CHAPTER 12

Lichens

Sarah E. Jovan[1]

The status of epiphytic (i.e., tree-dwelling) lichen communities is systematically tracked by the Forest Inventory and Analysis (FIA) and national Forest Health Monitoring (FHM) programs of the Forest Service, U.S. Department of Agriculture (http://fia.fs.fed.us/lichen/default.asp). Lichens are highly sensitive to climatic and chemical perturbations, and can be used for early detection of changes in climate and air quality (Jovan 2008). This forewarning gives land and air managers the opportunity to attempt mitigation before less sensitive organisms and ecosystem processes are affected. Monitoring to ensure maintenance of intact lichen communities likewise has direct consequence for forest health due to the ecological linkages of the lichen communities to other forest flora and fauna (http://www.lichen.com/fauna.html). Such linkages include provision of critical winter forage for ungulates, camouflaging nesting material for many species of bird and rodent, and fixation of atmospheric nitrogen (N) into a form useable by plants (Nash III 1996).

Several common pollutants affect lichens although relationships to sulfur dioxide (SO_2; Hawksworth and Rose 1970), N-containing pollutants (van Herk 1999, 2001; van Herk and others 2003), and acidic deposition (Gilbert 1986) are the best understood. Sensitivity to a particular pollutant is species-specific, and therefore, the better we understand responses of individual species, the more precisely we can use information on lichen distribution and abundance to map and quantitatively estimate air quality risks.

Core data of the FIA/FHM Lichen Communities Indicator are surveys of permanent 0.4 ha forested plots wherein the mixture and abundance of each species is recorded. Traditional Detection Monitoring (DM) activities for a particular region (e.g., a State or distinct ecoregion) involve analyzing these community data with a multivariate model. Large-scale assessments of air quality are produced (Jovan 2008), which often result in detection of one or more pollution hotspots (i.e., high risk areas) per region.

Both lichen projects –supported by Evaluation Monitoring (EM) funds through the FHM program—provide integral support for the air quality application of the FIA/FHM Lichen Communities Indicator. Controlled studies—such as those under the EM-funded project of Riddell and others (2008)—that link physiological response to pollutant dose are in short supply yet are among the most valuable research contributions in the field of lichen-air quality bioindication. The second EM-funded project by Petersen and Neitlich (2001) was an in-depth investigation of a pollution hotspot identified by DM activities in Colorado (McCune and others 1998). Smaller-scale inspection of such high-risk areas is essential to a thorough forest health inventory.

Project WC-EM-07-05: Improving the Interpretation of Lichen Biomonitoring for Nitric Acid and Ozone Air Pollution in the Detection Monitoring Program

Riddell and others (2008) measure the physiological effects of a highly phytotoxic vapor found in photochemical smog, nitric acid (HNO_3), on pollution-sensitive lichen. Scientists recently discovered the predominance of HNO_3 in the Los Angeles Basin where arid forest ecosystems receive exceptionally high N loading. Growing anecdotal evidence suggests HNO_3 has played a large role in degradation of lichen communities in the basin, which experienced a 50 percent loss in species since the flora was characterized at the end of the 19th century (Riddell and others 2008). Until recently, this role was attributed to ozone (O_3).

The research of Riddell and others (2008) is the first to measure experimentally the physiological effects of HNO_3 on lichens and demonstrate the high toxicity of HNO_3. Results directly inform nascent DM activities of the FIA/FHM Lichen Communities Indicator in southern California (due for publication in 2011). Results likewise provide an essential empirical basis for determining a HNO_3 critical load for lichens. Critical loads are pollutant loading thresholds below which sensitive species, like lichens, are unharmed; information about these loads increasingly is sought by policymakers for establishing air quality guidelines that preserve ecosystem integrity (Fenn and others 2008, Porter and others 2005).

[1] Research Lichenologist, U.S. Forest Service, Pacific Northwest Research Station, Portland, OR, 27205; telephone: 503-808-2070; email: *sjovan@fs.fed.us*.

Transplants of the lichen *Ramalina menziesii* were subjected to month-long fumigations in growth chambers. This formerly abundant species is now nearly extinct in the Los Angeles Basin. Besides in controls, nitric acid levels were varied in each chamber over 24 hours to simulate daily fluctuations experienced in the basin. Thus, each nitric acid treatment is described by a concentration range; chambers received dosages ranging from 7-25 µg m^{-3} to 26.4-35.3 µg m^{-3}, resembling moderate to high concentrations. Potential interactive effects of climate also were tested by simulating humid conditions in some chambers and dry conditions in others.

Results were dramatic. Photosynthetic ability was swiftly impaired in all lichens treated with HNO_3 as indicated by decreased chlorophyll content and carbon exchange capacity. Thalli became bleached. By about 28 days, both photosynthesis and respiration were arrested to near zero in lichens exposed to even the lowest HNO_3 dose. When rinsed, fumigated lichens became increasingly "leaky" over time, meaning their cells lost ions due to damage at the cell membrane. Riddell and others (2008) further demonstrated that HNO_3 toxicity seems more acute under dry conditions, a result that is particularly notable for the FIA/FHM Lichen Communities Indicator and associated critical load research.

Work on this project continues. For the second phase, investigators conducted a field study in summer 2009 to link lichen community composition to N measurements in the LA Basin (estimated completion: 2011); a main objective is to describe ecological effects of N and, if possible, parse out the influence of HNO_3 on community structure. Also under way is a second round of fumigations to determine if O_3 levels affect how HNO_3 affects lichen physiology and survivorship (estimated for completion in 2011).

