United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

General Technical Report RMRS-GTR-103

March 2003

Lichen Communities Indicator Results from Idaho: Baseline Sampling

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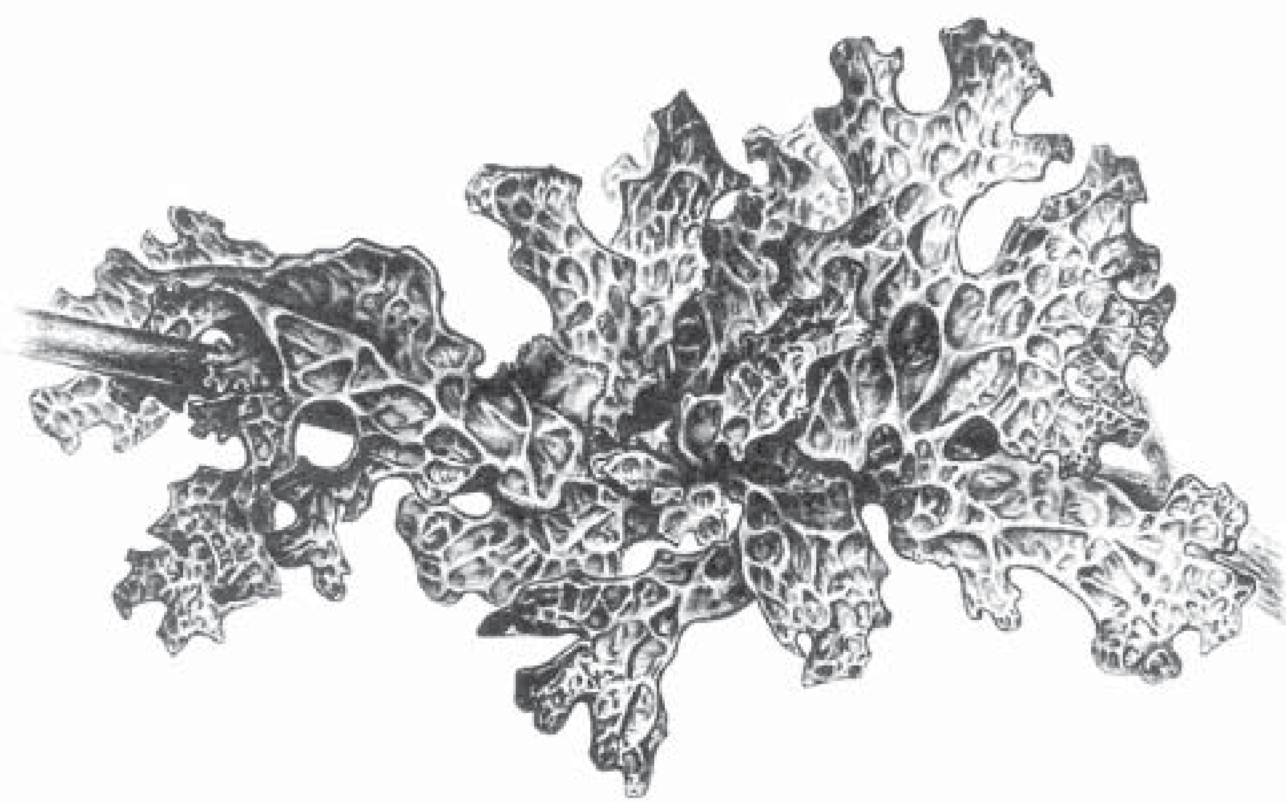

Neitlich, Peter; Rogers, Paul; Rosentreter, Roger. 2003. **Lichen communities indicator results from Idaho: baseline sampling**. Gen. Tech. Rep. RMRS-GTR-103. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 14 p.

Abstract

Epiphytic lichen communities are included in the national Forest Health Monitoring (FHM) program because they help us assess resource contamination, biodiversity, and sustainability in the context of forest health. In 1996, field crews collected lichen samples on 141 field plots systematically located across all forest ownership groups in Idaho. Results presented here are the baseline assessment of the statewide field survey. Seventy-five epiphytic macrolichen species were reported from Idaho. Mean species richness varied significantly from seven to 12 species per plot depending on ecoregion province ($p < 0.0001$). Four lichen species are reported for the first time in Idaho. Major community gradients in nonmetric multidimensional scaling (NMS) ordination are most strongly related to latitude, elevation, percent forest cover, and lichen species richness. Ecoregion provinces occupy significantly different subsections of n-dimensional species space in multi-response permutation procedures (MRPP, $p < 1 \times 10^{-8}$).

Keywords: lichens, Forest Health Monitoring, forest inventory, Idaho, air quality, biodiversity

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Acknowledgments

Peter Neitlich completed this work as a contractor to the FHM program, via funding from USDA Forest Service, State and Private Forestry, Forest Health Protection and USDA Forest Service, Research, Forest Inventory and Analysis. We thank Bruce McCune, Andrea Pipp, Susan Szewczak, Dayle Bennett, and Dave Atkins for advice and technical assistance with Idaho lichen data collection. Special acknowledgement for outstanding effort goes out to FHM field crew members Terry Briones, Peter Conklin, Linda Spillers, Sarah Hedrich, Ken Hehr, Brad Bolton, and Dana Lambert. We appreciate the time and intelligence submitted by technical reviewers of this document.

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Introduction

This publication assesses biodiversity and community structure of the Idaho lichen community by using a statewide plot–based sample. Secondary goals are to present basic lichen data analysis methods, document quality assurance techniques, and make some preliminary statements about air quality. Ultimately, a statewide inventory of lichen communities can aid managers in resource decisionmaking and lead to greater general ecosystem understanding by the public.

The Forest Health Monitoring (FHM) program seeks to assess the condition and trend of the forests of the United States (NAPAP 1993; Riitters and others 1992). FHM is linked with the national sampling grid established by the Environmental Monitoring and Assessment Program (EMAP) of the Environmental Protection Agency (Messer and others 1991) and now maintained by the USDA Forest Service's Forest Inventory and Analysis (FIA) program. Epiphytic lichen community sampling was included in FHM to help answer several key forest health assessment questions. These questions relate to contamination and sustainability of forest resources, changes in biodiversity, and overall forest health.

