatic lichen surveys were within the framework of the Aquatic Riparian Effectiveness Monitoring Program, which was created to monitor stream and overall watershed health across the Northwest Forest Plan area (Moyer et al. 2000). Aquatic lichen abundance for each stream was recorded by population size classes: 0 = 0, 1 = 1 – 10, 2 = 10 – 100, 3 = 100 – 1000, 4 = >1000 individuals. When a target lichen species was found, habitat data were also recorded.

Bryoria fremontii studies at Teakettle Experimental Forest: Tom Rambo at the University of California at Davis has been studying the ecology of *Bryoria fremontii* at Teakettle Experimental Forest in the Sierra Nevada (Rambo 2004, North et al. 2002). Although results from his study are not yet available, preliminary data from Teakettle indicated a positive association between *Bryoria* and red fir that increases with proximity to perennial water (Rambo 2004). Rambo is determining "...the ecological requirements of *Bryoria* (1) in relationship to overstory versus understory strategies of forest fuel reduction and (2) its positive association with red fir in the Teakettle red fir/mixed-conifer ecotone" (Rambo 2004).

Herbarium databases: Many herbaria around the world are in the progress of databasing their specimens, and making these data available over the web. Apparently no major collections have complete online databases at this time, but enough data are available to give a glimpse of the frequency of specimens from the Sierra parks in these herbaria. Other than the records in the MIN database, the representation of Sierra park lichens in herbaria is meager.

It is important to realize that even if herbarium records are found online, many of those specimens are identified incorrectly or have not been re-examined in light of our current species concepts. Thus, online database records must be treated with some skepticism. Still, they are quite useful as an indication of where to look for existing specimens.

Lichens on sequoia cones: Sequoia cones were collected from various canopy positions by Steve Sillett (Humboldt State University, Arcata, California) in selected trees in Sequoia National Park. These cones are a persistent, durable substrate for lichens. Many of these cones are, therefore, heavily colonized by lichens (mainly crustose species, some macrolichens). At present the epiphytic species on this sample of cones has not been systematically identified, but they represent another potential source of information on biodiversity, a component of the Park's flora that is unique to the Sierra Nevada. Further study of lichens on these cones could contribute both floristic and ecological information.

Lichen Inventory and Monitoring Needs

We envision several different classes of lichen inventory and monitoring approaches. These have potential to address more than one management issue (Table 8). Other approaches are possible, but we selected these to maximize the value of the work to the management issues.

We recommend that the Sierra parks consider the following short list for future inventory and monitoring work. Although many other topics deserve study, we chose this list based on the following criteria:

- Relevance to management issues in the parks, as described above
- Feasibility of yielding useful data in two time frames: short-term products and utility for long-term monitoring
- Affordability and practicality

Our top four recommendations are listed below, followed by a brief summary of the importance of the topic, and a suggested approach. In addition, we suggest several quick surveys to evaluate the need for monitoring work in several habitats.

Population status and trend of Bryoria

Importance: Of all major macrolichen species in the Sierra parks, *Bryoria fremontii* is in a particularly marginal, tenuous position, yet it is

Table 8. Connections of inventory and monitoring approaches to management issues in the Sierra Nevada national parks. The strongest connections are indicated by "X."

	Connections to management issues				
Inventory and monitoring approach	Biodiversity	Air quality	Fire	Water quality	Grazing
Revise and update lichen inventory	X	X		X	X
Bryoria fremontii populations – habitat models and monitoring		X	X		
Aquatic lichen survey	X	X		X	
FIA grid 3X intensification	X	X	X		
FIA lichen plots stratified by vegetation (see below)	X	X	X		
Plot-based lichen inventory, all species and substrates	X	X	X		X

likely important in food webs wherever it occurs in significant amounts. *Bryoria fremontii* is probably sensitive to excess nitrogen deposition and other air pollutants. It seems quite likely that *Bryoria* populations have greatly diminished through time, especially in Sequoia and Kings Canyon National Parks. If, indeed, *Bryoria* is rapidly being lost from the Sierra parks, then this project is urgent.

