The Bryologist 103(2), pp. 353–356

INVITED ESSAY

New Frontiers in Bryology and Lichenology

Lichen Communities as Indicators of Forest Health

BRUCE MCCUNE
Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331-2902, U.S.A. e-mail: mccuneb@bcc.orst.edu

BACKGROUND

Forest health: what is it? "Health" is an inherently fuzzy concept, even when applied to ourselves. And forests (and other ecosystems) are fuzzier than organisms, being weakly bounded and loosely organized. So the concept of "forest health" can seem hopelessly vague. Nevertheless, in extreme cases anyone can spot a "sick" forest. Despite forest health being a fuzzy concept, people want healthy forests and expect resource management agencies to monitor them.

The concept of ecosystem health is contentious not only because it is fuzzy, but also because it embodies societal values and preferences (Lackey 1998). The more that people disagree on these values, the more contentious the concept of ecosystem health.

One way ecologists make progress on inherently fuzzy concepts is to make them practical with operational definitions (Peters 1992). For example, we could define a person's health by a combination of their internal temperature, blood pressure, and cholesterol levels. These are indicators of health, not a comprehensive examination. Nor do the indicators in themselves usually allow the diagnosis of a specific problem. Rather, these indicators tell us when we need to examine a problem more closely. These data are easy to obtain, yet tell us a lot.

Similarly we want to identify indicators of forest health. The indicators should point to ecosystems where a problem exists or is emerging. They should also tell us when and where forest health is improving. Lichen communities have the honor of being included as indicators of forest health by the U.S. Forest Service and other government agencies.

WHAT IT TAKES

All organismal biologists would like to see their groups of special interest incorporated into long-term monitoring programs. But what does it actually take to accomplish this, beyond stable long-term funding? Some key components of the science are:

- Simple field method that is usable by nonspecialists (much as we would like to see professional lichenologists collect the field data, that option is financially hopeless).
- Repeatable field method.
- Meaningful data.
- Collaboration among many scientists and government agencies.
- Compelling links between the organisms and societal values (the public must value either the organisms themselves or ecosystem conditions that they indicate).
- Timely, clear, interesting products (reports, scientific papers, web sites, etc.).

The lichen part of the Forest Health Monitoring (FHM) program has accomplished the first three items (McCune et al. 1997*a,b*; Stolte 1997; http://willow.ncfes.umn.edu/fhm_fact/overview.htm); the last three items are ongoing challenges.

HISTORY

The FHM program seeks to assess the condition and trend of forests of the United States. FHM uses the national sampling grid established by the Environmental Monitoring and Assessment Program (EMAP) of the Environmental Protection Agency (Messer et al. 1991). The sampling design is unusual for forest ecology in that plots are chosen at random with respect to disturbance history, environment, internal homogeneity, and stand characteristics. The sampling design is ideal for characterizing a whole region.

Epiphytic lichen communities were included in FHM because they inform us about ecosystem contaminants and biodiversity. Hundreds of papers worldwide and dozens of review papers and books document the close relationship between lichen communities and air pollution, especially SO_2 and

0007-2745/00/353–356$0.55/0

TABLE 1. Selected lichen community biomonitoring efforts. A sample unit (SU) is an individual plot representing a grid point.

Country	Extent, km^2	Duration, years	Planned resampling interval, years	Resolution, SU/100 km^2	Number of SU's
Netherlands	2×10^4	30	5	18	ca 5,000
Switzerland	4×10^4	4	10†	2‡	826
U.S.A.*	8×10^6	8	4	0.16	2,600§

* Conterminous 48 states; includes many non-forested areas not part of FHM.

† Uncertain.

‡ Not a regular grid: area stratified by elevation and forest cover, then sampled 2% of the kilometer intersections in each stratum.