Project INT-EM-99-01: Impacts of Two Coal-fired Power Plants on Lichen Communities in Northwestern Colorado

Peterson and Neitlich's (2001) EM-funded project was a follow-up to DM efforts in Colorado. McCune and others (1998) used survey data from the FIA/FHM Lichen Communities Indicator (n = 185 plots) to summarize large-scale air quality patterns across Colorado. They identified the Steamboat Springs area of the Park Range as a potential pollution hotspot based on composition of the lichen communities there. Other lines of evidence specifically pointed to an SO_2 problem, as follows: (1) the Steamboat Springs area lies downwind of two coal-fired power plants in Yampa Valley, (2) high S was detected in lichen material collected from nearby Mt. Zirkel wilderness (Jackson and others 1996), and (3) relatively high nitrate and sulfate deposition (for rural Colorado) was measured by National Atmospheric Deposition Program monitors.

Peterson and Neitlich surveyed lichens at additional plots (n = 35, a 7x intensification of the FIA/FHM inventory grid) in the problem region, roughly defined as the western and upper eastern slopes of the Park Range. Upon closer inspection, no unequivocal statistical evidence of pollution damage was uncovered. Major patterns in community structure were closely patterned on topographic gradients—which is not to say lichens were unaffected by air quality but it suggests that pollution effects are not acute.

Evidence of pollution impact was subtle, suggested by the negative correlation of a highly pollution sensitive species, *Bryoria fuscescens*, with proximity to the pollution point sources. Loss of *Bryoria* species is ecologically damaging due to their use by wildlife for forage and nesting material. Fortunately, stricter emissions controls were implemented around the time of this study in response to evidence of ecological damage in Mt. Zirkel. Thus, pollution stress should lessen, and *Bryoria* may be able to recolonize any habitats in which it was extirpated.

Relevance to Policy and Land Managers

The keystone work of Riddell and others (2008) on HNO_3 critical loads made a significant contribution to efforts of the Environmental Protection Agency to set a secondary standard for nitrogen oxides; their study was heavily cited in HNO_3-focused parts of the Integrated Science Assessment (EPA 2008). The work of Peterson and Neitlich (2001) helped land managers assess whether Air Quality Related Values (AQRV) (i.e., pollution-sensitive resources) are being degraded in the Colorado Park Range. Managers are required by the Federal Clean Air Act to protect AQRVs in Mandatory Class I Federal areas, which include wilderness areas like Mt. Zirkel that exceed 5,000 acres in size.

Suggestions for Further Investigation

Any experimental investigation of the tolerances of individual lichen species to particular pollutants would be invaluable, as would experimental and observational studies that identify lichen critical loads for regions besides the well-studied Pacific Northwest. Moreover, the usefulness of the FIA/FHM Lichen Communities Indicator for monitoring climate change has been largely ignored in favor of air quality applications. At this early stage, we need more foundational work that elucidates reliable lichen indicator species of temperature and moisture shifts.

Literature Cited

Fenn, M.; Jovan, S.; Yuan, F. [and others]. 2008. Empirical and simulated critical loads for nitrogen deposition in California mixed conifer forests. Environmental Pollution. 155: 492-511.

Gilbert, O.L. 1986. Field evidence for an acid rain effect on lichens. Environmental Pollution. 40: 227–231.

Hawksworth, D.L.; Rose, F. 1970. Quantitative scale for estimating sulfur dioxide air pollution in England and Wales using epiphytic lichens. Nature (London). 227: 145–148.

Jackson, L. L.; Geiser, L.; Blett, T. [and others]. 1996. Biogeochemistry of lichens and mosses in and near Mt. Zirkel Wilderness, Routt National Forest, Colorado: influences of coalfired power plant emissions. U.S. Department of the Interior, Open-file Report 96-295.

Jovan, S. 2008. Lichen bioindication of biodiversity, air quality, and climate: baseline results from monitoring in Washington, Oregon, and California. Gen. Tech. Rep. PNW-GTR-737. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 115 p.

McCune, B.; Rogers, P.; Ruchty, A.; Ryan, B. 1998. Lichen communities for forest health monitoring in Colorado, USA. Internal report to the Interior West Region of the Forest Health Monitoring Program, U.S. Department of Agriculture Forest Service. http://www.fia.fs.fed.us/lichen/pubs [Date last accessed: July 27, 2011]

Porter, E., Blett, T., Potter, D.U., and Huber, C. 2005. Protecting resources on federal lands: implications of critical loads for atmospheric deposition of nitrogen and sulfur. Bioscience. 55: 603-612.

Peterson, E.B.; Neitlich, P. 2001. Impacts of two coal-fired power plants on lichen communities in Northwestern Colorado. Internal report. Interior West Region of the Forest Health Monitoring Program. U.S. Department of Agriculture Forest Service. http://fia.fs.fed.us/lichen/pubs [Date accessed: July 27, 2011].

Riddell, J.; Nash III, T.H.; Padgett, P. 2008. The effect of HNO_3 gas on the lichen Ramalina menziesii. Flora. 203: 47-54.

Van Herk, C.M. 1999. Mapping of ammonia pollution with epiphytic lichens in the Netherlands. Lichenologist. 31: 9–20.

Van Herk, C.M. 2001. Bark pH and susceptibility to toxic air pollutants as independent causes of changes in epiphytic lichen composition in space and time. Lichenologist. 33: 419–441.

Van Herk, C.M.; Mathijssen-Spiekman, E.A.M.; de Zwart, D. 2003. Long distance nitrogen air pollution effects on lichens in Europe. Lichenologist. 35(4): 347–359.