Chapter 5. Baseline Results from the Lichen Community Indicator Program in the Pacific Northwest: Air Quality Patterns and Evidence of a Nitrogen Pollution Problem

Sarah Jovan

Why Are Epiphytic Lichen Communities Important?

Lichens are one of the bioindicators used by the Forest Inventory and Analysis (FIA) Program to monitor forest health. To obtain data for use in its Lichen Community Indicator Program, FIA samples a regular network of permanent field plots to determine the composition of epiphytic, i.e., tree dwelling, lichen communities. The FIA lichens dataset is an important reservoir of information with many potential biomonitoring applications. The composition of a lichen community reflects various aspects of the local forest environment such as stand age, disturbance history, local climate, and stand structure. Perhaps the best known and most tested application of the Lichen Community Indicator data, however, is its utility for describing and monitoring air quality.

Many lichens are extremely sensitive to environmental change and are expected to be adversely affected by stressors such as air pollution before the rest of the ecosystem. Lichen community responses to various forms of both nitrogen (N) and sulfur (S) pollutants are well documented (e.g., Gauslaa 1995, Hawksworth and Rose 1970, Jovan and McCune 2005, McCune 1988, van Herk 1999), while responses to ozone are currently under investigation (Jovan and McCune 2005, Nash and Sigal 1999, Ruoss and Vonarburg 1995). The main purpose of this chapter is to provide an overview of potential air quality impacts on forest health in western Oregon and Washington as identified by the FIA Lichen Community Indicator Program. Baseline FIA results are reported together with a review of major findings from a related air quality study conducted by Geiser and Neitlich (2007).

Methods

Field methods—Members of each FIA field crew are trained and certified to conduct time-constrained lichen community surveys at FIA phase 3 plots (U.S. Department of Agriculture Forest Service 2006). These surveys last between 30 minutes and 2 hours, and during this time the abundance of each epiphytic species encountered is estimated using a broad abundance code (table 5.1). A voucher specimen is collected for each species and later identified by a lichen specialist in the lab. All material

Table 5.1—Abundance codes used during lichen community surveys

Code	Abundance
1	Rare (1–3 thalli[a])
2	Uncommon (4–10 thalli[a])
3	Common (>10 thalli[a]; species occurring on < 50 percent of all boles and branches in plot)
4	Abundant (>10 thalli[a]; species occurring on > 50 percent of boles and branches in plot)

[a]A thallus is the body of the lichen. Hence, "thalli," as used here, refers to the number of individuals.

is collected without the aid of ladders or tree climbing. Crew performance is audited by means of hot checks, in which specialists and crews survey simultaneously, or by means of blind checks, in which specialists resurvey plots within 2 months of the crew survey. Crews must capture at least 65 percent of the species found by the specialist, as this level of agreement has been shown to yield repeatable air quality estimates across observers (McCune and others 1997).

Model building and application—Analysts use the lichen community data to build gradient models with statistical tools such as regression and nonmetric multidimensional scaling ordination (NMS) (Kruskal 1964, McCune and Grace 2002). NMS models are the norm for lichen gradient modeling and provide estimates of both air quality and local forest climate. Basically, NMS analysis determines how the species composition of each plot differs from that of every other plot using a quantitative descriptor called a distance measure. This descriptor helps NMS detect gradients in lichen community composition and order plots along them. This ordering of plots in terms of lichen community is then related to environmental gradients. For instance, an air quality gradient across the landscape is often reflected by a detectable change in lichen community composition wherein certain indicator species increase in abundance while others decrease. Each plot gets a score along the community gradient, which serves as an estimate of relative air quality.

Geiser and Neitlich (2007), in collaboration with FIA and the Forest Service Region 6 Air Resource Program, developed an NMS model for biomonitoring air quality in Pacific Northwest (PNW) forests west of the Cascades crest (fig. 5.1). In this parent study, the model was applied to survey data from over 1,500 plots including FIA phase 3 plots, hundreds of sites on the Forest Service Region 6 Current Vegetation Survey grid (Max and others 1996), and "off-frame" sites in areas of special interest such as urban forests, wilderness areas, and forest stands near air quality monitors.

