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Lichen Elemental Indicators for Air Pollution in Eastern United States Forests: A Pilot Study in the Upper Midwest

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Forest Service | Pacific Northwest Research Station | General Technical Report PNW-GTR-985 | April 2020

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Cover: *Parmelia sulcata* Taylor (code name "Parsul"). Photo by Sarah Jovan.

Abstract

Will-Wolf, Susan; Jovan, Sarah; Amacher, Michael C.; Patterson, Paul L. 2020. Lichen elemental indicators for air pollution in Eastern United States forests; a pilot study in the upper Midwest. Gen. Tech. Rep. PNW-GTR-985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 178 p.

Five lichen species were evaluated as element-content pollution bioindicators for a pilot study in Wisconsin and adjacent U.S. states, using data for 20 elements. Good-quality elemental data for aluminum, cobalt, chromium, copper, iron, nitrogen, and sulfur—mostly from nonspecialist U.S. Forest Service Forest Inventory and Analysis staff collections with extensively documented protocols—clearly indicated a site pollution load in the project area. The percentage of nearby land in forest was the strongest predictor for sample collection at study sites of the two most frequent species; such knowledge facilitates improved broad applications. Improved protocols and three lichen species were recommended for implementation as elemental bioindicators in the north-central United States; species were also recommended for three other Eastern U.S. regions. The three reccomended species are *Evernia mesomorpha* Nyl.; *Flavoparmelia caperata* (L.) Hale, and the combined *Physcia aipolia* (Ehrh. ex Humb.) Fürnr var. *aipolia* and *P. stellaris* (L.) Nyl.

Keywords: Air pollution, element, forest health, land cover, indicator, lichen, metals, nitrogen, sulfur.

Summary

The presence of chemical elements in naturally growing lichens can passively indicate levels of air pollution and be used to supplement established air quality networks and facilitate improved estimates for local air pollution across large regions. In this pilot study, we designed and tested such an elemental biomonitoring protocol for application to the Eastern United States by the U.S. Forest Service Forest Inventory and Analysis (FIA) program. Measurements included nitrogen, sulfur, and heavy metal elements that are common indicators for general airborne inorganic pollutants. We collected a pilot dataset in Wisconsin and adjacent states of Illinois, Iowa, and Minnesota (total area ~215 000 km^2) from five lichen species common in forested FIA plots in the Eastern United States: *Evernia mesomorpha* Nyl. (abbreviated in this report as "Evemes"), *Flavoparmelia caperata* (L.) Hale ("Flacap"), *Parmelia sulcata* Taylor ("Parsul"), *Physcia aipolia* (Ehrh. ex Humb.) Fürnr var. *aipolia* and *P. stellaris* (L.) Nyl. combined ("Phyaip"), and *Punctelia rudecta* (Ach.) Krog ("Punrud").

Single-species composite lichen samples were collected from woody substrates, requiring 45 min/plot on average, by trained FIA staff near 75 FIA plots and by a lichen expert at additional sites. Species identification was confirmed by the expert before measurement of elements. Species recognition by FIA staff was reliable for Evemes, Flacap, and Phyaip but less reliable for Parsul and Punrud. Sample preparation time (for measurement) ranged from an average of 16 min/g for Evemes to 56 min/g for Phyaip. Concentrations in lichens of 26 elements were measured by combustion or digestion/optical emission spectroscopy. Data were validated and screened for anomalies before analysis.

Data for 20 elements in 203 samples from 83 sites were analyzed. Samples from fewer than the criterion of six or more different substrates per species (trees, etc.) or with visible extraneous contamination resulted in poor-quality data (containing outlier or anomalous values for several elements) regardless of species, and were excluded. Parsul and Punrud had more such samples than other species, probably linked to staff species recognition problems that might be alleviated with more intensive training. Samples smaller than the goal of ≥1 g for measurement took much longer than average to prepare; most small samples of Parsul and Punrud were excluded for poor data quality. Fully rigorous cleanliness protocols for sample handling used by FIA staff and the expert were necessary; samples from relaxed protocols also tested by the expert yielded data not suitable for analyses. Improvements to field and laboratory protocols as well as training are recommended based on FIA staff feedback and data evaluation.

Flacap (79 samples) and Phyaip (48 samples) represented most sites: Flacap was found more at sites with much nearby forested land cover and Phyaip more at sites with little nearby forest, including urban areas. The two species also covered the full pollution gradient. Evemes (26 samples) was collected only at northern sites with much nearby forest cover and in the cleaner half of the site pollution gradient; Parsul (26) and Punrud (23) were scattered across much of the pollution gradient. After conversion of data between species and calculation of site averages across species, aluminum, chromium, cobalt, copper, iron, nitrogen, sulfur, and two combined indices (one for nitrogen and sulfur, another for aluminum, chromium, cobalt, copper, and iron) all reliably indicated the relative local pollution load, as supported by strong correlations with monitor site measured data. Logistic regression of sample presence for three species found that percent of nearby forested land cover alone was the best predictor for samples of Flacap or Phyaip, and average maximum temperature alone best predicted Evemes. Flacap and Phyaip, with Evemes as a secondary species, are recommended as elemental bioindicators across all North Central U.S. states. Flacap and Evemes, with Phyaip as a secondary species, are recommended as elemental bioindicators in Northeastern U.S. states based on study results plus past lichen species distribution at FIA plots. Flacap and Punrud (requiring intensive training to distinguish), with Phyaip as a secondary species, are recommended as elemental bioindicators in the Mid-Atlantic and Southeastern U.S. states.

Contents

Introduction

Monitoring lichen response to air pollution is an important component of evaluating the health of forest and lichen communities in surveys by the U.S. Department of Agriculture Forest Service (Geiser and Neitlich 2007; Jovan 2008, 2009; Jovan et al. 2012; Will-Wolf et al. 2015a) and for monitoring natural biological systems more broadly (e.g., Fenn et al. 2003a, 2003b; Nimis et al. 2002). Estimation of pollutant load from elemental concentrations in naturally occurring lichens or mosses (passive biomonitoring) (Garty 2002) is a long-established technique to estimate local air quality (Ferry et al. 1973, Jackson et al. 1993, Martin and Coughtrey 1982). It is often used when instrument measurements of pollutants are not available near each desired site. Lichen elemental bioindication continues to be widely used in Forest Service projects (e.g., Donovan et al. 2016, Gatziolis et al. 2016, McMurray et al. 2013, Root et al. 2015, Will-Wolf et al. 2018a) as well as worldwide (e.g., Paoli et al. 2014, Yemets et al. 2014). Comparisons of lichen elemental concentrations with instrument measurement of pollutants have demonstrated that elemental bioindication provides accurate and cost-effective depiction of relative deposition patterns (e.g., Bari et al. 2001, Conti and Cecchetti 2001, Root et al. 2013).

Standard criteria for a lichen species used for elemental measurement are that it is common and widespread in the study area; is tolerant of air pollution, so that biomass elements reflect ambient conditions, not lichen metabolic response (Garty 2002, Garty and Garty-Spitz 2015, Nash 2008); and is easy to distinguish and collect in the field (Conti and Cecchetti 2001, Puckett 1988, Wolterbeek 2002, Yemets et al. 2014). Appropriate species typically differ by region or target sampling habitat (e.g., Bargagli and Mikhailova 2002, Conti and Cecchetti 2001, Ferretti and Erhardt 2002, Smith et al. 1993). Data from one species are preferred (Bargagli and Mikhailova 2002, Geiser 2004, Smith et al. 1993). However, data from multiple species (e.g., Cercasov et al. 2002, Karakas and Tuncel 2004, McMurray et al. 2013, Root et al. 2013, Sloof and Wolterbeek 1993, Will-Wolf et al. 2015b) are often needed to represent many sites in large regions. When element accumulation rates differ between species (e.g., Karakas and Tuncel 2004, Will-Wolf et al. 2018a), statistical models can convert elemental data between species for equivalence (Conti and Cecchetti 2001, Root et al. 2013, Sloof and Wolterbeek 1993).

Many Forest Service elemental bioindicator projects have been conducted in the Western United States. Information from the agency's Forest Inventory and Analysis (FIA) and Pacific Northwest Region lichen air quality programs includes suitable lichen species for the Western United States (Geiser 2004, Geiser and Neitlich 2007, Jovan and McCune 2006) and protocols for sample collection and laboratory measurement of elements (Gatziolis et al. 2016, Geiser 2004). Elemental data for several thousand lichen samples from FIA or Forest Service Current Vegetation Survey plots in California, Idaho, Montana, Oregon, Washington, and Wyoming from the 1990s to 2012, many for published studies (Geiser and Neitlich 2007, McCune et al. 1998, McMurray et al. 2013, Root et al. 2015), are archived in an internal Forest Service database (described on its Lichens and Air Quality website[1]), which includes some data from the Northeastern United States (including Cleavitt et al. 2015). Data from this study and others in the Eastern United States (e.g., Will-Wolf et al. 2018a) will be added to that database. The six lichen species routinely used in California and the Pacific Northwest are absent or very narrowly distributed in Eastern U.S. plots (Jovan et al., in press a), where different bioindicator species are needed. In addition to standard criteria, species for FIA and other large monitoring programs must be reliably recognizable in the field by nonspecialists; moreover, handling and measurement must be cost effective.

Objectives for the full pilot project were to evaluate the efficacy of using lichen species as elemental bioindicators across the Eastern United States for monitoring inorganic air pollution (nitrogen (N), sulfur (S), and heavy metals). The project was conducted mostly in Wisconsin (fig. 1). As we report on this study, we integrate the results of two other concurrent studies from the same field project:

- Will-Wolf et al. (2017a) evaluated lichen elemental data from five lichen species, handled with rigorous protocols, as indicators for local pollution load in the upper Midwest.
- Will-Wolf et al. (2017b) evaluated field and sample preparation methods that included relaxed protocols, which could save time and thus reduce program costs.

Three specific objectives for this study were to:

1. Recommend improvements in training and protocols to support implementation in the Eastern United States by the FIA program, based on results from this study and Will-Wolf et al. (2017a, 2017b).
2. Recommend improved elemental data evaluation and interpretation, based on this study and Will-Wolf et al. (2017a, 2017b).
3. Recommend lichen species as elemental bioindicators for different regions of the Eastern United States, based on this study with assistance of Will-Wolf et al. (2018b) results.

Details of methods and results are reported in online appendixes 1 through 7; original data are in appendixes 8 through 13.

[1] U.S. Forest Service Lichens and Air Quality website: http://gis.nacse.org/lichenair.