§ Currently 3,860 forested plots; ca 2,600 of those sampled for lichens; total of 6,441 plots anticipated after merger with FIA (Forest Inventory and Analysis).

acidifying or fertilizing nitrogen- and sulfur-based pollutants. Much of the sensitivity of epiphytic lichens to air quality apparently results from their lack of a cuticle and their total reliance on atmospheric sources of nutrition. Although trees may respond to moderate, chronic air pollution, all of the other influences on tree growth, such as variation in soils, make the responses of trees to pollutants difficult to measure in the field. So lichen communities provide not only a measure of air pollution impacts upon lichens, but also suggest air pollution impacts on aspects of forest health that are difficult to measure directly.

In addition to their utility as indicators of air quality, epiphytic lichens are an important and species-rich component of the biodiversity many forests. Lichens have numerous functional roles in temperate forests, including nutrient cycling (especially nitrogen fixation in moist forests) and as components of food webs. The complete dependence of epiphytes on woody plants makes them sensitive to forest management practices.

Other countries also use large scale monitoring of lichen communities (Table 1). The program in the Netherlands (van Dobben & de Bakker 1996; van Dobben & ter Braak 1998; and van Herk 1999) is outstanding for its length of record, fine spatial resolution of the sampling grid, high density of corresponding physical measurements of pollutants, and illuminating analyses of trends in lichen communities in response to the changing composition of air pollutants. The recently created program in Switzerland (Dietrich & Scheidegger 1997*a,b,* 1998) emphasizes detecting and evaluating rare lichen species. It will also be extremely useful for detecting human impacts on lichen communities.

Analysis of elemental content of lichen tissues is another common approach to biomonitoring of air quality (Stolte et al. 1993). After a two year trial, the FHM program rejected this as an indicator of forest health, for two reasons. First, high within-plot variability led to high repeat-measurement error. Subtle pollution signals were difficult to detect against the background of this statistical noise. Second, the ecological heterogeneity of North America precluded a simple standardization of the target species. Standardization is necessary because different species in the same environment differ markedly in their elemental contents. Even such candidate species as the seemingly ubiquitous *Parmelia sulcata* are rare or absent in large parts of the forested US.

The lichen community indicator for FHM (Fig. 1) is implemented in three phases 1) collect field data on the sampling grid and special plots in urban and industrial areas; 2) construct a gradient model of lichen communities to isolate and describe climatic and air quality gradients; and 3) apply the model to calculate gradient scores for additional plots. Scores for these plots are then used to describe the regional condition of lichen communities. Repeated sampling of these permanent plots will document changes in lichen communities over time and allow us to infer changes in regional air quality.

The FHM lichen community method determines the presence and abundance of macrolichen species on all standing woody plants in each FHM plot. The field crew collects samples for mailing to lichen specialists for naming. The field methods and quality assurance procedures are described in McCune et al. (1997*a*).

SYNTHESIS OF IMPORTANT DISCOVERIES

In the southeastern U.S. we found two major regional gradients in lichen communities (McCune et al. 1997*b*). The strongest gradient in the lichen communities corresponded to a macroclimatic gradient from the coast through the Piedmont to the Appalachian Mountains, primarily related to temperature. The second major gradient was correlated with air quality, with pollution-tolerant species and lower species richness in urban and industrial areas, and pollution-sensitive species and high species