Hundreds of papers worldwide (chronicled in the series "Literature on air pollution and lichens" in the Lichenologist) and dozens of review papers and books (for example, Nash and Wirth 1988; Richardson 1992; Seaward 1993; Smith and others 1993; van Dobben 1993) have documented the close relationship between lichen communities and air pollution, especially SO_2 and acidifying or fertilizing nitrogen and sulfur-based pollutants. In a comparison of biological responses between nearby and remote areas surrounding a coal-fired power plant, lichens gave a much clearer response (in terms of diversity, total abundance, and community composition) than either foliar symptoms or tree growth (Muir and McCune 1988). Lichens were one of the few components of terrestrial ecosystems to show a clear relationship to gradients of acidic deposition in the eastern United States (NAPAP 1991; Showman 1992). Much of the sensitivity of epiphytic lichens to air quality apparently results from their lack of a cuticle and their reliance on atmospheric sources of nutrition. Although trees may respond to moderate and chronic levels of airborne pollutant deposition, multiple influences on tree growth (e.g., variation in soil, moisture regime, canopy position, tree damage) make the responses of trees to pollutants difficult to measure in the field. Lichen communities not only provide a direct measure of air pollution impacts upon lichens, but also suggest possible air pollution impacts on whole forest ecosystems that are difficult to measure directly.

In addition to their utility as indicators of air quality, epiphytic lichens are an important component of many forests. Lichens often comprise a large portion of the diversity of total plant species in a forest. Lichens have numerous functional roles in temperate forests, including nutrient cycling (especially nitrogen fixation in moist forests) (Pike 1978) and as components of food webs (Dawson and others 1987; Maser and others 1986; Rominger and Oldemeyer 1989; Servheen and Lyon 1989).

Previous Work in Idaho

There have been numerous lichen studies in Idaho, including several using lichens as biomonitors of air pollution. Hoffman (1974) documented the influence of a paper pulp mill on the epiphytic lichens in the vicinity of Lewiston. Dillman (1996) studied the use of *Rhizoplaca melanophthalma* as a biomonitor of phosphate pollution near Pocatello. Rope and Pearson (1990) studied the use of lichens as air quality biomonitors in the semiarid areas of Idaho. Rosentreter (1990) correlated increasing lichen cover on desert shrubs with increased dust and excess nitrogen in the air. In Northern Idaho, McCune and Rosentreter (1998) examined lichen species richness by forest cover types over an elevational gradient. They found greater species richness in the moist low elevation forest cover types than in the subalpine forest cover. There have also been several lichen inventory efforts in Idaho. Schroeder and others (1973, 1975), Anderegg and others (1973) and Schroeder and Schroeder (1972) have compiled a catalog of the lichens of Idaho as well as site specific species lists.

Wildlife uses of lichen have received particular attention in Idaho. Rominger and others (1994) examined the impacts of timber harvesting on woodland caribou habitat, of which epiphytic lichens were a major forage component. Rosentreter and others (1997) and Hayward and Rosentreter (1994) examined the seasonal food habits of the northern flying squirrel in the interior conifer forests of central Idaho, finding that the epiphytic lichen *Bryoria* constituted a principal winter food source.

Atkins and others (1999) provide an overview of forest resources, forest change, and forest health issues generally in Idaho. Issues such as the changing distribution of grand fir, western larch, and ponderosa pine are likely to exert a great influence on future lichen communities.

Methods

Lichen Community Sampling

The lichen community indicator is implemented in two phases (fig. 1). In the calibration phase, a gradient model of lichen communities is constructed to isolate and describe climatic and air quality gradients. In the application phase, this gradient model is applied to calculate gradient scores for additional plots. Scores for these plots are then used to describe the regional condition and geographic variation in

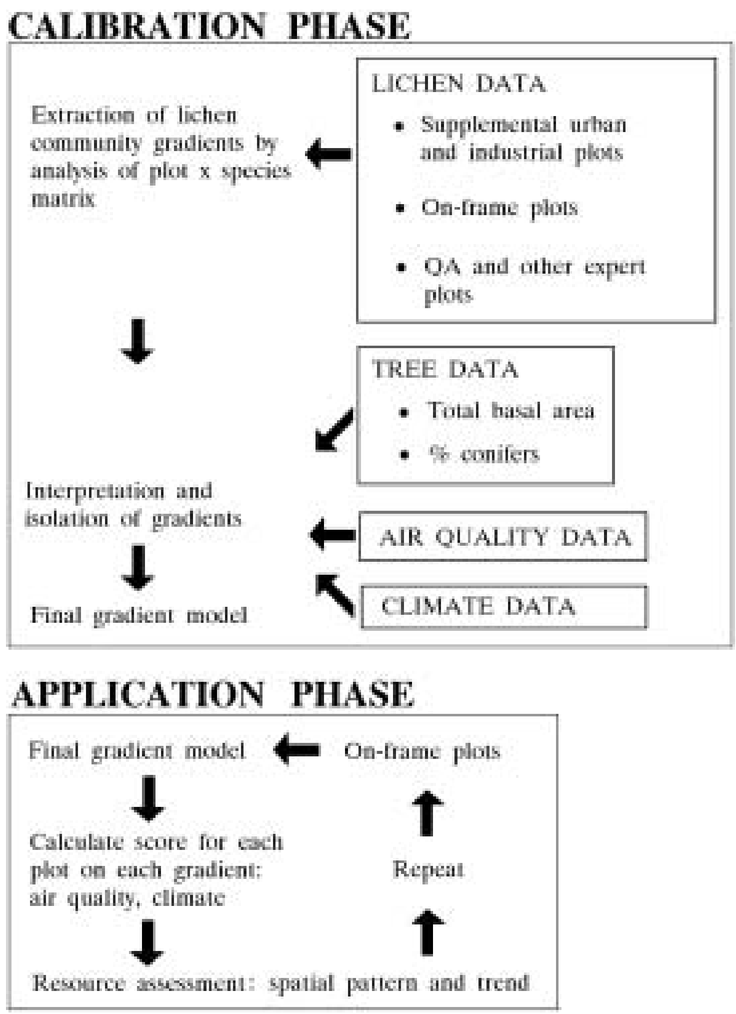

Figure 1—Implementation of lichen communities as an indicator in the Forest Health Monitoring program. This figure presents a conceptual model of data flow for lichen air quality scoring.

lichen communities. Repeated sampling of these permanent plots allows for the documentation of changes in the condition of lichen communities over time. Lichen data from FHM sampling are archived in a national database located in Las Vegas, Nevada.