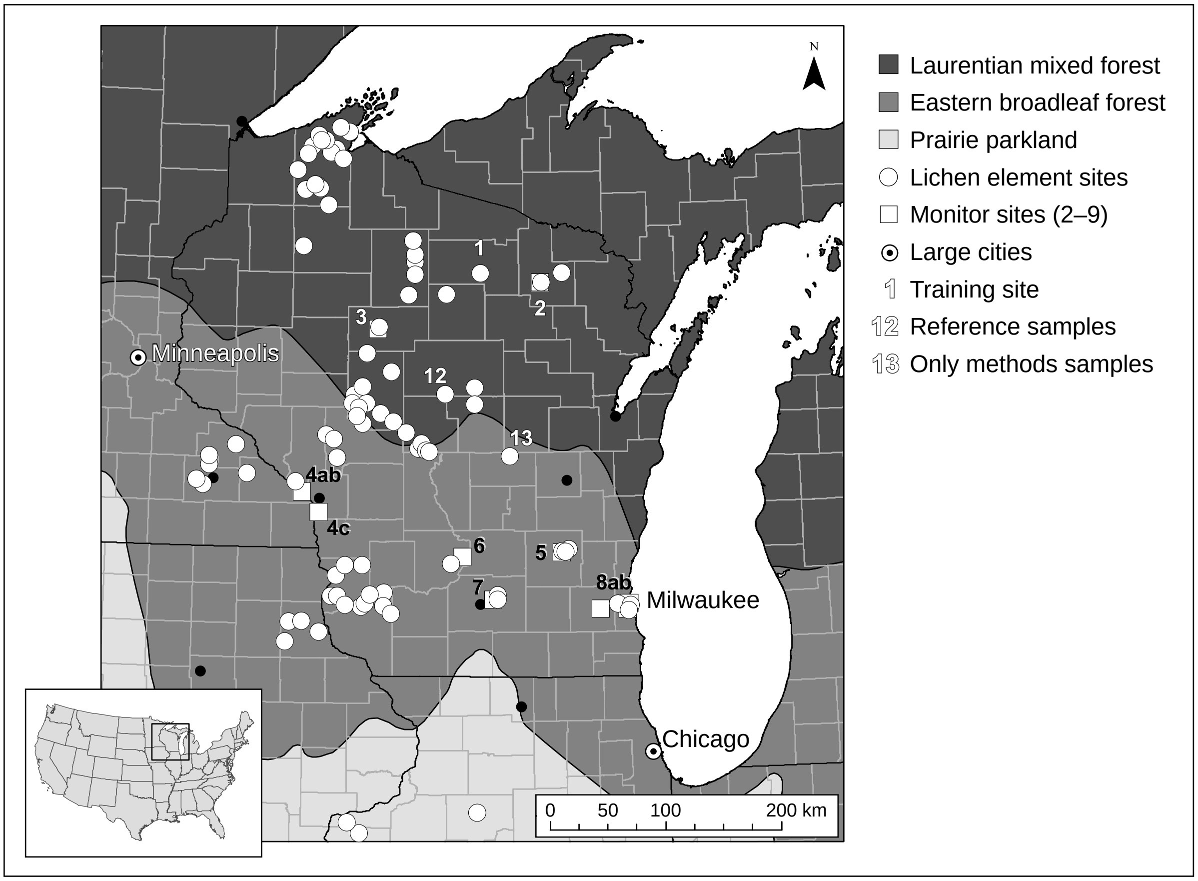

Figure 1—Location of lichen elemental sites and instrument monitor sites.

Methods

Project Region and Environmental Variables

The project was conducted in Wisconsin and nearby areas of adjacent Illinois, Iowa, and Minnesota (fig. 1). It covers ~215 000 km² and is mostly within two ecoregion provinces (Cleland et al. 2007, McNab et al. 2007): 212, Laurentian Mixed Forest, and 222, Midwest Broadleaf Forest. The few Illinois plots are in 251, Prairie Parkland (Temperate). Will-Wolf et al. (2017a) described ecoregions and environmental variables and correlated lichen elemental data with site data for climate, air pollution, vegetation, and percentage of nearby area in different types of land cover (forest, agriculture, etc.). Environmental data, also used for this study, were either downloaded from the FIA DataMart[2] or extracted from public Internet sources. Will-Wolf et al. (2017a) also compared project lichen elemental data with instrument-measured data and modeled pollutant variables for eight monitor sites (2 through 9) (fig. 1) to confirm that lichen elemental data were better estimators of site pollution load than modeled variables.

[2] DataMart web page: https://apps.fs.usda.gov/fia/datamart/datamart.html.

Bioindicator Lichen Species

The five macrolichen species (fig. 2) selected for the pilot project (Will-Wolf et al. 2017a) were *Evernia mesomorpha* Nyl. (a small- to medium-size fruticose lichen, abbreviated in this report by the code name "Evemes"); *Flavoparmelia caperata* (L.) Hale (large foliose, code name "Flacap"); medium foliose, *Parmelia sulcata* Taylor (code name "Parsul"); *Physcia aipolia* (Ehrh. ex Humb.) Fürnr. var. *aipolia* and *P. stellaris* (L.) Nyl. combined (small foliose, tightly appressed; code name "Phyaip"); and *Punctelia rudecta* (Ach.) Krog (large foliose, code name "Punrud"). FIA lichens data include all five (table 1). Flacap, Parsul, Phyaip, and Punrud are moderately pollution tolerant (Will-Wolf et al. 2017a) and are common in eastern North America (Brodo et al. 2001, Jovan et al., in press b). Evemes is somewhat pollution sensitive and more northern. Evemes, Flacap, Parsul, and Punrud have been used as elemental bioindicators in the East, Parsul also in the West (Geiser 2004, Root et al. 2013), with Flacap and Parsul plus an Evemes congener also used in Europe (reviewed in Will-Wolf et al. 2017b). Phyaip has not been used before for this purpose. Vouchers for each species are in the Oregon State University Herbarium.

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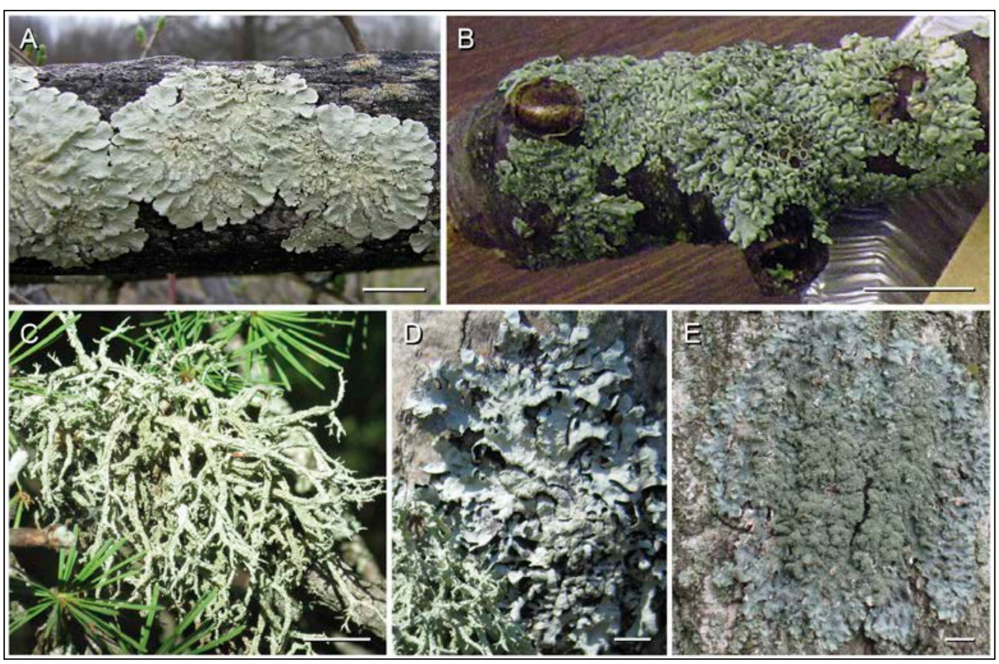

Figure 2—Selected elemental bioindicator lichens: (A) Flavoparmelia caperata (Flacap) on fallen stem; (B) Physcia aipolia/stellaris (Phyaip) on sugar maple twig resting on pie pan; (C) Evernia mesomorpha (Evemes) on tamarack twig; (D) Parmelia sulcata (Parsul) on sugar maple sapling (small Evemes at lower left); (E) Punctelia rudecta (Punrud) on white oak trunk. Scale bar = 20 mm in each image.

Table 1—Percentage of unique 1994–2005 Forest Inventory and Analysis (FIA) plots in Eastern U.S. lichen regions with selected elemental bioindicators

Lichen species	Species code name	FIA lichen region: North Central (204 plots)	Northeast (625 plots)	Mid-Atlantic (779 plots)	Southeast (357 plots)
		Percent			
Any species		96.6	97.0	91.9	88.2
Any of the four most frequent species		95.6	95.8	91.9	88.2
Any of the three most frequent species		**95.1**	**95.4**	**91.3**	**88.2**
Either of the two most frequent species		90.7	93.9	85.1	86.3
Evernia mesomorpha Nyl. (North American studies, congener in Europe)	Evemes	56.4	57.8	3.3	0
Flavoparmelia caperata (L.) Hale (North American, European studies)	Flacap	**69.1**	**63.0**	**76.9**	**60.2**
Parmelia sulcata Taylor (North American, European studies)	Parsul	**71.6**	**85.6**	**52.4**	4.2
Physcia aipolia (Ehrh. ex Humb.) Fürnr. and P. stellaris (L.) Nyl. (no other studies)	Phyaip	**78.4**	40.5	23.1	**32.8**
Punctelia rudecta (Ach.) Krog (North American studies)	Punrud	39.2	**64.0**	**58.0**	**78.7**
Punctelia missouriensis G. Wilh. and Ladd (possible bioindicator, no other studies)	Punmis	6.4	0	10.8	5.0

Note: The three most frequently found species for each region have numbers in boldfaced type; in parentheses after each lichen species name is the past use for elemental measurement in eastern North America and western Europe.

Data are from Jovan et al. (in press b).

Training

Training for collection and handling of lichen elemental bioindicator samples in a large monitoring program such as FIA has three objectives: (1) teach the field collectors (often nonspecialists) how to identify and distinguish the focus lichen species in the field; (2) teach protocols to collect and preserve healthy lichen samples uncontaminated by any offsite substances; and (3) explain the rationale for the indicator and reasons for the protocols to motivate trainees to accomplish their tasks successfully during the field season. Training methods and field protocols were adapted from documentation by Geiser (2004) of lichen elemental bioindicator practices for the FIA Pacific Northwest region and National Forest System Pacific Northwest Region.

Training for FIA permanent field staff to collect pilot study lichen samples was held 11 September 2013 at the Northern Research Station's Institute for Applied Ecosystem Studies, Rhinelander, Wisconsin (fig. 1, site 1), by lichen specialist Susan Will-Wolf (see app. 1 for the training schedule and app. 2 for the presentation). The training site included an indoor workroom (fig. 3) and immediately adjacent large wooded areas (fig. 4). Training materials featured specimens of the selected focus species and lookalikes (fig. 3), field season lichen recognition guides (fig. 5) included specimens of the main bioindicator species, and training methods emphasized hands-on learning and practice after a brief introduction. Followup e-mail correspondence answered questions during field work. Field staff evaluated the training, kept notes during the field season, and recommended improvements to training and field protocols for a lichen elemental indicator (see app. 3 for field staff feedback).

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Figure 3—Forest Inventory and Analysis staff learn to identify lichen species at training.

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Figure 4—Forest Inventory and Analysis staff practice field protocols at training.

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Figure 5—Field lichen recognition guides. Each copy includes samples of all five lichen bioindicator species.

Collection Sites and Field Protocols

The four FIA field staff (each a one-person crew) collected lichens at permanent FIA Phase 2 (P2; basic plot and vegetation information) plots (Woudenberg et al. 2010) in their preset fall 2013 schedule. Will-Wolf collected in summer/fall 2013 from 15 temporary sites in suitable wooded areas, mostly near eight air monitoring sites in Wisconsin or nearby, to compare lichen element data with instrument-measured pollutant amounts (Will-Wolf et al. 2017a) and to evaluate protocol variations (Will-Wolf et al. 2017b). Surveyed plots, though unevenly spaced, represented well the project area's major north-south environmental gradient and ecoregions (fig. 1).

Sample handling protocols are summarized here (see app. 1 for details). Lichen species were collected in forest openings or edges with visually estimated 20 to 50 percent canopy cover (regardless of tree size) to give equivalent exposure to air pollution across sites (because canopy density affects moss elemental concentrations) (Gandois et al. 2014). Areas near disturbances (active agricultural fields, lawns, roads, etc.) were avoided. Collections were near but not on permanent FIA plots (no destructive sampling was allowed) (Woudenberg et al. 2010), in suitable areas ≤500 m wide. Species were collected from any natural standing (live or dead) woody stem 0.5 m aboveground up to as high as one can reach (but not from fresh deadfall, following canopy criteria). The goal was a single-species sample of at least 1 g final dry weight of lichen collected from six or more separate substrates. FIA staff were to collect one composite sample of two focus species at each site, with duplicate samples of all species present at about every fifth site. Evemes, Flacap, and Punrud were designated primary species for FIA staff collection; Parsul and Phyaip were secondary species collected as needed. Will-Wolf collected two or more replicate samples of each focus species found at each temporary site. Rigorous field protocols (app. 1) (Will-Wolf et al. 2017a) were used by FIA staff for all samples and by Will-Wolf for some samples (fig. 1: site 1, near monitor sites 2 through 9, site 12 Flacap reference sample) to avoid chemical contamination from offsite or extraneous onsite material, and to protect and keep them dry and cool. Staff and Will-Wolf samples from rigorous protocols were combined for project data analyses. Variations of relaxed protocols (Will-Wolf et al. 2017b) were evaluated with other Will-Wolf samples from temporary sites.