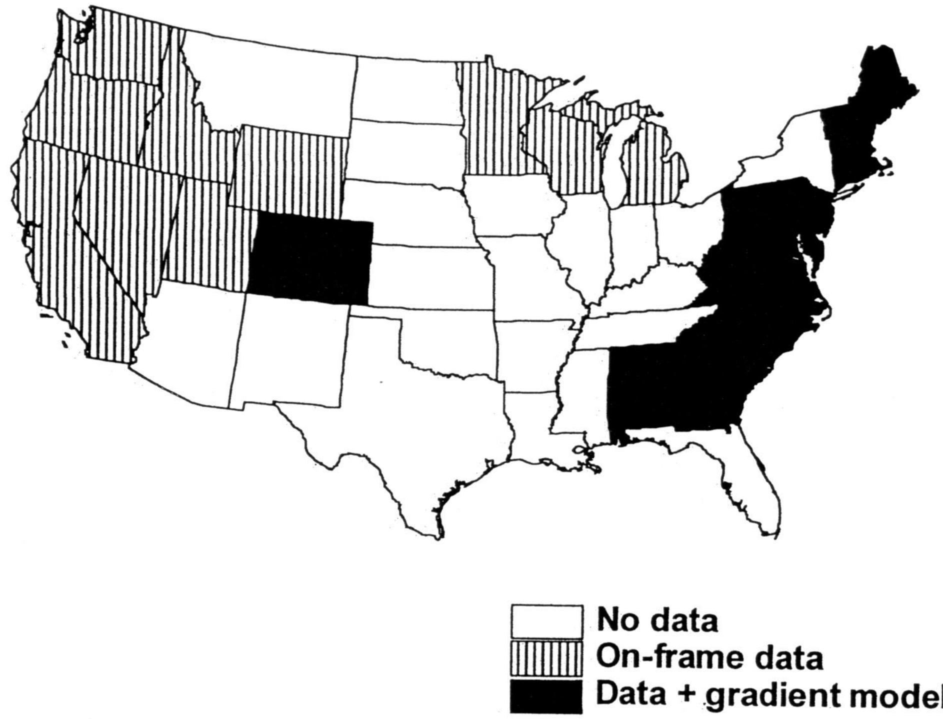

FIGURE 1. Status of lichen communities in FHM in the U.S. Shaded states have lichen data; blackened states also have a gradient model representing lichen communities in relationship to climate and air quality

richness in cleaner areas. Epiphytic macrolichens were sparse in urban areas with heavy industry. In many rural areas lichens were luxuriant and diverse.

The northeastern U.S. required a somewhat more complex model, with two climatic gradients (latitude and elevation) and an air quality gradient (S. Will-Wolf, unpubl. data). Lichens have low diversity and abundance in urban and industrial areas in the northeastern U.S. In Central Park of New York City, a single macrolichen species, *Physcia millegrana,* was found. This is the most pollutant tolerant macrolichen in eastern North America.

A climatic gradient was also strong in Colorado (McCune and others, unpubl. data). An elevation-moisture gradient explained over half of the variation in lichen communities. Because air quality scores, as expressed by lichen communities, were positively related to elevation, we needed to re-express air quality as a number of standard deviations away from expectation for a given elevation, using residuals from the regression of raw air quality scores on elevation. Lichen communities indicated poor air quality on the east side of the Front Range near Denver and Boulder, the Steamboat Springs area, and the Grand Junction area.

In all three models, use of special plots from urban and industrial areas was essential for fitting an air quality gradient. Application of the models in the future will allow us to monitor regional changes in air quality and climate.

WHY THIS TOPIC WILL YIELD SIGNIFICANT ADVANCES IN THE NEXT MILLENNIUM

The FHM program and similar efforts in other countries give us the first opportunity to document systematically the changing biota of a region. The main challenge facing that vision is the reluctance of government agencies to make long-term financial commitments to monitoring our biota–the same commitment given to monitoring weather and stream flows.

If FHM discontinues, we will still have a lichen snapshot of many forested areas of the country. This will provide the basis for follow-up comparisons. Think of the tremendous value that would be placed today on systematic lichen data from a hundred years ago.

Regional lichen community data have potential for many significant by-products, beyond the primary purpose. Some of the spinoffs are: documenting the invasion and extinction of species, enhancing our knowledge of the distribution and abundance of macrolichens (the data have already yielded many surprises), increasing appreciation by non-lichenologists for the importance of lichens as contributors to ecosystem function and diversity, contributing data to meet survey-and-manage mandates in the Northwest Forest Plan (USDA & USDI 1994), training numerous people in the basics of lichenology, and building collections from poorly studied areas.