There are a limited number of lichenologists and a relatively large number of sample plots nationally. Therefore, field procedures were designed for implementation by non-lichenologists for practical reasons of staffing field crews. In FHM's Interior West region, field crews have typically received between 2 and 3 days of intensive training in lichen community methods. To be certified, crews must attain the required measurement quality objective (MQO) of collecting 65 percent of an expert's species capture on the same plot. A crew must be certified to sample field plots. The method has two parts that are performed simultaneously:

(1) In each standard 0.94 acre (0.38 ha) FHM plot (Tallent-Halsell 1994), the field crew searches for macrolichens (relatively large leafy or pendulous lichens) on woody plants and collects a sample of each lichen believed to be a distinct species. Macrolichens are generally lichens that attain three dimensions and are relatively easily removed from their substrates, as opposed to the "flattened," or two-dimensional, forms that appear "painted on" to their respective substrates. Tree and shrub bases below 1.64 ft (0.5 m) are excluded from sampling to avoid distinct forest floor lichen communities. Recently fallen lichen litter, either unattached or on branches, may be included as they provide an excellent sample of forest canopy lichens. This collection method represents the species diversity of woody substrate macrolichens in the plot as fully as possible.

(2) The field crew estimates the abundance of each species using a four-step scale: 1 = rare (<3 individuals in plot); 2 = uncommon (4 to 10 individuals in plot); 3 = common (>10 individuals in plot but less than half of the boles and branches have that species present); and 4 = abundant (more than half of boles and branches in the plot have the subject species present).

Field personnel only distinguish among species and assign abundance estimates to each sample. Crews do not have to identify samples; specimens are sent to specialists for identification. Field methods are described in detail in Tallent-Halsell (1994). Quality assurance procedures and results are described in Cline (1995) and McCune and others (1997), and methods have been closely scrutinized and documented for repeatability (McCune and others 1997).

Analyses were designed to detect major community gradients in the lichen species data and the significant environmental variables strongly associated with these gradients. Multivariate analyses including ordination and multi-response permutation procedures were performed on the on-frame plot (see Data Sources below) community matrix of 141 plots by 75 species using PC-ORD (McCune and Mefford 1999, Mielke 1984).

Data Sources

This report summarizes results from a total of 155 plots, including 14 reference plots, as described below. Supplemental urban and industrial plots (not yet established) will provide a final data component in future analysis (see Methods, fig. 1). All data, as well as further information concerning the Lichen Communities Indicator, may be accessed online at: http://www.wmrs.edu/lichen/

On-frame plots—Lichen community data were collected by field crews on 141 on-frame permanent plots in 1996. "On-frame" plots are located on a formal sampling framework, according to standard sampling protocols for the EMAP hexagonal grid (Messer and others 1991). The strict sampling criteria applied to the on-frame data allow regional estimates of lichen community parameters. On-frame data can be used for assessment of regional status and trends because they comprise an unbiased sample (Messer and others 1991). In contrast, off-frame data, while useful in building a gradient model, cannot be used to answer such questions as, "Is lichen diversity in Idaho decreasing through time?"

Reference plots—In 1996, a reference location in Cache County, Utah, was sampled twice by each of seven crew members for a total of 14 reference plot data files. The purpose of these reference plots was to establish consistency between crews and to assess changes in crew performance over the season. These plots are for quality assurance assessment only and are not included in the Idaho dataset analysis.

Quality Assurance

Quality assurance for the 1996 Idaho dataset included reference plots and "hot" checks, but not "cold" checks (i.e., independent audits by specialists, either with or without crew knowledge). Although data were not kept of "hot" checks, an experienced trainer independently sampled plots, checked for procedural compliance, and answered sampling questions. Each reference plot (located near Logan, Utah, close to Idaho) was sampled twice by each crew member. Although expert plot scores were not available for this year, the high score of eight species was consistent with expert scores from other years in Logan Canyon and was used for calculation of the measurement quality objective (MQO). Crews improved in species capture by 9 percent over the season (table 1), starting the season with 68 percent of expert scores and ending at 73 percent.

Between-crew variability represented by the coefficient of variation (CV=[standard deviation/mean]*100) for the two measurements was 9 percent and 28 percent for the first and second visits, respectively. It appears that the rise in the CV in the second visit occurred as some crews gained skill over the season while others did not. The mean CV over all reference plots was 19 percent. A high rate of attainment of MQOs was achieved (93 percent overall) for reference plots, which lends good credibility to the on-frame dataset.

Results

Biodiversity and Community Structure

Seventy-five macrolichen species were found on FHM plots in Idaho in 1996 (table 2, table 3). The five most common lichen species in Idaho's forests were *Letharia vulpina* (70 percent plot frequency), *Bryoria fuscescens* (60 percent), *Hypogymnia imshaugii* (56 percent), *Melanelia exasperatula* (59 percent), and *Parmeliopsis ambigua* (48 percent) (table 3). Four species, *Hypogymnia austerodes*, *Hypogymnia bitteri*, *Ramalina dilacerata*, and *Usnea hirta* are reported in Idaho for the first time. General distributions of plots per species richness class are shown in table 4. Most FHM plots (68 percent) in Idaho had six to 15 species collected. The mean species richness per plot was 9.2 species (table 2) and species richness varied significantly by ecoregion province (Bailey and others 1994) ($F = 9.8$, $p < 0.0001$ in a one-way ANOVA), from 12.2 in the oceanically influenced Northern Rocky Mountain Province to 7.1 in the dry Intermountain Semi-Desert Province (table 5) (fig. 2). Patterns in species richness across the State may be attributed largely to moisture and temperature regimes accompanying each ecoregion's physical geography.

A variety of preliminary community analyses via nonmetric multidimensional scaling ordination (NMS) (Kruskal 1964) were tested. For these trials, plots and species with two or fewer occurrences and those for which key secondary measurements (e.g., basal area

Table 1—Summary of QA reference plots, Idaho, 1996 (located at a training site near Logan, Utah). "S" is mean species richness followed in parentheses by the standard deviation. Bias represents the signed mean deviation from the expert score. The Measurement Quality Objective (MQO) represented 65 percent of eight species, or five species.

	N	S (SD)	% of expert[a]	Bias	Improvement from 1st to 2nd sampling	CV between crews[b]	Crews achieving MQO
					- - - - - - - - - -	*Percent*	- - - - - - - - - -
All	14	5.6 (1.2)	71	–2.4	9	19	93
Sample 1 (June)	7	5.4 (0.5)	68	–2.6	—	9	100
Sample 2 (August)	7	5.9 (1.7)	73	–2.2	—	28	86

[a]As expert scores were not available, the high species count of eight was used. This was consistent with true expert scores in this same location for other years.
[b]Coefficient of variation. See text for calculation.

Table 2—Alpha with standard deviation (SD), beta, and gamma diversity of epiphytic lichens in 141 on-frame plots in Idaho. Alpha diversity (α) is mean species richness per plot. Beta diversity (β) is gamma/alpha and is a rough estimate of "community turnover." Gamma diversity (γ) is the total number of species found on all plots.