Sample Preparation, Measurement, and Data Evaluation

Samples were redried as necessary in the Will-Wolf lab, then kept cool and dry until prepared for measurement (see app. 4 for details). The species was confirmed and sample condition noted, then the sample was prepared using either fully rigorous protocols to maintain chemical cleanliness or one of the relaxed protocols for some Will-Wolf samples (Will-Wolf et al. 2017b). Preparation time was recorded and the prepared sample was weighed to estimate cleaning rate, calculated for both full and partial removal of substrate. For “Full Removal,” samples were cleaned under a dissecting microscope; >99 percent (by surface area) of visible adhering substrate and other extraneous material were removed (Will-Wolf et al. 2017b). “Partial Removal” samples were cleaned by eye; large pieces of extraneous material were removed but small pieces visible to the eye remained (~95 percent of extraneous material removed). Samples were not rinsed, to avoid reducing concentrations of water-soluble elements (Bargagli and Mikhailova 2002, Cercasov et al. 2002, Makholm and Mladenoff 2005, McMurray et al. 2013). Five samples of *Ramalina americana* Hale (small- to medium-size fruticose, code name “Ramame”) deliberately collected by FIA staff and Will-Wolf, and two samples of *Punctelia missouriensis* G. Wilh. and Ladd (large foliose, code name “Punmis”) mistakenly collected by FIA staff as Punrud, were measured to investigate their possible future use as indicators. Samples were measured for 26 elements in three batches January through May 2014 in a Logan, Utah, Forest Service laboratory supervised by elemental analysis expert Michael C. Amacher. The [Forest Service standard] cost of $50/sample to measure 26 elements is affordable for a large monitoring program and was 30 to 35 percent of 2014 costs for similar measurements at U.S. commercial laboratories. Lichen elemental concentration was reported as a percentage (= ppm × 10,000 or g/100g) for calcium (Ca), carbon (C), magnesium (Mg), phosphorus (P), potassium (K), N, and S (two analysis methods), and as mg/kg (= ppm) for all other elements. Elements are listed using their standard codes (IUPAC 2014).

Elemental data were first screened: for extremely high outlier values samples were remeasured as possible and the new values replaced the outlier values. If remeasurement was not possible, high outlier values were removed. Screened data were validated (see app. 5 for details and validation summary) by Will-Wolf et al. (2017a) for 20 elements using these criteria: fewer than 5 percent of samples were below detection limits (Gatziolis et al. 2016), and average relative standard deviation was <25 percent for each set of project replicates including references. Validated data were further screened to identify entire problem samples (see app. 6 for details). Will-Wolf et al. (2017b) evaluated the impact of field sample quality on data quality and identified entire samples with validated but anomalous data to exclude from analyses. Scatterplots of elemental values by species helped identify samples with moderate outlier and anomalous data.

Data Conversion and Evaluation of Relationships

Differences between other lichen species and Flacap (which had the most samples) (table 2) in concentrations of each element were evaluated pairwise by Will-Wolf et al. (2017a) by using univariate general linear models (GLM) or linear regression, with element-specific recommendations for use of original or log10-transformed data for analyses. Comparisons of lichen elemental data with instrument-measured data from nearby monitor sites (fig. 1, sites 2 through 9) and modeled pollution deposition identified aluminum (Al), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), N, and S as linked with air pollution, and suggested urban and industrial sources in the project area. Will-Wolf et al. (2017a) also developed two composite multielement indices to compensate for missing data: “Pollution Index N + S” from N and S, and “Pollution Index 5 metals” from Al, Co, Cr, Cu, and Fe. To calculate an index site value (see table 3): (1) site values for an element (average of converted data for samples of all species) were averaged across sites; (2) the N average was divided by the average for another element; (3) average value at each site for that element was multiplied by the value from “(2)” to rescale the mean and range of each element to those of N; and (4) rescaled site values for each element in an index were averaged for the combined index site value.

Table 2—Number of samples from rigorous protocols and sites for the five main bioindicator species

	All		Screened	
Species code name	**Samples**	**Sites**	**Samples**	**Sites**
Evemes	26	21	26	21
Flacap	80	59	79	58
Parsul	31	23	26	19
Phyaip	53	38	48	35
Punrud	31	22	24	14

Data are summarized from appendix 8. See table 1 for full species names.
All = all measured samples from rigorous protocols at all sites; screened = samples and sites for analyses after data screening.

Scatterplots in this study of element values by lichen species vs. one of the elemental indices for both original and converted data visualized both data patterns between species and success of data conversion. Previous results (Will-Wolf et al. 2017a) showed that temperature, latitude, precipitation, percentage of nearby area in forested land cover, Pollution Index N + S, and Pollution Index 5 metals were each significantly correlated with the presence at sites of elemental samples for each

Table 3—Summary of calculations for combined lichen pollution indices

	Original site values				Rescaled site values		
Element	**Average**	**Maximum**	**Minimum**	**Multiplier**	**Average[a]**	**Maximum**	**Minimum**
Aluminum	309.83	692.93	123.70	0.0044	1.350	3.019	0.5389
Chromium	0.6334	2.1996	0.2820	2.131	1.350	4.687	0.6010
Cobalt	0.2121	0.4125	0.115	6.365	1.350	2.626	0.7320
Copper	3.127	7.402	1.222	0.4317	1.350	3.195	0.5272
Iron	393.47	949.17	137.76	0.0034	1.350	3.256	0.4726
Nitrogen	1.350	2.645	0.4722	1.0	1.350	2.645	0.4722
Sulfur	0.1190	0.2333	0.0392	11.342	1.350	2.646	0.4429
Lichen Pollution Index N + S				—	1.354[b]	2.639	0.4429
Lichen Pollution Index 5 metals[c]				—	1.350[b]	2.650	0.6349

[a] Rescaled averages for other single elements differed from that of nitrogen (N) in the 6th to 8th decimal place.
[b] Calculated by first averaging within site, second averaging across all sites. Seven sites had sulfur (S) but no nitrogen values.
[c] The five metals are aluminum, chromium, cobalt, copper, and iron.
Data are adapted with permission from Will-Wolf et al. (2017a).

lichen species. Preliminary analyses and logistic regressions (Freeman and Moisen 2008a) in SPSS® Statistics[3] (IBM Corporation 2015), and final analyses in R (R Core Team 2017, Freeman and Moisen 2008b) identified the strongest predictors of sample presence at sites for selected species to support recommendations for planning bioindicator species selection in future studies (details are in app. 7).

Results and Discussion

Training and Field Support

Training was mostly successful at facilitating FIA staff recognition of bioindicator lichen species and teaching methods for collecting quality samples for elemental measurement. Staff feedback and evaluation of study results suggested training improvements (see app. 1 for details). Thus, in this section, we describe how we achieved part of our first specific objective. FIA staff feedback (app. 3) indicated that the use of physical specimens (rather than images, e.g., fig. 2) of lichen species during training (fig. 3) and in a field guide (fig. 5) were critical elements for learning to recognize lichen species in the field. Recommendations were to shorten the presentation of indicator rationale and to add optional additional reading. The large indoor workroom (fig. 3) and immediately adjacent large wooded areas having most of the focus lichen species (fig. 4) contributed to the success of the Rhinelander, Wisconsin, training site. Nearby forest allowed two rounds of sample collection followed by indoor specimen examination;

[3] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

these activities facilitated rapid learning to recognize species and follow field protocols. Staff requested that a full demonstration of field collection protocol by the expert be added to the training. Future trainings should incorporate all these recommendations.

FIA staff labeling during the field season was ~95 percent correct for Evemes, Flacap, or Phyaip samples, but ~70 percent for Parsul or Punrud (Will-Wolf et al. 2017b). Evemes and Flacap are visually quite distinctive for the region; success at field recognition of untried Phyaip was a welcome surprise. Samples mislabeled as Parsul or Punrud suggested that the presence of other gray foliose lichen species contributed to recognition problems (Will-Wolf et al. 2017b). Rapid expert feedback on the quality of early field samples facilitated improved sample quality but did not substantially improve recognition of Parsul or Punrud. More intensive training might improve field staff success with those two lichen species. Recommendations for future applications are:

1. During planning, evaluate regional lichen communities for potential lookalikes; if possible, select bioindicator species likely to be easily recognized by nonspecialists.
2. Intensify hands-on training with actual specimens, including lookalikes, when it is necessary to include difficult species as bioindicators for a region. Always consider the regional lichen community context in training for bioindicator species recognition.

The following protocol elements should be emphasized in training; see more discussion below in the section “Sample Handling and Data Validation” (revised protocols in app. 1):

1. No individual sample with visible external contamination or damage should be collected. Observation of three individuals on separate substrates should precede collection of a species; final samples from fewer than six substrates should not be measured. Too few substrates was the most common reason for excluding samples regardless of species, followed by too little biomass (which varied by species) and by specimen contamination (Will-Wolf et al. 2017b).
2. Collection of a sample large enough to yield ≥1 g air dry weight after preparation should be emphasized, with good samples displayed at training for visual size recognition.
3. Collection only under the designated canopy range should be emphasized. Failure to adhere to this can increase variability and decrease sensitivity of the indicator. Some variability in Phyaip data may have resulted from an undocumented failure to adhere to the canopy range.
4. Follow all protocols to dry samples as quickly as possible in the field and keep them cool and dry postfield. Under warm and humid summer field conditions, fungal growth and sample degradation can occur in a few hours

for damp samples in sealed bags. This Eastern United States protocol element is usually not needed in the more arid West (Geiser 2004).

Field supplies and their organization were rated by FIA staff as generally good (app. 3), with suggested improvements to supplies and equipment (details are in app. 1). Recorded collection time for two samples/plot by FIA field staff using rigorous protocols was about 45 minutes; postfield handling time (not recorded: drying, cooling, mailing) was reported as reasonable (staff field notes and app. 3). FIA staff noted that adding this indicator for a one-person Phase 3 (P3; summer, includes forest health measurements) (USDA FS 2015) crew might often exceed a 1-day workload, though they decided that a lichen elemental bioindicator would fit best with the FIA P3 data collection goals. The ability to efficiently include elemental bioindicator sample collection with other scheduled FIA plot tasks is important to the long-term success of such an indicator.

Sample Handling and Data Validation

Project data from nonspecialist FIA staff collections, plus rigorous sample handling and data validation protocols, clearly supported lichen elemental bioindication (Will-Wolf et al. 2017a). Recommended revised protocols for sample collection (app. 1), laboratory handling and measurement (app. 4), and data screening and validation (app. 5) are summarized in this section, which describes how we achieved our first study objective.

Sample collection rate was slightly below the goal of 90 percent of FIA plots. FIA staff collected good sample(s) of a focus species near 70 of 75 plots searched for lichens (93 percent of plots), but of 81 FIA plots visited (86 percent; not enough time to search six visited plots). More stringent sampling conditions are not recommended; they might reduce further the percentage of plots with samples. A total of 273 single-species composite lichen samples across all five focus species had elements measured (site information is in app. 8; sample elemental data are in apps. 9 and 10): 221 samples (all five species: 146 from 70 permanent plots; 75 from 13 temporary plots) with fully rigorous protocols (table 2) (Will-Wolf et al. 2017a), and 51 from 14 temporary plots with relaxed protocol variants (described in app. 10) (Will-Wolf et al. 2017b). Ten unmeasured FIA staff samples (not counted above) had non-focus species or too little biomass. Flacap was the most frequently collected (table 2) for samples from rigorous protocols (app. 9), followed by Phyaip. A single sample was collected at 18 FIA plots (26 percent of total plots): Flacap at 7 plots, Parsul at 1, and Phyaip at 10. Project collection goals for FIA staff included collecting samples of all available bioindicator species at some sites, to support evaluation of all species and data conversion. The collection goal for implementation might be two composite samples/site, of one or two of the designated bioindicator species.