The FHM program is giving a big boost to lichenology in the U.S. With support from the lichenological community, it has great potential to advance our understanding, and perhaps even influence the fate of our lichens and forests in North America.

Acknowledgments

Peter Neitlich, Paul Rogers, Ken Stolte, and Susan Will-Wolf shared the lead with me in developing the lichen part of the FHM program and adopted the leadership after I moved to other work. Other lichenological contributors include Ann DeBolt, Jonathan Dey, Karin Heiman, Jeri Peck, Roger Rosentreter, Andrea Ruchty, and Bruce Ryan. Philippe Clerc and Theodore Esslinger assisted with difficult specimens. Han van Dobben and Christoph Scheidegger provided information on lichen monitoring in the Netherlands and Switzerland, respectively. Bill Smith provided data on the FHM grid. Funding was provided by the Forest Health Monitoring Program, an interagency program including the USDA Forest Service, the U.S. Environmental Protection Agency, USDI Bureau of Land Management, USDA Natural Resource Conservation Service, Tennessee Valley Authority, and participating state agencies. This paper has not been subjected to reviews by any of those agencies, therefore it does not necessarily reflect the views of the agencies. No official endorsement should be inferred.

Literature Cited

Dietrich, M. & C. Scheidegger. 1997*a*. Frequency, diversity and ecological strategies of epiphytic lichens in the Swiss Central Plateau and the Pre-Alps. Lichenologist 29: 237–258.

——— & ———. 1997*b*. A representative survey of frequency of epiphytic lichens at the regional and national levels and its use for the red list of Switzerland, pp. 145–154. *In* R. Türk & R. Zorer (eds.), Progress and Problems in Lichenology in the Nineties. Bibliotheca Lichenologica, J. Cramer, Berlin, Stuttgart.

——— & ———. 1998. Diversity of forest lichens in Switzerland, pp. 343–349. *In* P. Bachmann, M. Köhl & R. Päivinen (eds.), Assessment of Biodiversity for Improved Forest Planning. Kluwer, Dordrecht.

Lackey, R. T. 1998. Seven pillars of ecosystem management. Landscape and Urban Planning 40: 21–30.

McCune, B., J. Dey, J. Peck, D. Cassell, K. Heiman, S. Will-Wolf & P. Neitlich. 1997*a*. Repeatability of community data: species richness versus gradient scores in large-scale lichen studies. The Bryologist 100: 40–46.

———, ———, ———, K. Heiman & S. Will-Wolf. 1997*b*. Regional gradients in lichen communities of the southeast United States. The Bryologist 100: 145–158.

Messer, J. J., R. A. Linthurst & W. S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environmental Monitoring and Assessment 17: 67–78.

Peters, R. H. 1992. A Critique for Ecology. Cambridge University Press, Cambridge.

Stolte, K. W. 1997. 1996 National Technical Report on Forest Health. USDA Forest Service, Administrative Report FS-605.

———, D. Mangis, R. Doty, K. Tonnessen & L. S. Huckaby. 1993. Lichen as Bioindicators of Air Quality. USDA Forest Service General Technical Report RM-224.

U.S. Department of Agriculture and U. S. Department of Interior. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl. Attachment A: Standards and Guidelines for Management of Habitat for Late-Successional and Old-Growth Forest Related Species within the Range of the Northern Spotted Owl. U.S. Government Printing Office, 1994-589-11/0001, Washington, D.C.

van Dobben, H. F., & A. J. de Bakker. 1996. Re-mapping epiphytic lichen biodiversity in the Netherlands: effects of decreasing SO_2 and increasing NH_3. Acta Botanica Neerlandica 45: 55–71.

———, C. J. F. ter Braak. 1998. Effects of atmospheric NH_3 on epiphytic lichens in the Netherlands: The pitfalls of biological monitoring. Atmospheric Environment 32: 551–557.

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