Plot type	Number	α (SD)	β	γ
On Frame	141	9.2 (4.3)	8.2	75

Table 3—Epiphytic macrolichen species found on 141 on-frame plots in Idaho, 1996. Matrix contents: 141 plots by 75 species. Percent frequency = number of occurrences/total number of plots. Relative abundance = sum total abundance/total possible abundance sum for all plots. Status was assessed using percent frequency values as follows: 0–1 = uncommon; 2–10 = occasional; 11–25 = common; >25 = abundant. Axis 1 and Axis 2 r^2 values are correlations of species with ordination axes (see fig. 3 for ordination). Only r^2 values > 0.04 are shown. Indicator values: *= p < 0.05; **= p < 0.01 (see table 7 for explanation of ecoregion province codes and/or Bailey and others [1994] for province and section information). Ecological distribution notes classify the lichens in one of five categories: oceanic influence, moist interior, widespread, boreal, and continental. These reflect a gradient from moist to dry sites.

Species	% freq	Relative abundance (%)	Status	Axis 1 r	Axis 2 r	Ecoregion province and/or section indicator values	Ecological distribution notes
Ahtiana sphaerosporella	1	0.9	Uncommon				Moist interior
Alectoria imshaugii	12	8.9	Common	0.12			Moist interior
Alectoria sarmentosa	31	26.2	Abundant	0.42		**M333, *M333D	Oceanic influence
Bryoria capillaris	13	11.7	Common	0.18		*M333, *M333A	Oceanic influence
Bryoria fremontii	16	13.1	Common				Moist interior; open sites
Bryoria furcellata	1	0.5	Uncommon				Oceanic influence
Bryoria fuscescens	60	46.8	Abundant	0.05			Widespread
Bryoria pseudofuscescens	16	14.5	Common	0.11	0.05	*331	Moist interior
Bryoria simplicior	1	0.2	Uncommon				Moist interior
Candelaria concolor	4	2.5	Occasional				Widespread; excess N indicator
Cetraria canadensis	9	6.6	Occasional	0.08			Moist interior
Cetraria chlorophylla	30	22.7	Abundant	0.37		**M333, *M333A	Widespread
Cetraria merrillii	9	5.3	Occasional			*331	Continental
Cetraria orbata	21	17.4	Common	0.17		*M333	Oceanic influence
Cetraria pallidula	1	0.5	Uncommon				Moist interior
Cetraria pinastri	1	0.2	Uncommon				Widespread; boreal
Cetraria platyphylla	29	23.8	Abundant	0.18	0.04		Continental
Cladonia sp.	9	5.7	Occasional	0.10			Widespread
Cladonia chlorophaea	1	0.7	Uncommon				Widespread
Esslingeriana idahoensis	9	6.0	Occasional	0.10			Moist interior; predominantly M333
Evernia prunastri	13	8.0	Common	0.08			Oceanic influence; predominantly M333
Hypocenomyce scalaris	1	0.2	Uncommon				Widespread
Hypogymnia apinnata	1	0.5	Uncommon				Oceanic influence
Hypogymnia austerodes	4	2.0	Occasional				Boreal; new record for Idaho; M332 only
Hypogymnia bitteri	1	0.5	Uncommon				Boreal; new record for Idaho
Hypogymnia enteromorpha	1	1.2	Uncommon				Oceanic influence
Hypogymnia imshaugii	56	47.3	Abundant	0.27	0.18		Moist interior
Hypogymnia inactiva	2	2.0	Occasional				Oceanic influence; M333 only
Hypogymnia metaphysodes	12	9.8	Common			*331	Oceanic influence
Hypogymnia occidentalis	12	11.2	Common	0.19			Oceanic influence; predominantly M333
Hypogymnia physodes	21	18.6	Common	0.27		*M333	Widespread
Hypogymnia rugosa	1	0.5	Uncommon				Oceanic influence
Hypogymnia tubulosa	13	11.5	Common	0.16		*M333	Widespread; predominantly M333
Letharia columbiana	30	23.0	Abundant	^{n}0.12	0.08		Continental

(con.)

Table 3 (Con.)

Species	% freq	Relative abundance (%)	Status	Axis 1 r	Axis 2 r	Ecoregion province and/or section indicator values	Ecological distribution notes
Letharia vulpina	70	55.1	Abundant		0.17	*331	Continental
Lobaria pulmonaria	6	5.5	Occasional	0.14			Oceanic influence; predominantly M333
Melanelia elegantula	6	4.8	Occasional	[n]0.04			Continental
Melanelia exasperatula	59	45.4	Abundant	[n]0.07			Continental
Melanelia glabra	2	1.1	Occasional		[n]0.11	**342	Continental; 342 only
Melanelia multispora	15	11.2	Common				Oceanic influence
Melanelia subaurifera	4	3.0	Occasional		[n]0.05	*342	Widespread
Melanelia subelegantula	10	7.6	Occasional				Continental
Melanelia subolivacea	15	11.5	Common	[n]0.06			Continental
Nephroma helveticum	1	0.4	Uncommon				Oceanic influence
Nephroma parile	1	0.7	Uncommon				Oceanic influence
Nephroma resupinatum	4	2.5	Occasional	[n]0.05			Oceanic influence
Nodobryoria abbreviata	30	22.9	Abundant		0.27	**331, *331A	Continental; coniferous forest
Nodobryoria oregana	1	1.1	Uncommon				Moist interior
Parmelia hygrophila	19	15.2	Common	0.16			Oceanic influence
Parmelia sulcata	26	20.7	Abundant	0.14			Widespread
Parmeliopsis ambigua	48	35.1	Abundant	0.15			Widespread
Parmeliopsis hyperopta	13	10.1	Common	0.09			Oceanic influence
Peltigera collina	1	1.2	Uncommon				Oceanic influence; epiphyte
Physcia adscendens	11	7.6	Common	[n]0.06	[n]0.11	*342D	Widespread; excess N indicator
Physcia aipolia	4	1.6					Widespread
Physcia biziana	2	0.9		[n]0.04			Widespread; on hardwoods
Physcia callosa	1	0.2	Uncommon				Moist interior; rare
Physcia dimidiata	3	2.0	Occasional	[n]0.07	[n]0.10		Continental; mostly on juniper
Physcia tenella	2	1.1	Occasional	[n]0.04	[n]0.09		Widespread; excess N indicator
Physconia detersa[a]	1	0.9	Uncommon				Widespread; apparently uncommon in Idaho
Physconia distorta	1	0.4	Uncommon				Currently not classified
Platismatia glauca	33	29.3	Abundant	0.58		**M333, **M333A	Moist interior; predominantly M333, moist areas
Platismatia stenophylla	2	2.0	Occasional				Oceanic influence; M333 only
Pseudocyphellaria anthraspis	1	0.9	Uncommon				Oceanic influence; M332 only in these data
c.f. Punctelia rudecta	1	0.4	Uncommon				Needs further study
Ramalina dilacerata	1	0.5	Uncommon				Widespread; on hardwoods; new record for Idaho
Ramalina farinacea	1	0.5	Uncommon				Moist interior; on hardwoods
Usnea sp.	1	0.7	Uncommon				Widespread
Usnea hirta	1	0.2	Uncommon				Continental; new record for Idaho

(con.)