Examination of samples generated recommendations for improvements to field protocols and training (see “Training and Field Support” section above). Species identification was confirmed by Will-Wolf before measurement; based on a subsample, *Physcia aipolia* predominated in Phyaip specimens (app. 4). Most measured samples met collection criteria, and most samples (~85 percent) had associated field notes about sample quality and collecting conditions (apps. 8 and 9). For 20 measured samples (15 percent), FIA staff found less than 1g air-dry prepared weight, or collected from too few substrates (often linked to Parsul and Punrud recognition problems). Eighteen crew samples (12 percent) were damp upon arrival to the expert (most on large pieces of bark or branches) and were redried. Two with visible dust or grit were shaken, brushed, and briefly rinsed with distilled water before measurement; all apparently clean subsamples were measured.

Rate of substrate removal from samples for “full” removal (>99 percent removed; see the “Sample Preparation, Measurement, and Data Evaluation” section) from samples collected with rigorous protocols decreased for all species as final prepared sample weight increased (fig. 6). Parsul (fig. 6B) had an approximately linear decrease of rate with increase in weight; Flacap and Evemes (figs. 6A and 6D) had approximately linear rate decreases to a maximum weight, then no further rate change with increased weight. For Punrud and Phyaip (figs. 6C and 6E), maximum rate decreased as weight increased, but point distribution was scattered, suggesting that removal rate was also affected by other undetermined sample characteristics. Average removal rates for a final prepared sample with air-dry weight ≥1.0 g (the goal) were as follows: Evemes: 0.27 hours per gram (hr/g) of final sample (n = 24); Flacap: 0.5 hr/g (n = 84); Parsul: 0.61 hr/g (n = 26); Punrud: 0.83 hr/g (n = 32); and Phyaip: 0.94 hr/g (n = 40). Phyaip required additional time partly because prepared fragments were repackaged into new bags for safe shipping. Rates for “partial” removal (~95 percent) of substrate were indeed faster: ~60 percent of “full” removal for Phyaip (n = 7) from sites near “7” (fig. 1) and ~70 percent of “full” removal for Flacap or Punrud from site 13 (n = 6 each), for final sample weights of 1.3 to 5 g.

Will-Wolf et al. (2017b) showed that project elemental measurement protocols (combustion and digestion/optical emission spectroscopy) (app. 4) gave data comparable to published values from other protocols for most elements at lower cost, and gave more consistently reliable data for N than the neutron activation analysis that usually is used in European studies. Based on cost comparisons, economical implementation of elemental bioindicators in the Forest Service will depend on continued availability of elemental measurement at the Northern Research Station’s Forestry Sciences Laboratory in Grand Rapids, Minnesota, or at an equivalent Forest Service facility.

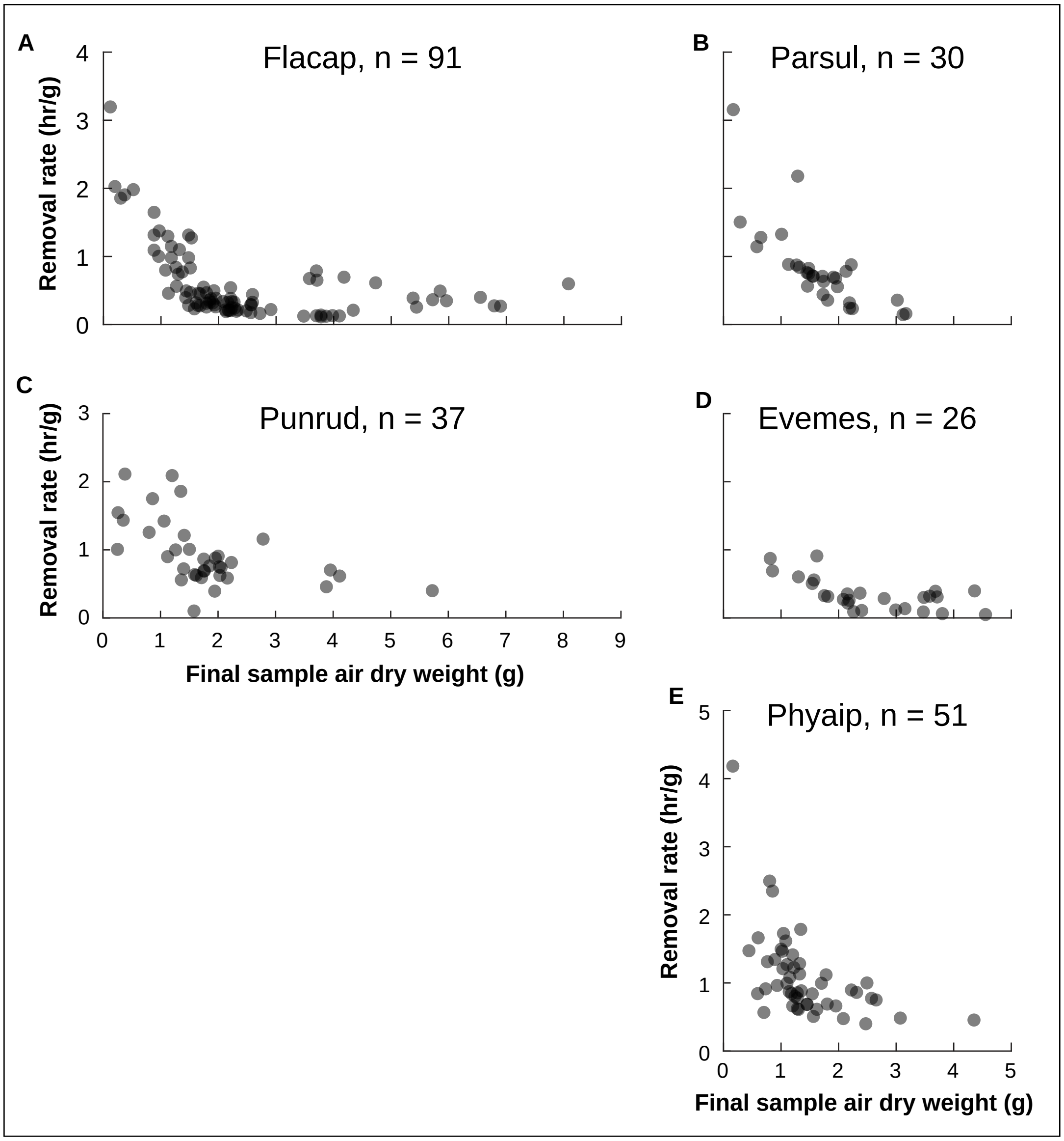

Figure 6—Rate of substrate removal for lichen species samples from rigorous protocols.

Will-Wolf et al. (2017a) found that validation of 20 measured elements (app. 5) supported reliable biomonitoring analyses. The external standard and internal reference were both essential elements in data validation; such references are recommended for future studies. Data conversion models for Flacap and Punrud were shown to be both scale- and region-dependent based on comparisons with other studies using the same protocols (Will-Wolf et al. 2017a). These patterns support the general convention for lichen elemental bioindication (e.g., Ferretti and Erhardt 2002) that species conversion factors should not be applied at notably different spatial scales from nor far outside the original study region.

Sample Evaluation

Sample data evaluation, followed by recommendations for future studies in this section, represent the first part of our second specific objective. Protocols for postvalidation sample evaluation, and recommendations for evaluation of bioindicators for new regions from unusual ecological perspectives, are two important contributions of this part of the study. Differences in performance by FIA field staff (not tested) contributed to the variability of data for each element.

Post-validation sample screening was critical to supporting reliable elemental data analyses (details are in app. 6). Will-Wolf et al. (2017b) excluded from most analyses 18 samples (none of them Evemes) from rigorous protocols because of multiple data anomalies per sample (noted in app. 9; all but one had noted sample quality problems). Exclusions left data on 203 samples from 83 sites (no site eliminated) for most analyses (table 2). Samples from protocol variants had good data quality (app. 10). Otherwise good but damp samples had good-quality data, owing to collection in cool fall weather. Rapid drying remains a critical collection protocol element in an Eastern U.S. summer field season. Many of the samples from too few substrates (52 percent), and all those with visible contamination (removal unsuccessful), were excluded for poor data quality regardless of species. A sample with either problem should not in the future have elements measured. Low-weight samples had species-specific impacts: most low-weight samples of Parsul or Punrud, but few low-weight samples of Flacap or Phyaip, were excluded for poor quality data. Flacap or Phyaip samples ≥0.6 g mostly yielded good data. Minimum weight ≥1.0 g is recommended to measure Parsul or Punrud samples (app. 4); a similar practice is recommended for other difficult species. Sparse samples of difficult species might have unrecognized failures to meet other collection criteria. Data from accepted FIA staff Parsul and Punrud samples were equivalent to expert data (Will-Wolf et al. 2017b), suggesting that better training on difficult species could support reliable elemental bioindication. The novel Will-Wolf et al. (2017a) dust contamination signal from high Ca or strontium (Sr), plus low values for pollution elements, suggested a cause for poor data quality in two excluded samples with no noted field problems (Will-Wolf et al. 2017b). This dust signal needs further testing before wide recommendation. It was contrasted by Will-Wolf et al. (2017a) with Al and Fe linked to dust in smaller scale European studies; Al and Fe in our project and in other large-scale Eastern U.S. studies were clearly linked with air pollution, another possibly scale-linked pattern.

Relaxation of chemical cleanliness protocols or only partial substrate removal generated data significantly different from fully rigorous protocols (Will-Wolf et al. 2017b); most time-saving variants were rejected. More extensive testing of the least-relaxed variant (app. 10; least impact on data quality) was recommended: wiping hands with alcohol rather than wearing nitrile gloves while collecting the sample. Wearing nitrile gloves on hot, humid days in the East is uncomfortable enough to possibly reduce sample quality from busy nonspecialist field staff.

Data for two additional lichen species (app. 10) supported contrasting recommendations. Three of five samples of Ramame were low weight; all had much lower values for metal elements than other species at that site. Ramame is not recommended for further testing; its low metal accumulation would require impractically large 3 to 5 g samples. Punmis elemental data were of good quality, but values differed from other species at the same site and would require full conversion. Punmis is found in drier central Midwestern regions (Brodo et al. 2001) with low-forest landscapes, where Punrud and Flacap were found less frequently (Jovan et al., in press b); it could be a useful elemental bioindicator in some Eastern U.S. regions after thorough evaluation.

Conversion Between Species and Data Patterns

In this section, we describe the second part of our second specific study objective: to evaluate recommended protocols for elemental data conversion between species, to present conversion formulas to support implementation, and to interpret elemental data patterns. Additional ecological analyses to evaluate bioindicators and recommendations for implementation, also featured in this section, comprise the remainder of our second specific objective.

Conversion to equivalence with Flacap (had the most samples, table 2) of data for each other lichen species was mostly successful (Will-Wolf et al. 2017a), from multiple sites spanning most of the pollution range for each species pair (data are in app. 9; formulas and instructions are in app. 11). One or more shared sites with valid but moderate outlier or anomalous data (often first noted on scatterplots, see next paragraph) were often excluded to achieve reliable data conversion. Punrud sodium (Na) data were excluded from further analyses; conversion was not successful. Site averages (app. 12) were calculated across all species after data conversion (data excluded for conversion, app. 11, were also excluded from site averages). The composite Pollution Index N + S and Pollution Index 5 metals (Al, Co, Cr, Cu, and Fe) from site averages (summarized in table 3) effectively represented the full pollution gradient across the project region in this study and in Will-Wolf et al. (2017a, 2017b).