Ideally, direct measurements of air pollution concentrations are used to help calibrate NMS lichen models. Air quality monitoring station coverage was insufficient, so Geiser and Neitlich (2007) supplemented most community surveys with collection of lichens for chemical analysis. Lichens accumulate airborne chemicals, and elemental concentrations in the lichen are indicative of local deposition (Bruteig 1993, Geiser 2004, Søchting 1995).

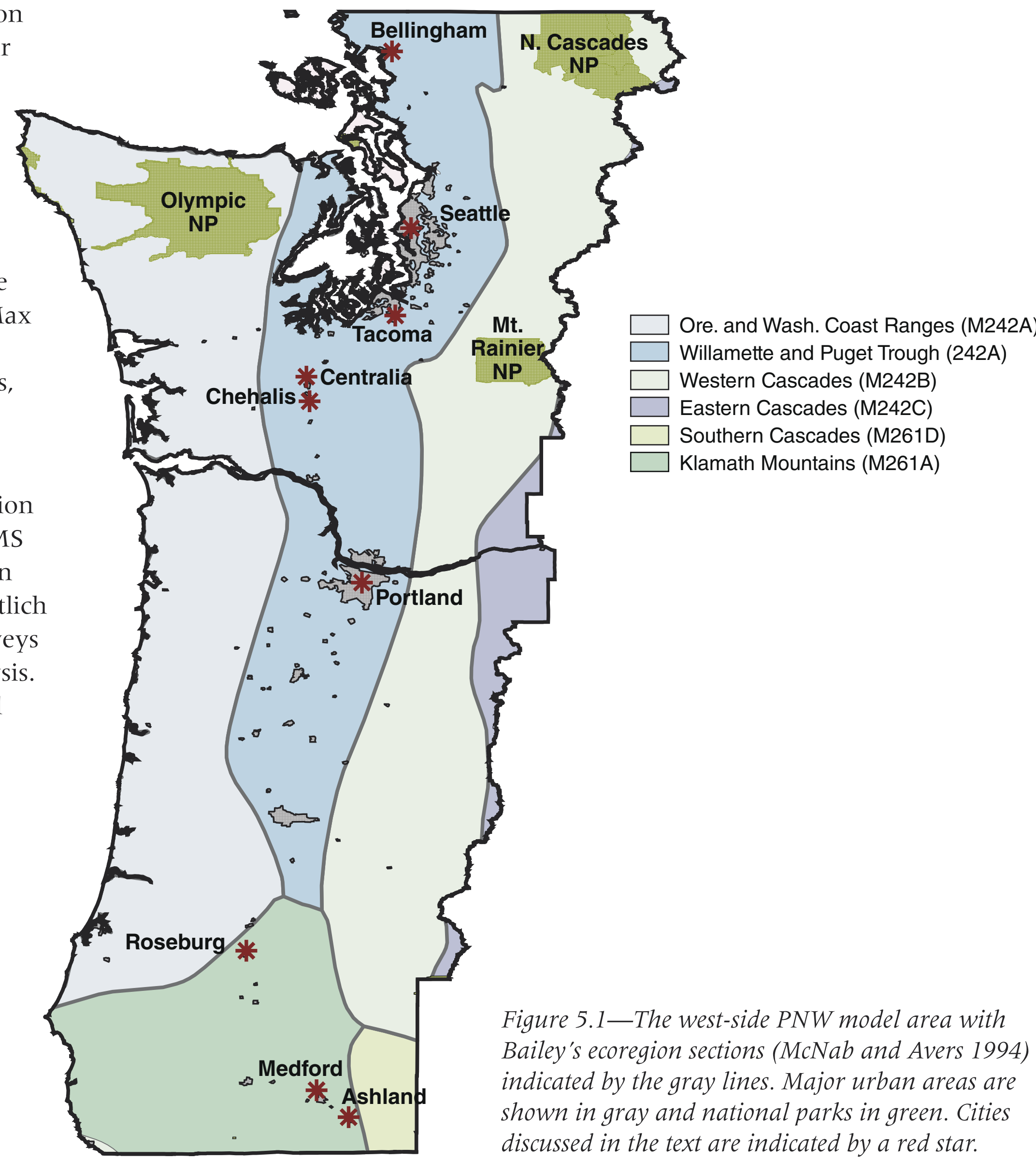

Figure 5.1—The west-side PNW model area with Bailey's ecoregion sections (McNab and Avers 1994) indicated by the gray lines. Major urban areas are shown in gray and national parks in green. Cities discussed in the text are indicated by a red star.