Table 3 (Con.)

Species	% freq	Relative abundance (%)	Status	Axis 1 r	Axis 2 r	Ecoregion province and/or section indicator values	Ecological distribution notes
Usnea lapponica	26	18.6	Abundant		[n]0.04	**M331	Continental; southern Rocky Mountains
Usnea plicata agg.[b]	3	2.5	Occasional				Continental
Usnea scabrata	1	0.7	Uncommon				Oceanic
Usnea subfloridana	6	4.8	Occasional				Oceanic
Xanthoria fallax[c]	22	14.7	Common	[n]0.24	[n]0.23	**342	Widespread; excess N indicator
Xanthoria polycarpa[d]	19	13.5	Common		[n]0.18		Widespread; excess N indicator

[a] This taxon has now been divided into several others including *Physconia enteroxantha*, *P. isidiigera* and *P. perisidiosa*.
[b] Recent taxonomic changes may place this aggregate within the *Usnea filipendula* group.
[c] It is likely that these records may have included specimens of this species as well as *X. fulva* and *X. oregana*.
[d] It is likely that these records may have included specimens of this species as well as *X. hasseana* and/or *X. montana*.
[n] This value represents a negative relationship.

Table 4—Number of plots by species richness classes, 1996, Idaho.

Lichen species richness class	Number of plots	Percent of plots
0 (0 spp.)	2	5
1 (1–5 spp.)	32	32
2 (6–15 spp.)	97	68
3 (>15 spp.)	9	5

Table 5—Lichen species richness with standard deviation (SD) according to Bailey's Ecoregion Provinces (Bailey and others 1994), with highly associated lichen species at province levels, Idaho, 1996. Associated species were determined with Indicator Species Analysis (Dufrene and Legendre 1997). Indicator values: *= p < 0.05; **= p < 0.01. Gamma diversity (total species number) was 75 and is not presented by province because of unequal sample sizes.

Ecoregion province	N	Species richness (SD)	Highly associated species
331. Palouse Dry Steppe	6	11.8 (4.4)	*Nodobryoria abbreviata***, *Bryoria pseudofuscescens**, *Cetraria merrellii**, *Hypogymnia metaphysodes**, *Letharia vulpina**
M331. Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow	12	7.3 (2.4)	*Physcia adscendens**, *Usnea lapponica***
M332. Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow	71	8.1 (4.1)	
M333. Northern Rocky Mountain Forest-Steppe-Coniferous Forest-Alpine Meadow	37	12.2 (3.3)	*Alectoria sarmentosa***, *Bryoria capillaris**, *Cetraria chlorophylla***, *C. orbata**, *Hypogymnia physodes**, *H. tubulosa***, *Platismatia glauca***
342. Intermountain Semi-Desert	15	7.1 (4.0)	*Melanelia glabra***, *Melanelia subaurifera**, *Xanthoria fallax***
Total for State	141	9.2 (4.3)	

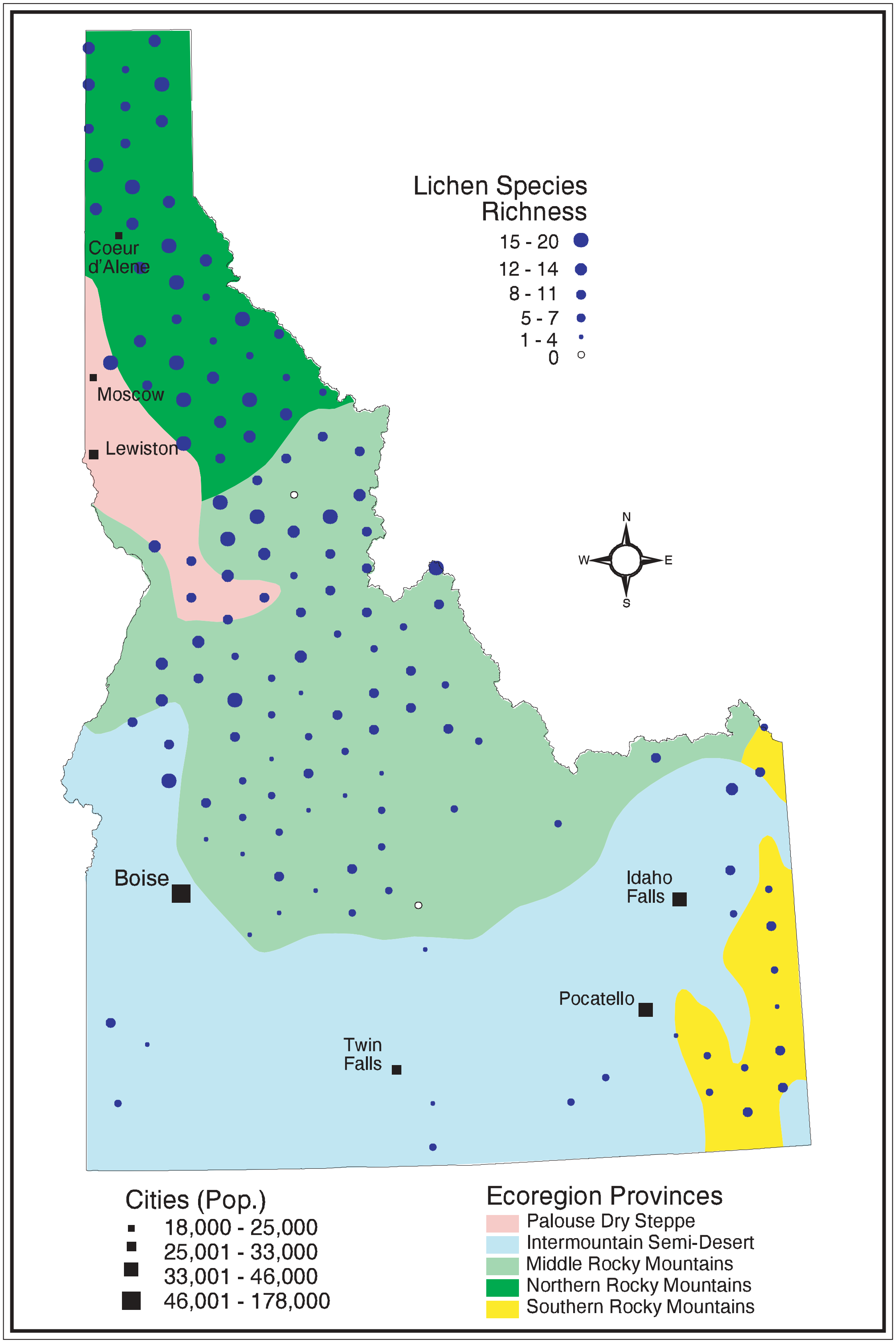

Figure 2—FHM lichen species richness for 141 on-frame plots in Bailey's Ecoregion Provinces, Idaho, 1996. Major cities with populations of over 18,000 are shown. Boundaries from Bailey and others 1994.