Scatterplots show different patterns for each element of original (figs. 7 through 12, left-side graphs; data in app. 9) and converted (figs. 7 through 12, right-side graphs) elemental sample data for each species vs. the lichen pollution index with which it was most strongly correlated. Instrument monitor sites, graphed in scatterplots by the average pollution index of lichen sites near them (fig. 1) (lichen

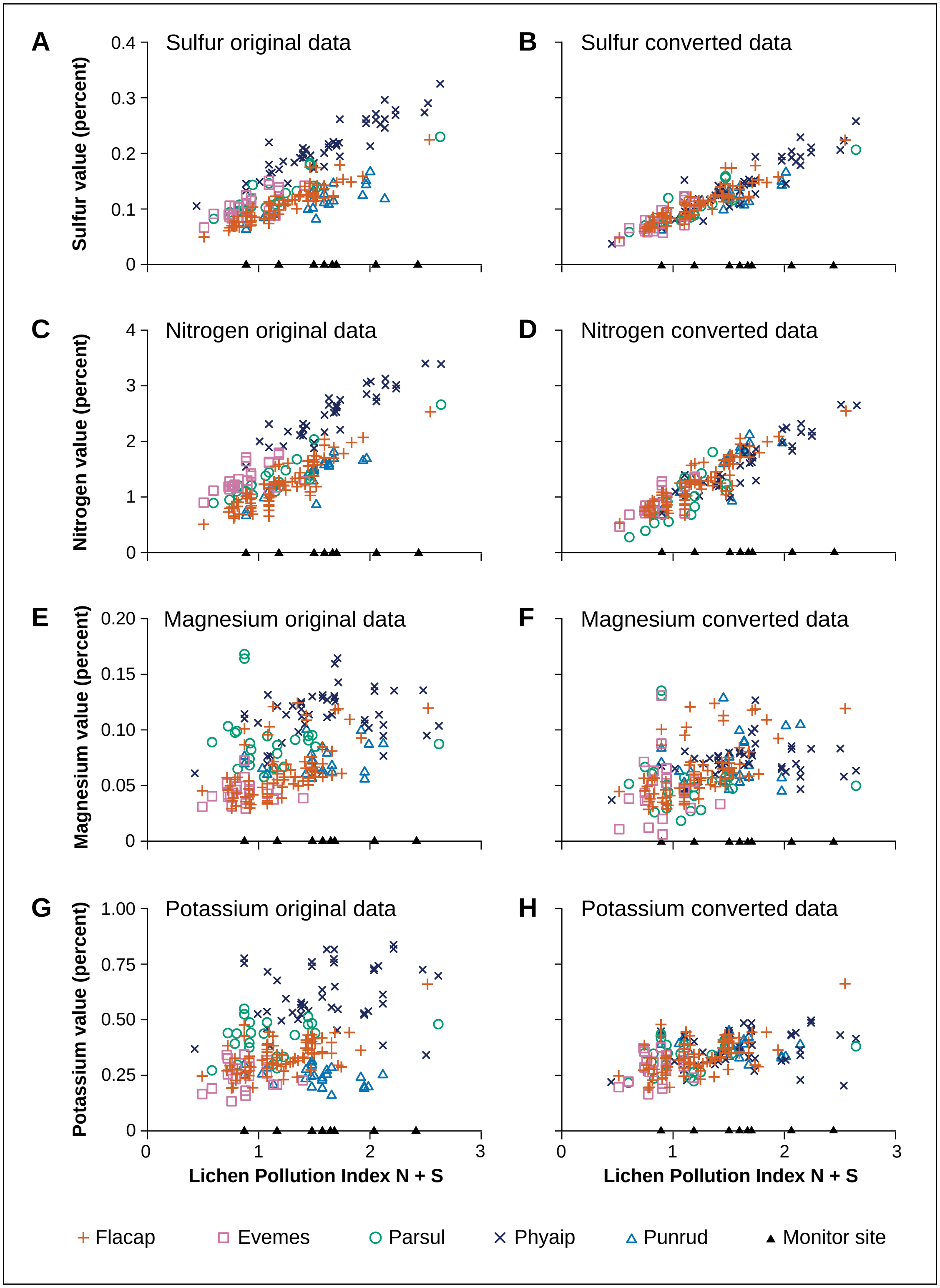

Figure 7— Scatterplots by species of original and converted sample values for elements positively correlated (r/rho ≥ 0.9) with Pollution Index N + S (N = nitrogen; S = sulfur).

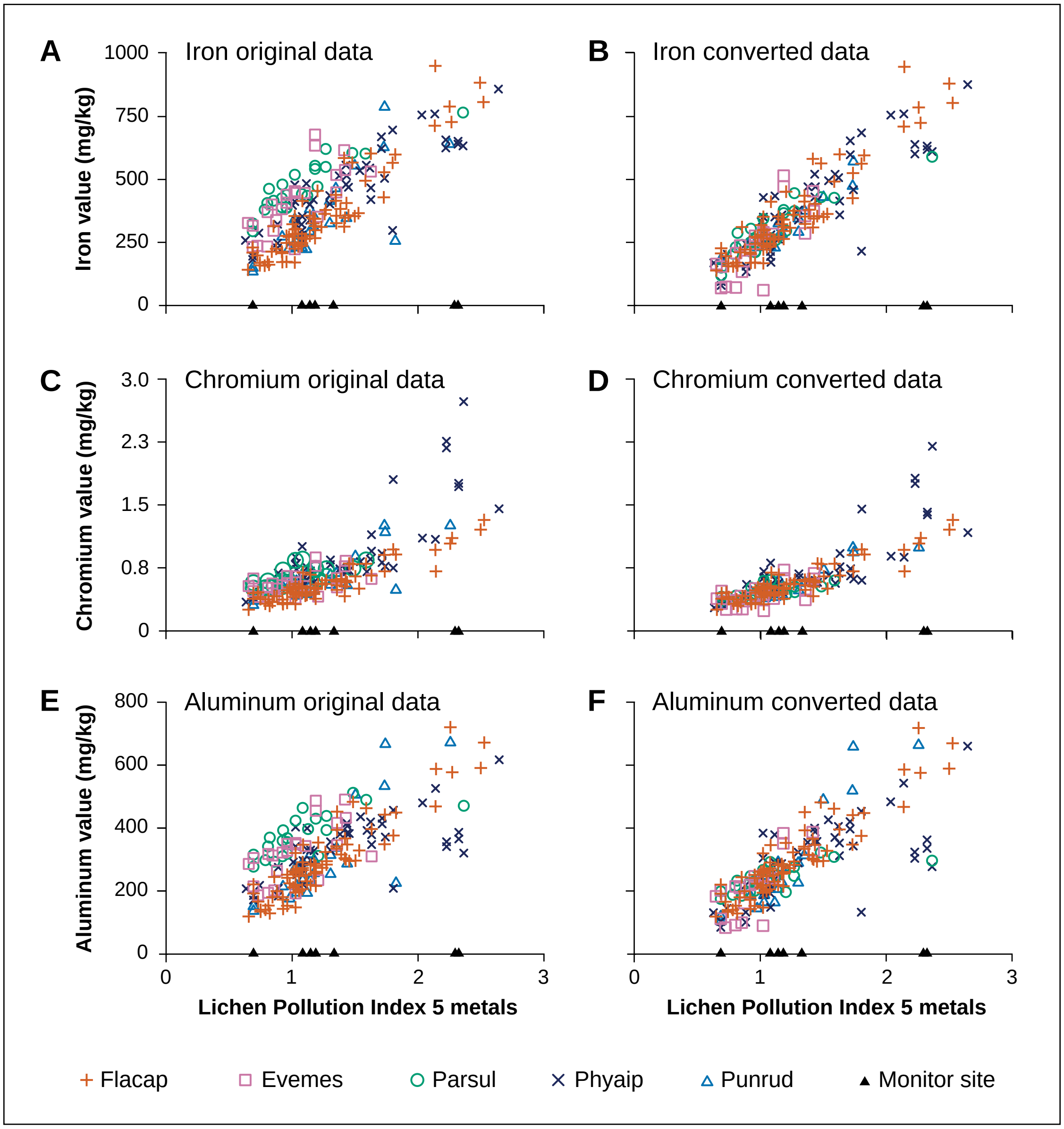

Figure 8—Scatterplots by species of original and converted sample values for elements strongly positively correlated (r/rho ≥ 0.9) with Pollution Index 5 metals.

site data are in app. 8; monitor site data are in app. 13), were more frequent in the upper, more polluted half of the index range. Converted data often included fewer sites for a species (exclusion details are in app. 11). Elements graphed in figure 7 had their strongest significant positive correlation with Pollution Index N + S; those in figure 8 (strong) and figure 9 (weak) with Pollution Index 5 metals. Elements in figure 10 had negative trends with Pollution Index N + S (most were not significant). Elements in figure 11 had very weak relationships with Pollution Index N + S; in figure 12 with Pollution Index 5 metals (patterns no stronger vs. climate

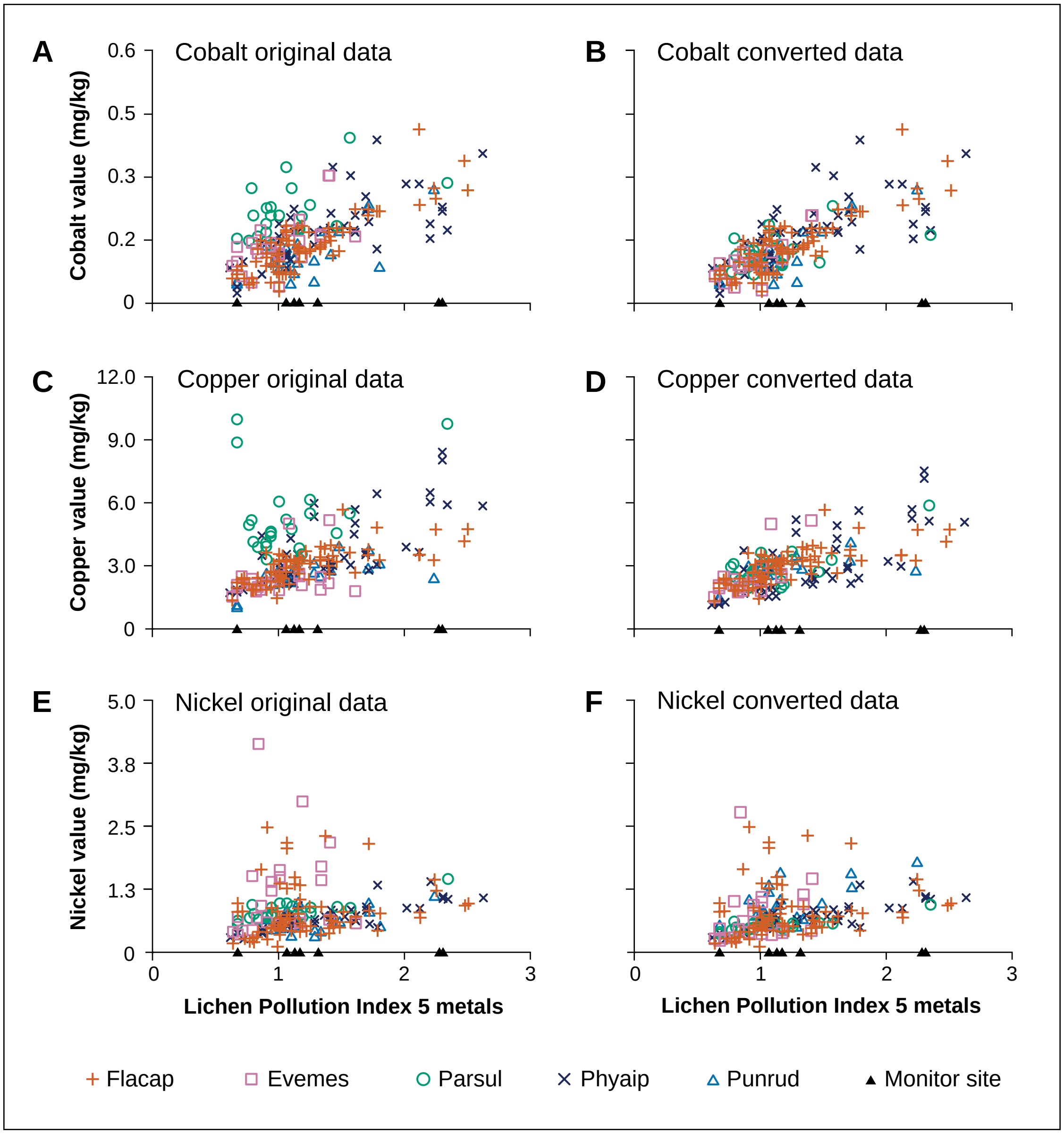

Figure 9—Scatterplots by species of original and converted sample values for elements positively correlated (r/rho = 0.5–0.9) with Pollution Index 5 metals.

variables or percentage of nearby area in forested land cover). All elements showed stronger overlap between species with converted data, signaling conversion success. Most elements also had similar or narrower ranges within site for converted vs. original data. Will-Wolf et al. (2017a) found that correlations of pollution element and index values (averages after conversion) for nearby lichen sites with instrument-measured data (fig. 1, sites 2 through 9) were stronger (average $r^2 \approx 0.7$) than for modeled N or S pollution variables (average $r^2 \approx 0.4$), supporting the view that lichen elemental data more reliably represented site pollution load.