For the following summary, the NMS model was applied to data from 243 plots sampled for lichens between 1998–2001 or 2003, which constitute a full cycle of FIA survey data. Results are integrated with highlights from the research of Geiser and Neitlich (2007). Data for about 75 percent of FIA plots were included in the extensive analytical dataset analyzed by Geiser and Neitlich. Sites surveyed on the FIA phase 3 grid provide an unbiased, systematic sample of conditions across the forested landscape and serve as the official basis for comparison. Eleven of the 243 FIA phase 3 lichen plots also were included among 293 plots in the calibration dataset used by Geiser and Neitlich (2007) to develop the model.

What Do the Data Show?

Is nitrogen the culprit?—The data analyzed by Geiser and Neitlich (2007) contained strong evidence that nitrogen (N) pollution, in particular, is a major contributor to air quality degradation in western Oregon and Washington. The first clue lies in the N content of lichens, which served as the strongest predictor of air quality scores ($r^2 = 0.53$) reported by Geiser and Neitlich (2007); plots with high scores tended to have lichens with high N. A map of N in lichens can be found in Fenn and others (2003a).

A second clue is the prominence of certain species at high-scoring sites that are indicators of N-rich conditions. These lichens, known as the “nitrophytes” (fig. 5.2), are currently used to help detect where elevated N inputs are reaching forests in California (Jovan and McCune 2005, 2006). Characterization of nitrophyte populations similarly forms the backbone of numerous European N-biomonitoring programs (Lambley and Wolseley 2004).

The positive association between nitrophytes and high gradient model scores is simply illustrated by overlaying a nitrophytic species’ abundance on plot coordinates from the NMS model (fig. 5.3). This basic relationship is likewise demonstrated statistically by Geiser

Figure 5.2—Physcia adscendens, *a common nitrophytic lichen (top), and pollution-sensitive* Lobaria oregana *(bottom). Photos courtesy of Sarah Jovan (top) and Eric Straley (bottom).*

and Neitlich (2007). They used indicator species analysis (ISA) (Dufrêne and Legendre 1997) to determine that three classically nitrophytic species (*Candelaria concolor*, *Physcia adscendens*, and *Xanthoria polycarpa*) were the strongest indicators of plots with the highest scores. "Strong indicators" as defined by ISA in this case technically means that these species are consistently present in high-scoring plots, but uncommon in plots with low air scores (McCune and Grace 2002). From a community perspective, however, nitrophyte enhancement is only half the story. Several species exhibit a