Table 6—Correlations of moderately to highly correlated environmental variables in 1996 on-frame Idaho dataset with two ordination axes in NMS ordination (McCune and Mefford 1999). Environmental variable values where $r^2 > 0.04$ are shown.

Variable	Axis 1 r^2	Axis 2 r^2
Latitude	0.72	
Longitude	0.29	0.11
Elevation	*0.45	
Species richness	0.45	
Basal area (Total)	0.12	0.04
Basal area hardwoods		*0.05
Basal area live hardwoods		*0.05
Basal area conifers	0.12	0.07
Basal area live conifers	0.10	0.08
Percent of subplots forested		0.18

* This value represents a negative relationship.

live trees, basal area conifers) were absent were excluded from the starting community matrix (141 plots x 75 species) resulting in a reduced community matrix of 135 plots x 57 species. The ordination explaining the greatest amount of variance (79 percent) yielded a three-dimensional solution with an extremely strong correlation of two of the three primary community gradients with species, latitude, elevation, species richness, and longitude. A two-dimensional solution explaining 70 percent of the variance was chosen for increased interpretability, better correlations of environmental variables, and elimination of strong species and environmental variable correlation along more than one axis (table 6). Forty-eight percent of the variance was explained by Axis 1 and 22 percent explained by Axis 2 (coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space [r^2] were 0.48 and 0.22 for Axis 1 and 2 respectively). Plots clustered strongly in species space by ecoregion province (fig. 3) and provinces maintained strongly distinct subsections of n-dimensional species space in multi-response permutation procedures ($p < 1 \times 10^{-8}$)

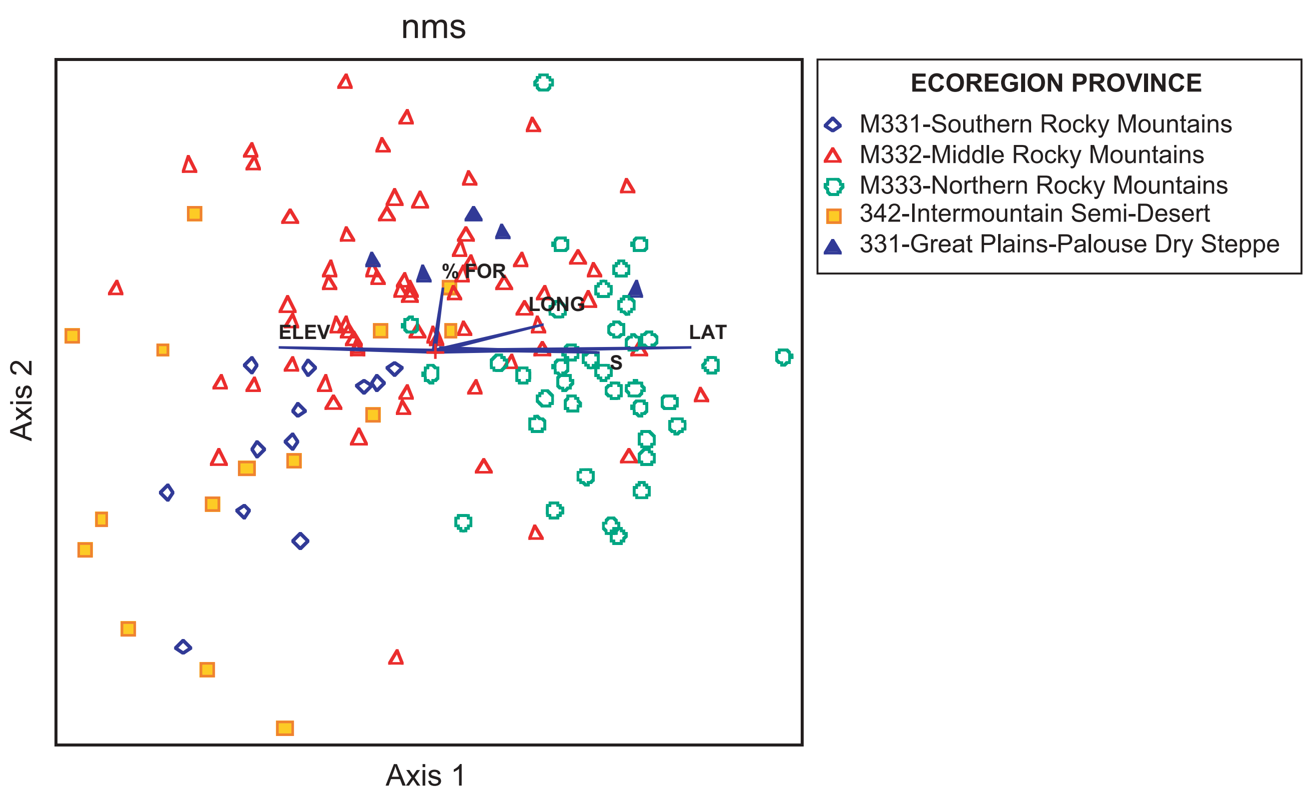

Figure 3—Ordination of a reduced community matrix of 135 Idaho plots by 57 species with nonmetric multidimensional scaling (NMS, Kruskal 1964). Vectors from centroid are proportional to strength of correlation (table 6). Vector values: LAT = Latitude; S = Species richness; LONG = longitude; % FOR = percent of plot forested; ELEV = elevation. Ecoregion province designations follow Bailey and others (1994).

(Mielke 1984). This statistic is complemented additionally by the high beta diversity (8.2) found in the original unreduced community matrix (141 plots), suggesting that there is more than one distinct lichen community present in the dataset. Northern Rocky Mountain province plots appeared to cluster more tightly than any other province's plots in both two- and three-dimensional solutions. Mean values for basic environmental attributes are shown by ecoregion provinces in table 7.