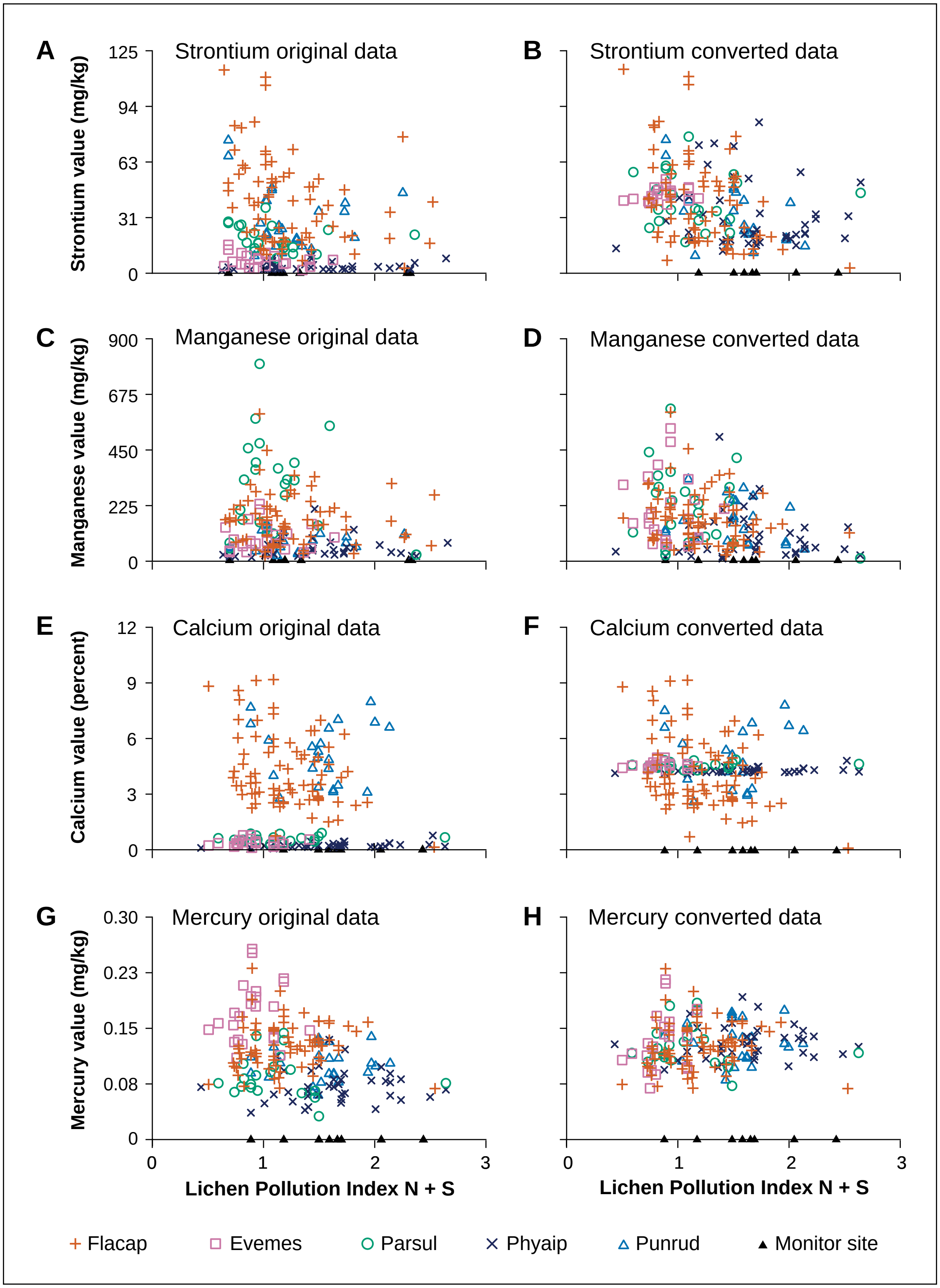

Figure 10—Scatterplots by species of original (left) and converted (right) sample values for elements showing a negative trend with Pollution Index N + S (N = nitrogen, S = sulfur).

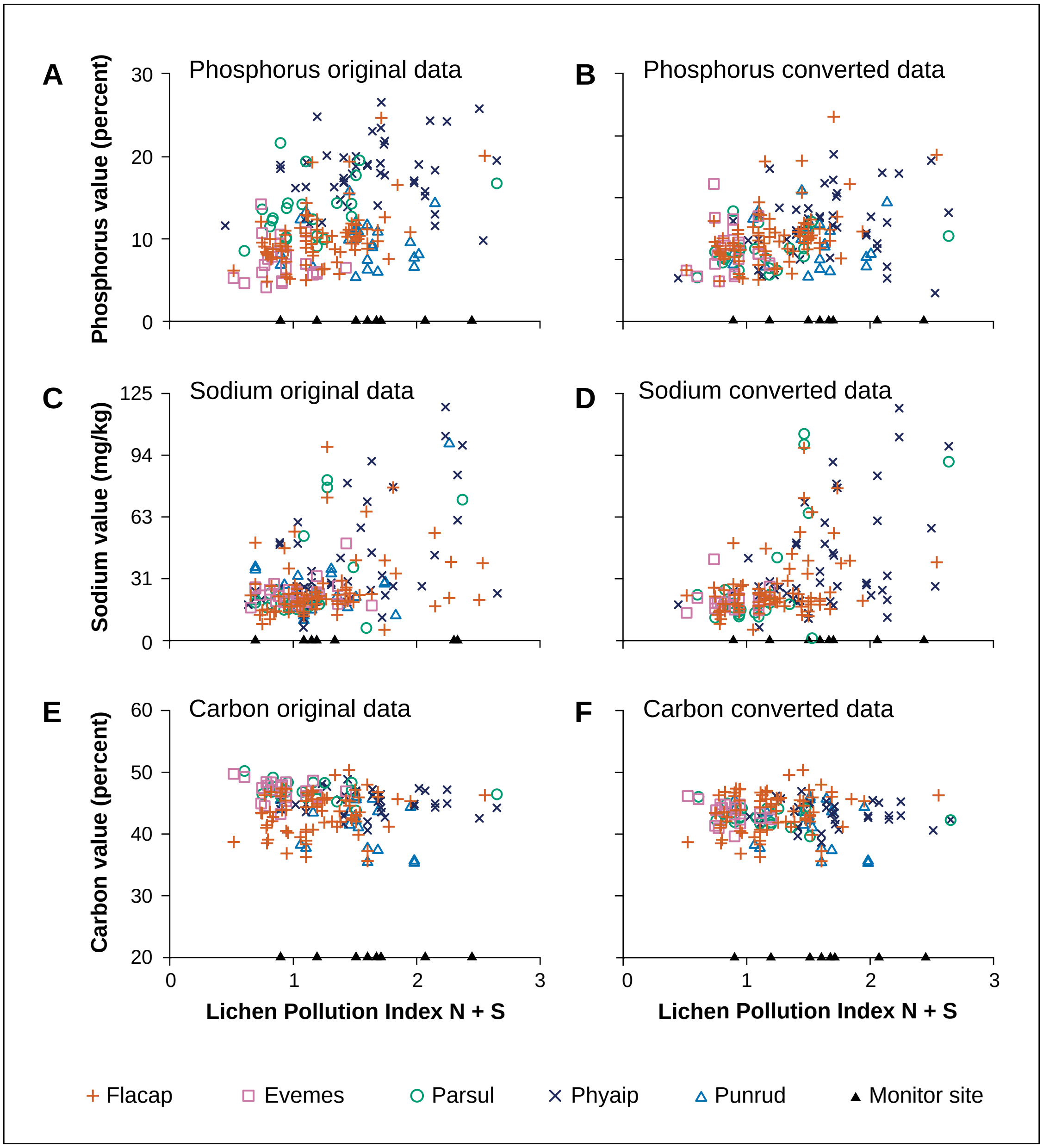

Figure 11—Scatterplots by species of original and converted sample values for elements showing weak trends with Pollution Index N + S (N = nitrogen, S = sulfur).

Differences between species varied by element. Most elements in figs. 7 through 9 show tight clustering with their pollution index because all but nickel (Ni) were included in their index. That said, S and N (fig. 7A and C) plus Fe, Cr, and Al (fig. 8A, C, and E) illustrate patterns of relatively small though significant differences between species with original data that are mirrored by C (fig. 11E) and lead (Pb), cadmium (Cd), or zinc (Zn) (fig. 12A, C, and E). In contrast, Co, Cu, and Ni (fig. 9A, C, and E) show stronger differences between species' original values. This

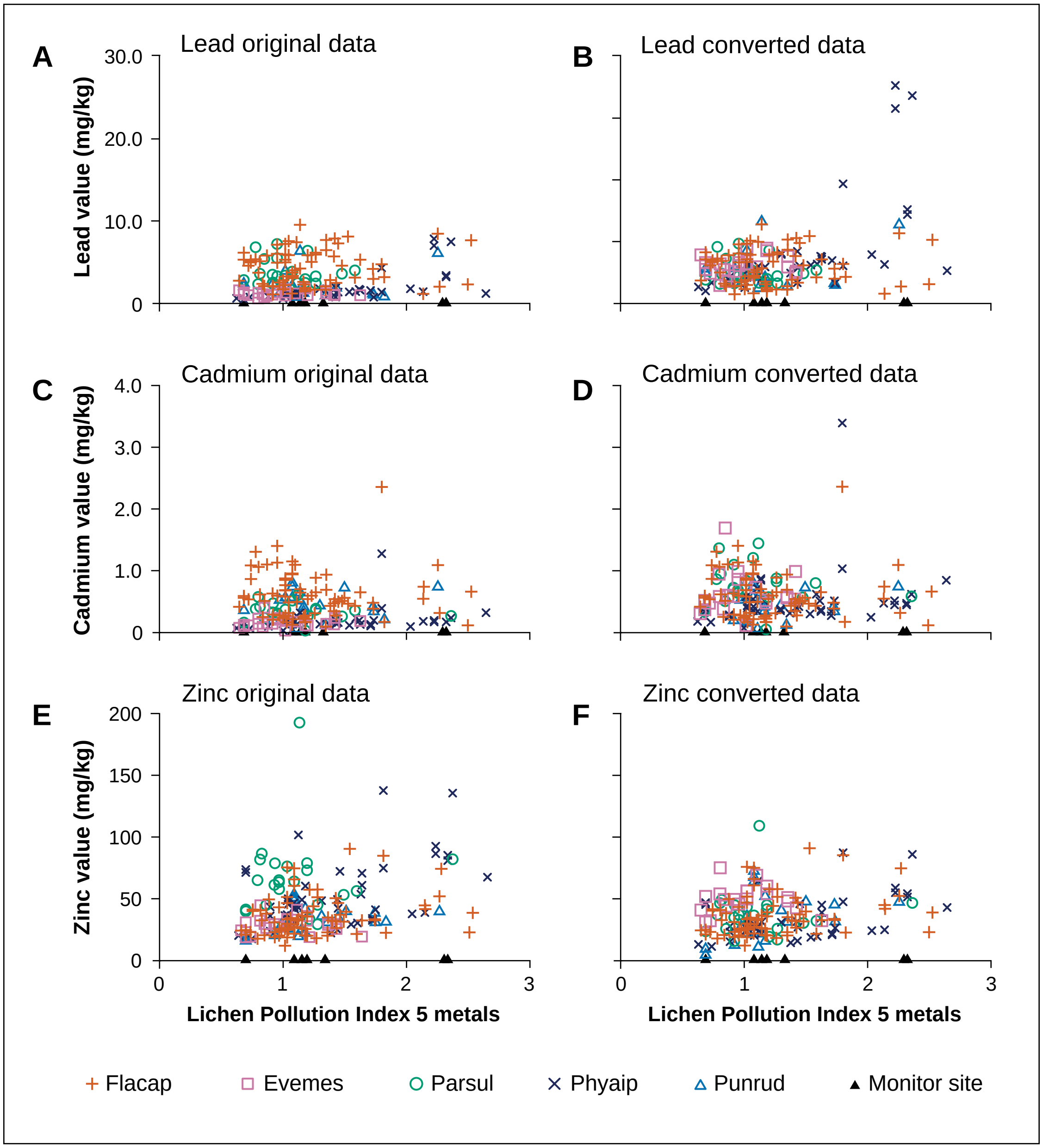

Figure 12—Scatterplots by species of original and converted sample values for elements showing weak trends with Pollution Index 5 metals.