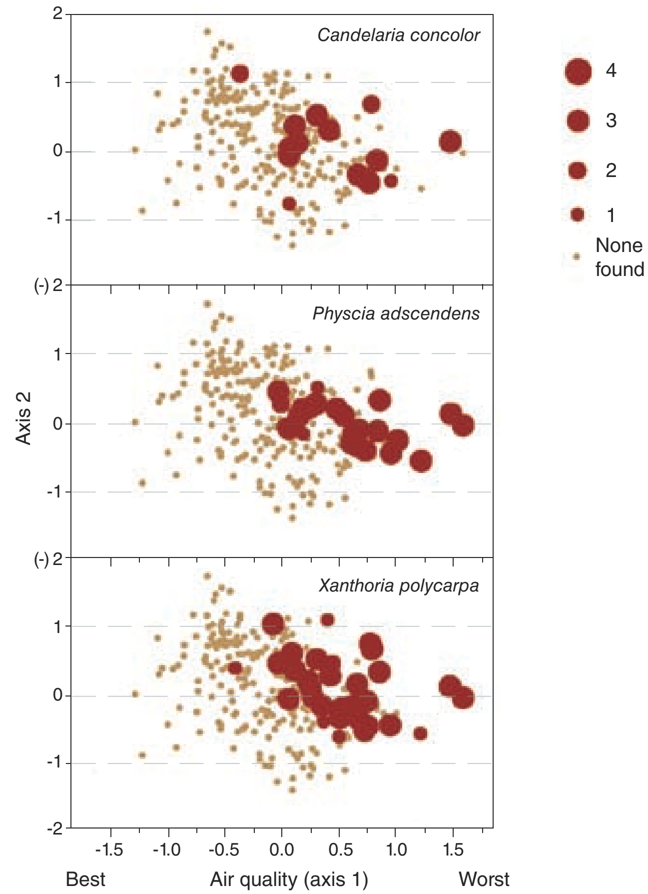

Figure 5.3—Abundance codes (table 5.1) for the three strongest indicator species of polluted plots (Geiser and Neitlich 2007) overlaid on plot scores. Plot scores for the two gradients in the nonmetric multidimensional scaling ordination model are represented by plot coordinates on the two axes in the diagram. Axis 1 represents the air quality gradient, while axis 2 represents a climatic gradient (not discussed here; see Geiser and Neitlich 2007). Plots where each species was absent are tan. Otherwise, symbol size indicates abundance code. (Additional data source: U.S. Department of Agriculture Forest Service, FIA Program)

marked negative association with the air quality gradient (fig. 5.4). Examples include the well-known sensitive species *Bryoria capillaris*, *Lobaria oregana* (fig. 5.2), and *Sphaerophorus globosus*, which Geiser and Neitlich (2007) determined to be among the strongest indicators of the "cleanest" sites (fig. 5.4).

Geographic distribution—Air quality scores for FIA plots are summarized in figure 5.5 and table 5.2 using six "air quality zones" devised by Geiser and Neitlich (2007): best, good, fair, degraded, poor, and worst. Zones are based on the distribution of air quality scores for

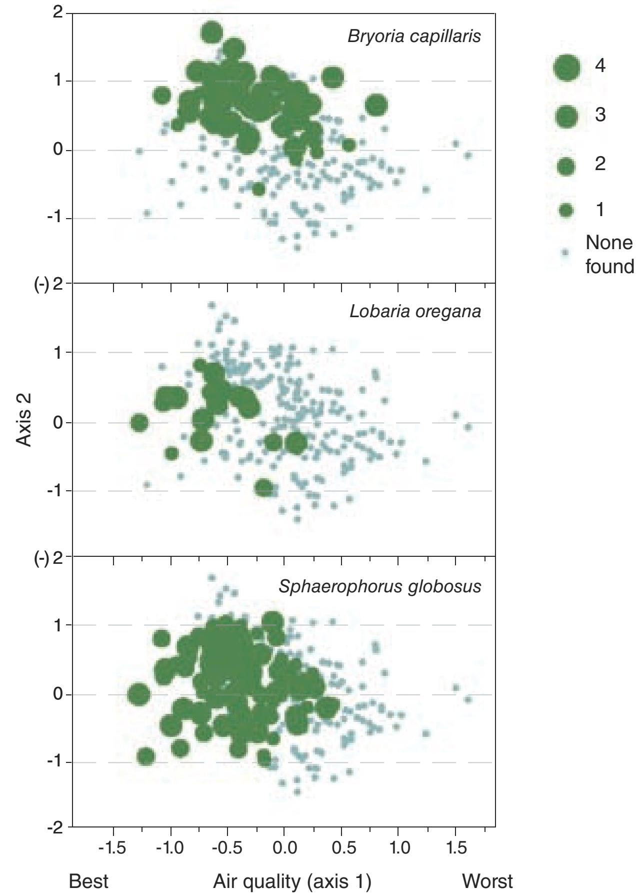

Figure 5.4—Abundance codes (table 5.1) for the three species that are strongest indicators of clean air (pollution-sensitive species) (Geiser and Neitlich 2007) overlaid on plot scores. Plot scores for the two gradients in the nonmetric multidimensional scaling ordination model are represented by plot coordinates on the two axes in the diagram. Axis 1 represents the air quality gradient, while axis 2 represents a climatic gradient (not discussed here; please see Geiser and Neitlich 2007). Plots where species was absent are blue. Otherwise, symbol size indicates abundance code. (Additional data source: U.S. Department of Agriculture Forest Service, FIA Program)