Axis 1 explained 79 percent of the variance in the original data matrix; it was strongly associated with subregional climates with the northern Rocky Mountain plots defining the positive end of this gradient (fig. 3). Latitude, longitude, and species richness were strongly positively correlated with Axis 1, while elevation was strongly negatively correlated (table 6). Species richness was higher in the oceanically influenced, lower elevation mountains of northern Idaho (Northern Rocky Mountain Province). Richness was lower in the higher and drier central and southern mountain regions (Middle and Southern Rocky Mountain Provinces). Species such as *Alectoria sarmentosa*, *Platismatia glauca*, *Cetraria chlorophylla*, and several *Hypogymnia* species were strongly correlated with Axis 1, and most of these were strongly associated indicator species for the Northern Rocky Mountain Province (table 3). These and several other species occurred exclusively or primarily in the wet conifer forests of northern Idaho. Species such as *Xanthoria fallax* and *Letharia columbiana* were negatively correlated with Axis 1 and were associated with the drier Intermountain Semi-Desert and/or Southern and Middle Rocky Mountain Provinces. A species cluster including such taxa as *Melanelia elegantula*, *M. subolivacea*, *M. exasperatula*, *Physcia dimidiata*, and *Physcia adscendens* joined the latter two species on the dry end of this gradient. The negative correlation of elevation with the primary climatic axis relates mainly to the lower mean elevation status of northern Rocky Mountain plots (3600 ft/1097 m) than of other regions (5300–7200 ft/1615–2194 m). It should be stressed that in interpreting broad patterns in species richness across the State, primary correlation is expected to relate to climate rather than air quality.

Axis 2 explained 22 percent of the variance in the species by plots matrix. This axis was most strongly correlated with percentage of subplots forested and mean basal area of live conifers, and was most negatively correlated with mean basal area of live hardwoods (table 6). Provinces with a high mean percentage forested (96–98 percent for 3 northern provinces) also had the highest mean basal area of conifers, therefore these two variables were closely related. Species strongly positively associated with this axis were conifer forest dwellers (e.g., *Hypogymnia imshaugii*, *Letharia vulpina*, *Nodobryoria abbreviata*), while those negatively associated tended to occur on hardwoods or conifer woodlands in nitrogen-enriched areas (e.g., *Xanthoria fallax*, *X. polycarpa*, *Physcia* spp.) As forest cover and basal area were lowest in the dry southern regions, many of the species most strongly negatively correlated with Axis 2 also had negative correlations with Axis 1.

The correlation of hardwood basal area with Axis 2 was based on a very limited set of plots with hardwoods present (table 7). The hardwood correlation was likely to have been reduced further because the few plots

Table 7—Environmental attributes of 135 FHM plots for which secondary data exist, Idaho, 1996. Standard deviation of the mean is provided in parentheses after the mean value. Ecoregion province designations follow Bailey and others (1994).

	Ecoregion Province				
Variable	**331. Palouse dry steppe**	**342. Inter-mountain semi-desert**	**M332. Middle Rocky Mountain steppe-coniferous forest-alpine meadow**	**M333. Northern Rocky Mountain forest-steppe-coniferous forest-alpine meadow**	**M331. Southern Rocky Mountain steppe-open woodland-coniferous forest-alpine meadow**
N	5	15	66	37	12
Mean elevation	5300 (1315)	5960 (884)	6381 (1473)	3659 (1070)	7108 (931)
Mean basal area (ft^2/ac)	12 (7)	11 (7)	18 (11)	21 (11)	15 (11)
Mean basal area hardwoods (ft^2/ac)	0.2 (0.4)	2.4 (6.0)	0.5 (1.3)	1.1 (2.9)	0.6 (1.4)
Mean basal area live hardwoods (ft^2/ac)	0.2 (0.4)	2.2 (5.5)	0.4 (1.3)	1.1 (2.8)	0.5 (1.2)
Mean basal area conifers (ft^2/ac)	12 (8)	8 (7)	18 (11)	20 (11)	14 (12)
Mean basal area live conifers (ft^2/ac)	12 (7)	8 (7)	16 (10)	17 (10)	12 (10)
Mean % of plot forested	98 (4)	86 (27)	98 (11)	96 (14)	85 (25)

containing hardwoods in the northern Rockies differed both in tree and lichen species from the hardwood plots in southern areas. As the hardwood lichen flora is dramatically different from that of conifers, analysis of these trends would require targeted sampling of hardwoods. Analysis of hardwoods separately within northern and southern provinces would also be likely to give a stronger signal. For the construction of a gradient model, it is likely that the semi-desert province will be grouped with other Great Basin provinces, while the montane provinces will be grouped with others in Montana and eastern Oregon.

Ecoregional analysis provided several insights into the floristics of Idaho's lichens. Two ecoregion provinces stood out prominently in hosting a large number of indicator species strongly associated with that province (table 5). The Northern Rocky Mountain Province hosted seven indicator species, all of which represented common species west of the Cascade crest in the Pacific Northwest. The Palouse Dry Steppe Province also hosted seven indicator species dominant in eastern Oregon and Washington including *Nodobryoria abbreviata*, *Letharia vulpina*, and *Cetraria merrillii*. Because of the small number of plots in this province, however, the high indicator values in these cases should be treated with caution—these species occurred reliably in the few plots in this particular province but most of these species are widespread throughout at least one to two other provinces. The Southern and Middle Rocky Mountain Provinces tended to be more transitional in species composition between the Northern Rockies and the Semi-Desert. *Letharia columbiana* and *L. vulpina*, which overlap in much of their range, showed divergent distribution in Idaho. *Letharia columbiana* occurred predominantly in drier forests, while *L. vulpina* proved widespread.

Discussion: Epiphytic Lichen Status and Trends Relative to Forest Dynamics

Increase in Douglas-fir Stands and Stand Density

The Boise National Forest has documented a major shift in forest cover from mature open growth ponderosa pine to denser, smaller diameter Douglas-fir (O'Laughlin 1994), which impacts the distribution of lichen communities. This shift is attributed to forest harvesting practices and fire suppression. Historic ratios of approximately 80:20 percent ponderosa pine to Douglas-fir have changed to a ratio of 20:80 percent cover of the forested portions of the landscape (O'Laughlin 1994).