pattern is shared by most elements with weak correlations: Mg and K (fig. 7E and G); Sr, manganese (Mn), Ca, and mercury (Hg) (fig. 10A, C, E, and G); and P, Na, and C (fig. 11A, C, and E). The unusual Ca (fig. 10E) pattern mirrored less strongly by Sr (fig. 10A) is a strong distinction between highly variable elemental values for large foliose Flacap and Punrud, but low values with very narrow ranges for the other three smaller species. Unusually high values of Ca and Sr helped signal sample soil contamination (see "Sample Evaluation" above) (Will-Wolf et al. 2017a).

Morphological pattern linked with "dust" elements suggests that passive particle trapping related to physical structure (Bargagli and Mikhailova 2002) may explain the pattern. Pb and Cd (fig. 12A and B; fig. 12C, and D, respectively) each had a few quite elevated values, especially after data conversion. Unusually high Cd values (not high enough for human health risks as in Donovan et al. 2016) were from near a rural manufacturing plant. Unusually high values for Pb were from Phyaip in urban areas; Cr (fig. 8C and D) and Na (fig. 11C and D) showed less dramatic high urban values.

Either Flacap or Phyaip (both with many samples, table 2) was collected at all but three sites. As expected, frequently used and cost effective Flacap (easily recognized by field staff, second fastest to prepare, good data from low-weight samples) was the most important bioindicator for our project (Will-Wolf et al. 2017a). Unexpectedly, untried Phyaip was the second most important because of easy field recognition despite being designated only a secondary species for FIA staff collection, and taking the longest time (and thus being most costly) to prepare. Less frequent Evemes samples were limited to the cleaner and more northern half of the pollution range (figs. 7 through 9). Original Evemes pollution element values (Al, Co, Cr, Cu, Fe, N, and S) peaked at Pollution Index 1–1.25 (about 25 to 30 percent along the index range from cleanest), then remained constant or declined ("saturated," as in Yemets et al. 2014) to index 1.5–1.7, with no samples at higher values. Thus Evemes, the most cost effective to collect and prepare, was useful in only the cleanest third of our pollution gradient (samples above index = 1–1.25 were excluded for data conversion) (app. 11). Pollution element values for all other species consistently increased with their pollution index; variation in original Flacap and Phyaip values usually increased with their pollution index. Parsul and Punrud were less useful bioindicators because each had few samples with quality data (~20 percent excluded) that were scattered along the pollution gradient. Original elemental values for Evemes (at sites below pollution index 1–1.25) and Phyaip were higher than Flacap values for most pollution elements. The relation of Parsul values to Flacap varied by element, and Punrud values for many elements did not differ much from the morphologically similar Flacap (conversion not needed for six elements) (app. 11). Phyaip converted values often appeared somewhat more variable than those for Flacap or other species. Two factors may have contributed to this: (1) two species were combined for Phyaip (confirmed, app. 4), and (2) Phyaip was often collected when larger species were not seen, so collection criteria may have been loosened to obtain the sample (unconfirmed).

Logistic regressions (details in app. 7) for Flacap, Phyaip, and Evemes on environmental factors helped answer questions about sample distributions and identified some surprising results. Flacap and Phyaip were selected because study results suggested complementary distributions of their samples were not explained mostly by pollution load, despite apparent scatterplot patterns in figs. 7 through 9. These results were that (1) in scatterplots (figs. 7 through 9), Flacap pollution element values did not appear to level off at higher pollution loads, contrasting with the Evemes pattern; (2) healthy samples from an earlier Wisconsin study (Will-Wolf et al. 2015a) had higher Flacap values for pollution elements; (3) Flacap samples were absent from several sites with Phyaip samples in lower pollution sites that also had little nearby forest (Will-Wolf et al. (2017a); and (4) Will-Wolf et al. (2018a) found that sample presence for Flacap and Phyaip varied substantially with both pollution index and percent of nearby land in forest. Evemes was selected because it had the strongest evidence (of the five focus species) for sample limitation by pollution (figs. 7 through 9; see previous paragraph). Also, the few Evemes samples served a key bioindication role: two of three sites lacking samples of either Flacap or Phyaip had Evemes samples.

For all three species, the logistic regression model with the single strongest environmental factor was statistically no different from models with multiple strong environmental predictors (details are in app. 7). We selected the most parsimonious single-factor models for interpretation. For presence/absence models, the model area under the receiver operator characteristic (ROC) curve (AUC) is considered a more reliable measure of relative model strength (Manel et al. 2001), than the more familiar Akaike information criterion (AIC). Thus Evemes had a highly accurate model (table 4), followed by Phyaip and Flacap with accurate though slightly weaker models (Manel et al. 2001). Surprising results for Flacap and Phyaip showing that the percentage of nearby area in forested land cover alone predicted their sample distribution, suggest that impacts of landscape pattern on distribution of common

Table 4—Logistic regression models for three indicator species

	Coefficients			
Species by factor	**Model[a] AUC (AIC)**	**Intercept (probability)**	**Factor (probability)**	**Threshold**
Flacap by nearby area in forested land cover ↑	0.79 (72.23)	-2.1033253 (p = 0.0014)	0.05039203 (p < 0.00001)	0.7
Phyaip by nearby area in forested land cover ↓	0.85 (77.06)	3.2343800 (p = 0.0001)	-0.0557801 (p < 0.00001)	0.36
Evemes by average maximum temperature ↓	0.93 (40.08)	15.1744872 (p = 0.0017	-2.9739942 (p = 0.0020)	0.425

[a] This model for Flacap, Phyaip, or Evemes is the most parsimonious of three equally valid models (= Model 3 for each species in app. 13). See table 1 for full species names. AUC = area under curve; AIC = Akaike information criterion.

lichen species are stronger than was previously appreciated. Will-Wolf et al. (2014) found that percentage of area in nearby forested land cover was linked with lichen species number in several Eastern U.S. regions, along with other environmental variables; results of this project are even stronger. The result that temperature alone predicted Evemes sample distribution well is also surprising, because Evemes elemental concentration patterns suggested that pollution affected its metabolism. One possible explanation for the pattern mismatch is that because Evemes is much easier to collect than other focus species, field staff might have searched harder for this species even when it is uncommon. Thus smaller and less vigorous Evemes individuals with affected elemental concentrations might have been included in samples from sites with intermediate pollution. Field staff were unlikely to do the same for Flacap or Phyaip because they were more difficult to collect.

Recommended Elemental Bioindicators

In this section, recommendations of elemental bioindicators for four Eastern U.S. FIA lichen regions mark the completion of our third specific objective. Potential coverage with the five focus species based on 1994–2005 FIA plot lichen data (table 1) was higher in the North Central and Northeast regions (fig. 13) than in the Mid-Atlantic and Southeast regions. Frequency in plots increased substantially in each region, with the two or three most frequent species combined. Inclusion of the fourth and fifth most frequent species increased coverage in the Northeast region but had little effect in other regions.

Bioindicator frequency from lichen species presence at FIA plots is not a precise predictor of whether elemental samples can be found from ≥90 percent of plots in a region. For example, in the Mid-Atlantic region, Flacap (at 77 percent of all Mid-Atlantic plots) (table 1) was present at 93 percent of 219 lichen study plots (Will-Wolf et al. 2018a), while only 85 percent of 26 subset plots had a Flacap elemental sample. Our recommendations relied on species characteristics and project results as much as past frequency in FIA plots. Will-Wolf et al. (2018b) found that distributions of Flacap, Parsul, Phyaip, and Punrud from the Northeast and Mid-Atlantic 1994–2005 data subsets were not strongly linked to amount of nearby area in forested land cover, contrasting with this project using samples collected in 2013. They noted that air pollution since 2005 declined substantially across the Eastern United States and speculated that amount of nearby area in forested land cover might by default now be as important elsewhere as in this project area.

Flacap, frequent in FIA regions (table 1) and a known successful elemental bioindicator (our project; Mid-Atlantic region (Will-Wolf et al. 2018a); other states and Europe (Will-Wolf et al. 2017b), is recommended for all four regions.

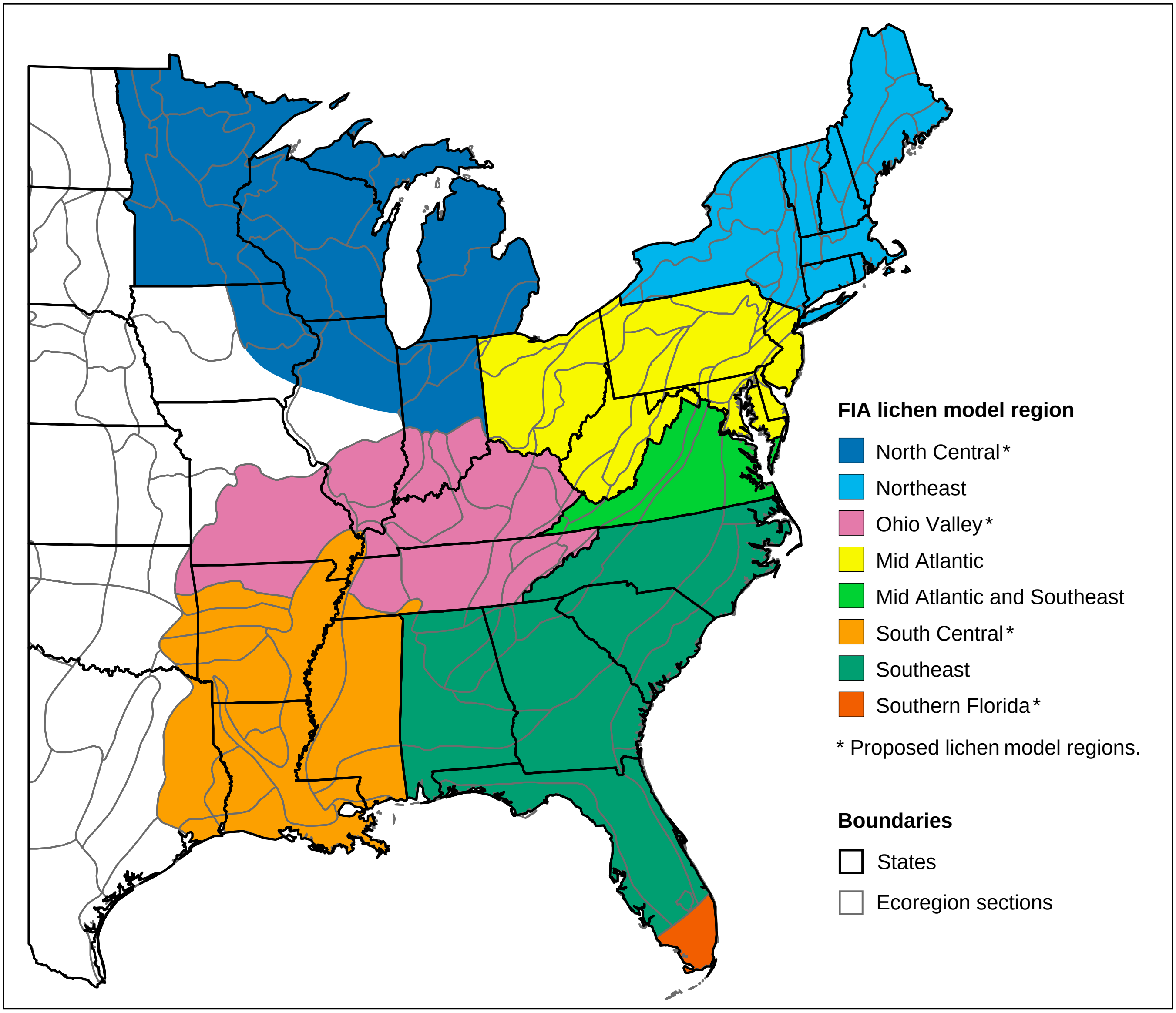

Figure 13—Forest Inventory and Analysis (FIA) program lichen model regions in the Eastern United States (some are only proposed).