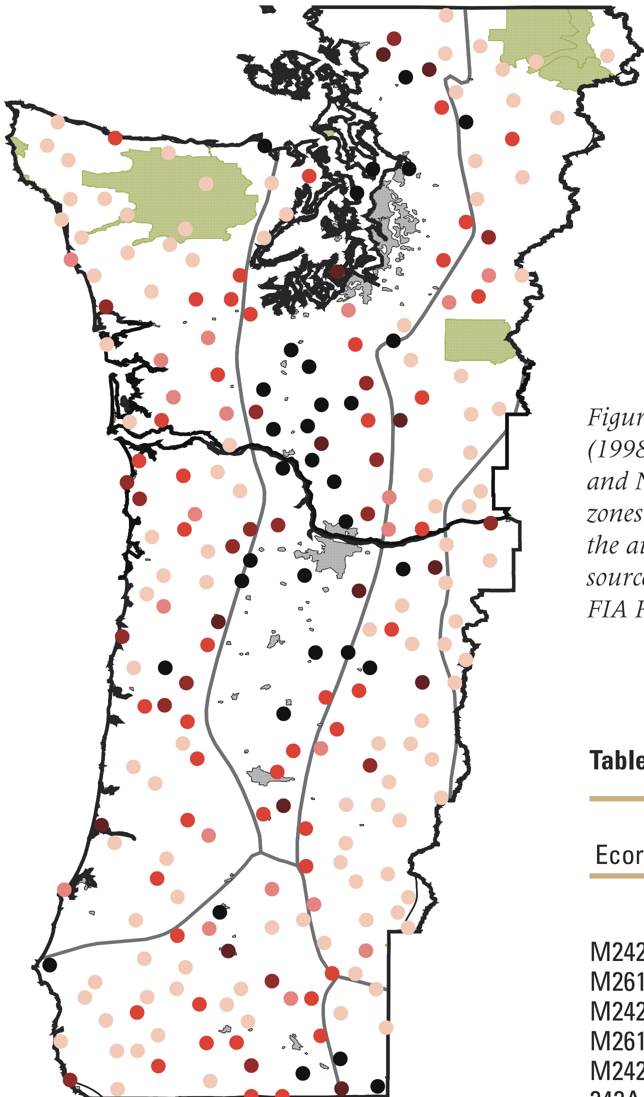

Figure 5.5—Map of air quality scores for all FIA plots (1998–2001, 2003) based on the gradient model of Geiser and Neitlich (2007). Scores are divided into air quality zones signified by colors. The higher the score, the poorer the air quality. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, FIA Program)

Table 5.2—Summary of FIA plots by ecoregion section and air quality zone

Ecoregion section	Total plots	Best	Good	Fair	Degraded	Poor	Worst
				no.			
M242C—Eastern Cascades	11	10	0	0	1	0	0
M261A—Klamath Mountains	39	18	3	11	3	1	3
M242A—Ore. and Wash. Coast Ranges	70	34	9	15	8	2	2
M261D—Southern Cascades	6	3	0	0	0	1	2
M242B—Western Cascades	64	40	7	9	2	3	3
242A—Willamette Valley and Puget Trough	53	6	1	11	7	6	22
Total	243	111	20	46	21	13	32

FIA = Forest Inventory and Analysis.
Source: Geiser and Neitlich (2007).

plots inhabited by the ISA-derived indicator species. Upper bounds of the best, good, and fair zones are based on the 75th, 90th, and 97.5th percentiles of scores associated with the clean air indicators. For example, 75 percent of plots hosting the clean air indicator species had air quality scores <0.11, which serves as the upper bound of the "best" zone (as well as the lower bound of the "good" zone). The upper bound of the "degraded" zone is the 25th percentile of the air quality scores for plots hosting the pollution indicators, while the upper bound of the "poor" zone corresponds to the 100th percentile for clean air indicators. Thus, by definition, none of these sensitive species were present in "worst" plots.