Decline in Mature Larch

Western larch (*Larix occidentalis*) may support a unique population of lichen species in central and north Idaho (McCune and Rosentreter 1998; Rosso and Rosentreter 1999). This tree can live 600 years and is affected less by insects and disease than other conifer species. Larch is associated with the upper range of moisture in the State of Idaho and has fire-resistant characteristics. Harvest practices, lack of natural fires, and artificial regeneration of other tree species have caused a decline in mature larch in Idaho and Montana. This tree is held sacred to the Native Americans who collect forage lichens from its branches to be cooked and added to their pemican for winter sustenance (Turner 1977). This tree species supports large populations of forage lichens and produces large amounts of biomass that are utilized by wildlife (Rosso and Rosentreter 1999). Larch decline may contribute to a decline in the abundance of the forage lichens in the northern part of the state. Collaboration between FHM and other forest surveys (for example, Forest Inventory and Analysis) should yield ample information on larch population trends and lichen diversity.

Increase in Orange Lichens Due to Excess Nitrogen

The increase of orange lichens (*Xanthoria* spp. and others) on desert shrubs and elsewhere (Kauppi 1980), due to excess nitrogen is documented in Idaho (Rosentreter 1990) and may be affecting forests and woodlands near sources of nitrogen pollution. From FHM plot data observed here, nitrophilous species such as *Xanthoria fallax* and *X. polycarpa* (*sensu lato*) were highly associated with the Intermountain Semi-Desert Province. This association is due in part to the naturally high deposition of soil nitrogen via dust in semi-arid areas, although the extent to which anthropogenic sources have contributed to an increase of these taxa is unknown. While a small group of lichen taxa are known to respond positively to nitrogen enrichment, a much larger group exhibits deleterious effects including dieback, deformities, cancer-like growths, and dissociation of the algal and fungal partners of the lichen (Kauppi 1980).

A prominent anthropogenic source of nitrogen in Idaho is livestock; specifically concentrated dairy farming in the southern part of the State. Idaho's dairy industry has expanded rapidly in recent years. While the total number of dairies has decreased, average size and overall dairy production have increased (Mitchell and Beddoes 1999). This trend may be linked to a broader pattern of increasing atmospheric and terrestrial nitrogen levels in the western U.S. (LeJeune and Seastedt 2001). Elevated nitrogen pollution is likely to continue and lichen community monitoring may be able to detect and track its areas of impact.

Decline in Large Riparian Hardwoods

Due to forest conversion, streamside disturbance, regulated stream flows from dams, splash dams for logs, and road building along the stream channels, riparian areas with large hardwoods have declined in the State (USDA 1997). These hardwoods, most prominently aspen and cottonwood, support a diverse and occasionally rare lichen flora (Hutchinson and McCune 2001). Since no plots occurred in riparian areas, gradient model plots or Evaluation Monitoring (a subsection of FHM) studies will examine several such areas in assessing trends in diversity in riparian areas. The results of these special studies can complement regional gradient models and on-frame plots by specifically targeting less common regional habitats that may significantly contribute to overall diversity.

Further Research Needed

Air Quality

Some common macrolichen genera growing on trees in Idaho are presented in table 8. Based on the pollution sensitivity of species in these genera in the Pacific Northwest (McCune and Geiser 1997) and Colorado (McCune and others 1998), we have listed their likely indicator values in Idaho, but further research will determine their actual value as indicators here.

Table 8—Characteristics of some common macrolichen genera growing on trees in Idaho.

Genus	Appearance	Indicator value and functional roles
Alectoria	Yellow, hair-like	Pollution-sensitive; strong indicator of wet-montane climate.
Bryoria	Brown, hair-like	Pollution-sensitive; forage lichen; many uses by animals. Some species strong climate indicators.
Candelaria	Yellow, very small foliose	Pollution and dust tolerant, mainly on hardwoods.
Cetraria	Greenish, broad-lobed foliose	Generally intermediate in pollution sensitivity and in climate indication.
Cladonia	Grey-green stalks or cups with small frills	Forest floor, tree bases, and rotting wood. Intermediate to sensitive to air pollution; most common in wetter climates.
Hypogymnia	Grey or brown, foliose, hollow lobes	Mainly on conifers, some species pollution tolerant.
Letharia	Yellow to chartreuse shrubby	Widespread in continental conifer forests; somewhat pollution sensitive.
Melanelia	Brown to olive, foliose, medium size	Nearly ubiquitous; some species pollution tolerant; on both hardwoods and conifers.
Nephroma	Brown, foliose, small	A nitrogen-fixing lichen with oceanic affinities, pollution-sensitive.
Parmelia	Grey, foliose, medium size, black below	Widespread, pollution tolerant, on both hardwoods and conifers.
Parmeliopsis	Grey or green-gray narrow lobed foliose	Mid to upper elevation conifers; intermediate in pollution sensitivity.
Phaeophyscia	Small, cryptic, gray or brownish, foliose	Usually on hardwoods; most species pollution tolerant.
Physcia	Small, white, foliose	Some species nitrogen-loving; some species almost restricted to hardwoods.
Physconia	Small, frosty-coated, foliose, often forming neat rosettes; brown, gray or white	Usually on hardwoods; pollution tolerant, nitrogen-loving.
Platismatia	White, foliose, large	On conifers in wet climates, pollution-tolerant to intermediate.
Usnea	Greenish fruticose, tufted or hanging, branches have a central cord	Abundant in the mountains, somewhat pollution sensitive but persisting in polluted areas as dwarf, compact forms.
Xanthoria	Orange or yellow, foliose	Widespread but more abundant in areas of elevated nitrogen, somewhat pollution tolerant.

Air pollution impacts on lichens have been documented from a variety of sources in Idaho (Dillman 1996; Hoffman 1974; Rope and Pearson 1990). Pollution is likely to be having effects in the Boise and Pocatello area, but determination of the nature and severity of these effects awaits a gradient model. As in other western States (e.g., Colorado) (McCune and others 1998) pollution is likely to have the greatest influence at low- to mid-elevations, where the climate is driest and lichen flora are naturally species-poor. Low species richness near Boise (western Intermountain Semi-Desert and southern Middle Rocky Mountain Provinces) should not necessarily be attributed to pollution. Pollution impact on lichens has been documented in Lewiston (Hoffman 1974) and is likely to produce patterns different from those farther south, as diversity is naturally higher in this wetter zone.

The main research needed to place these findings in perspective is regional gradient modeling (fig. 1). Examples of gradient analysis from other regions of the country may be viewed online at: http://www.wmrs.edu/lichen/. By sampling intensively around urban and industrial areas and known clean air sites, we will be able to model the changes in lichen communities from clean air to polluted air in a variety of ecoregions and elevations. An air quality scoring system is the key product of the gradient model. The gradient model can be applied to individual plot locations to give us a better picture of air quality impacts on State lichen communities specifically, and Idaho forests generally. With a gradient model in place, we will be able to assess air quality trends after the second cycle of lichen sampling is completed in 2005.

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