Suggested approach: Conduct an extensive survey of presence-absence, approximate abundance, and maximum length of *Bryoria fremontii* throughout the Sierra parks. Use this information to construct a habitat model, formalizing the relationship between *Bryoria* populations and habitat characteristics. Future losses or gains of *Bryoria* populations (significant departures from expectations) could then be easily detected in particular habitats. Specimens should be archived for the purpose of future analyses of metals and other toxic substances.

Macrolichen community monitoring

Importance: Casual inspection suggests that the macrolichen flora of Sequoia NP has already deteriorated, through reductions in abundance of the natural flora and increase in abundance of weedy nitrophilous species. It does not appear that the lichen flora of Yosemite NP has degraded as much as Sequoia NP. It is urgent that we capture a clear snapshot of this system in transition, and establish a basis for evaluation of future changes. Crustose lichens are also potentially informative, but we lack the regional context for interpreting them that is provided for macrolichens by the FIA program.

The benefits of regional lichen community data include documenting the invasion and extinction of species, enhancing our knowledge of the distribution and abundance of lichens, understanding the potential for indicating air quality and forest health, increasing appreciation by non-lichenologists for the importance of lichens as contributors to ecosystem function and diversity, and building collections from poorly studied areas (McCune 2000). The FIA program in the western states is providing many of these results, but the existing density of FIA plots in the Sierra parks is insufficient to represent the status and trends of lichen communities on a park-by-park basis. An intensified system of FIA-style lichen community plots in the Sierra parks would provide a multi-purpose lichen monitoring framework.

Suggested approach: Install a set of about 25 plots in each of the three major parks, five plots in each of 5 vegetation types for each park. Use the FIA-style plots (circular, 0.38 hectares) to maximize comparability and integration of the results with the regional FIA grid and to minimize the number of permanent markers required (one per plot center). Use lichen communities to calculate air quality scores for the plots based on the model in Jovan and McCune (2006). Calculate climate scores based on gradient model of lichen communities in Jovan and McCune (2004). Plots can be revisited and new scores calculated periodically, to evaluate changes in the parks.

Update the inventory of lichen biodiversity

Importance: We have a good start on a floristic inventory of Sequoia National Park, but the other Sierra parks are far behind. A lichen inventory not only documents a large and as-yet-unknown chunk of biodiversity in the Sierra parks, but also provides improved basis and support for ecological studies. In particular, macrolichen community monitoring would benefit from a careful study of the Park's flora. We recommend targeted field sampling of neglected habitats and taxonomic groups, followed by identification, preparation of vouchers, and additions to a database. Neglected habitats include alpine, high subalpine, and aquatic environments. Calcareous rock and soil also deserve more attention. Better knowledge of the crustose lichens provides a basis for evaluation of other management issues relating to lichens, such as biodiversity, the potential "bathtub ring" if Hetch Hetchy Reservoir is drained, and evaluation of air pollution impacts on rock faces. The representation of the lichen flora in park herbaria would also improve.

Suggested approach: The problem needs to be attacked on several fronts: improvement of the park herbaria, revision of specimens in selected regional and national herbaria, intensive collection and documentation of biodiversity by a team of professional lichenologists, and assembling all of this information into a database.

Quick Surveys

We found it difficult to evaluate the importance of several management issues to lichens, for lack of information on lichens. This need could be relieved with several quick surveys, perhaps one week of field effort for each:

- Aquatic lichens
- Biotic crusts in calcareous areas
- Biotic crusts (terrestrial lichens) in grazed meadows
- Crustose lichens on rock climbing routes
- Pin lichens

Each of these surveys could be approached in a similar way – by having scientists with experience in lichen ecology and floristics visit a series of sites. It is important that the lichenologists be skilled with crustose species, because these are likely to be the majority of species in many cases. Sites for each survey could be chosen in a range of topographic positions. A short report would summarize the species found by location, the prominence of lichens in the various habitats, and an evaluation of the need for more formal monitoring in each case.

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