FIA plots in the "worst" air zone were predominantly clustered in ecoregion section 242A—Willamette Valley and Puget Trough [approximately 69 percent of plots in this category (fig. 5.5, table 5.2)]. Many of these sites were associated with large urban areas, e.g., greater Portland metropolitan area, Seattle, Tacoma; as well as smaller cities lining the Interstate 5 corridor, e.g., Bellingham, Chehalis, and Centralia, WA. More remote forests sampled on the periphery of the Willamette Valley, in the eastern Oregon Coast Range, and at low elevations in the Western Cascades, likewise tended to score as "degraded" or worse. Pollution impacts were also detected in forests farther south, in the vicinity of Roseburg, Medford, and Ashland, OR. Geiser and Neitlich (2007) observed the same major hotspots of degradation. Poorly scoring sites on the immediate coast were widely scattered (fig. 5.5), and Geiser and Neitlich (2007) attributed their distribution to local occurrence of pollution point sources and in some cases, the influence of marine aerosols. Few of the FIA sites that were surveyed were within the boundaries of national parks, but sites that were close to national parks were mostly in the "best" category (fig. 5.5). Best scoring sites were located mainly in remote parts (usually midhigh elevation or interior forests) of the Olympic, Cascades, Klamath, and Coast Ranges.

Prognosis

Several ecologically important pollutants are emitted in western Oregon and Washington (Eilers and others 1994, Geiser and Neitlich 2007, Oregon Department of Environmental Quality 2005) and multiple compounds may be influencing lichen communities in that area. However, it is clear that one or more N compounds are primary factors driving the observed patterns. As would be expected, poor scores were common for stands near agricultural and urbanized areas where one finds the most important anthropogenic sources of N, i.e., animal husbandry, fertilizers, and combustion of fossil fuels (Fenn and others 2003b).

N appears to have a major role in shaping the lichen communities farther south in the largely agricultural central valley and surrounding ecosystems, i.e., central coast and Sierra Nevada foothills, in California (Jovan and McCune 2005, 2006). Deposition in western Oregon and Washington appears less severe overall (Bytnerowicz and Fenn 1996, Fenn and others 2003b), although results from the lichen indicator suggest some forests have begun on a trajectory of N enrichment. Currently, forests within and near the 242A—Willamette and Puget Trough ecoregion section seem to be at greatest risk of N impacts (fig. 5.5, table 5.2) (Geiser and Neitlich 2007).

The relatively recent discovery of altered N cycling in some Western U.S. forests has invigorated efforts to monitor deposition and its ecological impact (Baron and others 2000; Fenn and others 1996, 2003a). As most forests in the PNW are naturally adapted to a limited N supply, fertilization can profoundly affect forest function and the quality of associated aquatic systems (Aber and others 1989, Fenn and others 2003a). It is difficult to anticipate ecological impacts of current N levels, however, because critical loads have yet to be identified for most terrestrial systems in the PNW and susceptibility varies widely as a function of numerous biotic and abiotic factors (Porter and others 2005).

Moreover, total N deposition for western ecosystems is largely unknown because patterns in dry N deposition are heterogeneous and poorly characterized (Fenn and others 2003b, Porter and others 2005). While wet deposition is generally low, (see chapter 4) dry N deposition is a major contributor to total N deposition in the Western United States (see chapter 4; Fenn and others 2003a). The bioindication study of Geiser and Neitlich (2007) actually provides the most comprehensive information on N patterns in the region.

The most N-sensitive biological components of western ecosystems, including lichen, fungi, and some plant communities, may be altered by total N deposition as low as 3 to 8 kg N per year (Fenn and others 2003a). From a lichenological standpoint, continued eutrophication in western Oregon and Washington is expected to lead to further dominance by nitrophytes, which possess many of the traits traditionally regarded as "weedy," characteristics that would allow them quickly to establish and dominate a community when conditions are suitable. There would likely be a parallel reduction in ecologically important species like cyanolichens, e.g., *Lobaria oregana*, (fig. 5.2) and species utilized as forage by wildlife, e.g., *Bryoria* spp., which are among the most pollution sensitive (Fenn and others 2003a). These trends will be tracked closely as additional cycles of data are collected by FIA and the Region 6 Air Resource Program.

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