Recommendations for other species differ between regions. Phyaip, even though frequent only in the North Central region, was considered for each region as the study species most associated with low-forest landscapes. Evemes, frequent only in one region, was recommended for the North Central and Northeast regions to cover northern plots. Punrud was useful for elemental bioindication in the North Central and Mid-Atlantic regions with expert collectors (Will-Wolf et al. 2015b, 2017c) and was frequent in three regions; Parsul was frequent in two regions. Based on FIA staff recognition and data quality problems in this project, neither species is recommended unless necessary. Punrud was recommended for the

Mid-Atlantic and Southeast regions, but only with more intensive training. No recommendations are made for Eastern U.S. regions without FIA lichens data (fig. 13) (Jovan et al., in press b). Results of small-scale studies in such areas can suggest species but cannot predict success for elemental bioindication across large regions, nor for collection by nonspecialists. Lichen pollution sensitivity sometimes varies between geographic areas (Will-Wolf et al. 2006, 2015a, 2018a); sensitivity for bioindicators should be evaluated from local sources in any new region. Response of potential indicators to climate and landscape pattern should also be considered for a new region. Widely reported region- and spatial-scale dependency of data conversion between species (Will-Wolf et al. 2017a) means that new conversion models must be developed for each region even when using the same species.

For the full North Central lichen region, Flacap and Phyaip are recommended as primary elemental bioindicators, with Evemes as a secondary species for northern plots to achieve >90 percent plot coverage. The success and importance in our project of previously untried Phyaip as well as the less frequent but successful Evemes (table 1) support these recommendations. Data conversion models for Phyaip and Evemes from our project can be applied to the full North Central region, with perhaps minimal additional comparisons between Flacap and Phyaip elemental values at sites with high pollution and much nearby area in forested land cover. Michigan and Indiana as well as large parts of Illinois, Iowa, and Minnesota were not represented in our project. Michigan and Minnesota include more area in Laurentian Mixed Forest than does Wisconsin. Evemes (easy to collect and handle), with its more northerly distribution than either Flacap or Phyaip (Brodo et al. 2001, Jovan et al. 2019b), might thus be more useful in the full North Central region. For North Central application, Evemes sites should be plotted against their latitude and longitude along with interspersed Flacap sites; Evemes sites interspersed with or at Flacap sites having Lichen Index values of 1.0 to 1.25 should have Evemes data excluded from analyses as possibly being in its saturation range. Much area in Michigan and Indiana is in the Eastern Broadleaf Forest ecoregion, well represented in the project. Southwestern Minnesota, western and southern Iowa, most of Illinois, and part of northwestern Indiana are in the Prairie Parkland ecoregion, similar to northern Illinois and represented by three project sites.

For the Northeast region, our recommendations are Flacap and Evemes (which both occur quite frequently there; see table 1) as the primary target species, and Phyaip as a secondary target species. All three species would be useful with the training effort used in this pilot project, and might well cover >90 percent of FIA plots. Will-Wolf et al. (2018) found that less-frequent Phyaip (at more southern, more polluted sites) was a better complement to Flacap for site coverage than was the much more frequent Parsul (would require intensive training for successful collection by nonspecialists). They also showed that Evemes was limited to Northeast region plots with less pollution and more nearby area in forested land cover. As in the North Central region, such limits would be balanced by its efficiency and cost-effectiveness. The limits beyond which Evemes will not be useful in the Northeast region can be roughly estimated from its distribution in sampled northeastern FIA plots ordered by the lichen-based Northeast region pollution index or climate index (Will-Wolf et al. 2015a). When data are available, Flacap and Evemes pollution element values at sites should be compared to find the Evemes saturation level, above which it would not reliably indicate pollution load. Cleavitt et al. (2015) successfully used Evemes for elemental bioindication in northern (usually less polluted and more forested) parts of the Northeast region. Although recommended species are the same as for the North Central region, new species conversion models will be needed for the Northeast region.

For the Mid-Atlantic region, our recommendations are to select Flacap and Punrud as primary target species, requiring more intensive training for successful Punrud recognition by nonspecialists. Phyaip is recommended as a secondary species when neither Flacap nor Punrud is common enough to collect. Will-Wolf et al. (2018b) found that Parsul was more strongly limited to low-pollution, higher elevation sites than either Flacap or Punrud, so Parsul provided little complementary coverage to them. Selecting only Flacap as the primary bioindicator species (because of its high frequency) (table 1), with Phyaip as the secondary species, requires only the training effort used in our study, but runs the risk of having 10 to 15 percent of FIA plots with no data (table 1). Punmis could also be evaluated as a secondary bioindicator species, probably requiring intensive training similar to Punrud to yield quality data. The frequency of Punmis in Mid-Atlantic region plots, while less than half that of Phyaip, was mostly from Ohio and Pennsylvania with much former prairie and current open woodland (Jovan et al., in press a). Will-Wolf et al. (2018a, 2018b) found it to be somewhat more tolerant of pollution than Phyaip in that region, while also linked with low-forest landscapes. Punmis (similar to Flacap and Punrud in size) might be faster to handle than Phyaip. Will-Wolf et al. (2018a) Mid-Atlantic region conversion models between Flacap and Punrud for elemental data can be applied in future studies, whereas Phyaip conversion models must be developed, and Punmis needs full evaluation. Inclusion of Virginia in both Mid-Atlantic and Southeast lichen regions (fig. 13) will facilitate reevaluation of region boundaries on ecological as well as political criteria.

For the Southeast region, our recommendations are the same as for the Mid-Atlantic region; Flacap and Punrud as primary elemental bioindicators, with Phyaip as a secondary species. Punrud is very important as the tested elemental bioindicator most frequent in the Southeast region (table 1), even though intensive training will be required to support its successful recognition by nonspecialists. The main elemental bioindicators together cover a lower percentage of Southeast region FIA plots than in other regions, and Punmis was too uncommon to have potential in this region. Another lichen species common especially in the South Atlantic Coastal Plain ecoregion should be evaluated as a potential elemental bioindicator here. Development of new conversion models as well as full evaluation of new species will be required for implementation in the Southeast region.

Conclusions

This study achieved all four of our specific goals and reinforced the need for both good science and careful attention to practical aspects of implementing elemental bioindicators in a large monitoring program. Careful selection of bioindicator species and special training were both needed to support successful field collection of lichens by nonspecialists. Protocols to achieve cost effectiveness included collecting composite samples from restricted canopy coverage. Data were averaged across known variations related to lichen age, substrate tree species, and other within-site variation (Garty 2002) to support reliable site-level signals. Revisions to bioindicator protocols and training were suggested from both project data quality and FIA staff feedback. Time and costs for field data collection and sample handling were reasonable for a large monitoring program, as were costs to measure elements at a Forest Service facility. After elemental bioindicators are widely implemented in the Forest Service, comparisons of elemental measurements between facilities and between times at the same facility should be conducted.

Rigorous field and handling protocols were in one companion study (Will-Wolf et al. 2017b) shown to generate quality data from nonspecialist collectors; time-saving protocol variants failed to deliver quality data. In another companion study, Will-Wolf et al. (2017a) made comparisons to other studies to emphasize the scale- and context-dependence of lichen bioindicators. Models for data conversion between species apply only to the region and general spatial scale at which they were developed; bioindication by elements also varies by region and spatial scale. Lichen elemental data averaged within site accurately represented relative local pollution load, from correlations with monitor site instrument-measured data. The few available monitor sites and the greater relevance to lichen community response of elemental bioindicator data vs. regionally modeled pollution data highlighted the importance of this lichen bioindicator to support evaluation of forest ecosystem response to air pollution.

Elemental bioindicator development for the FIA program in the Eastern United States and elsewhere should consider both program and regional context. Success collecting a target species by nonspecialist staff appears to depend on lichen community context in the region (presence of lookalikes) and on training intensity as much as on inherent characteristics of likely bioindicator species. Characterization of the lichen community context will be easier for U.S. regions in the future, with the recently available national FIA lichen atlas (Jovan et al., in press a) and lichens database (Jovan et al., in press b). Our recommended improved protocols are applicable across the Eastern United States, and bioindicator species are recommended for regions that already have FIA lichens data (Jovan et al., in press b). Comparisons of bioindicator species abundance at FIA sites with available environmental variables for each new region (beyond the limited analyses in Will-Wolf et al. 2018b) would be useful during planning. As we demonstrated in this study, selecting elemental indicator species based on response to forest fragmentation may be as important as response to air pollution to ensure broad plot coverage in Eastern U.S. regions, even with estimation of site pollution load as the elemental bioindication goal. The surprising importance of nearby forest cover for Flacap and Phyaip samples collected under the same criterion of 20 to 50 percent forest canopy adds to our growing understanding of stresses on lichens; even very common species appear to respond to landscape context. The Northeast (Will-Wolf et al. 2015a), Mid-Atlantic (Will-Wolf et al. 2018a), and Southeast (McCune et al. 1997b) regions have pollution indices based on lichen community response in the past. An elemental bioindicator in each region will provide a cost-effective proxy for site pollution load to estimate risks to forest ecosystems in the future. Correlation of elemental bioindicator data with future condition of lichen communities and other forest ecosystem components can help reliably assess ongoing forest ecosystem response to those risks.

Acknowledgments

This project was partly funded by cooperative agreement SRS09-CA1130145101 between the U.S. Forest Service Forest FIA program and University of Wisconsin-Madison, for research by Susan Will-Wolf. The pilot study was designed, and Wisconsin selected as the site for it, in collaboration with Dennis May and Christopher Woodall (acting), FIA Northern Region program managers, and Robert Ilgenfritz, FIA Northern Region supervisory forester. Training and the field season were planned in collaboration with Ilgenfritz and Peter Koehler, FIA Northern Region supervisory forester; Koehler also collaborated on development of training and informational materials. We thank FIA Northern Region foresters John

Benaszeski (northwest Wisconsin), Benjamin Nurre (southwest Wisconsin, northern Illinois, Iowa, and Minnesota), and Willard Smith (central Wisconsin), as well as ecologist Sjana Schanning (north-central and northeast Wisconsin), each of whom collected lichens in fall 2013 and provided valuable feedback on training and field procedures. Benaszeski also helped select training survey locations. We also thank Elizabeth Freeman, who gave Paul Patterson extensive advice on logistic regression models and supplied R software; and Emily Blessing, who assisted in the Will-Wolf laboratory with sample tracking and preparation. Sample measurement personnel in the Amacher laboratory included Kay Laird, Jessica Hoffmann, and Leticia Hoffmann. Robert "Wes" Hoyer prepared figure 1; Sarah Friedrich prepared other figures. Comments from reviewers Shanti Berryman, Steven Leavitt, Randy Morin, and Elizabeth Freeman helped us improve the final version of the report.

U.S. Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Meters (m)	1.094	Yards
Kilometers (km)	.621	Miles
Square kilometers (km^2)	.386	Square miles
Liters	.265	Gallons
Milligrams (mg)	.000352	Ounces
Grams (g)	.0352	Ounces
Kilograms (kg)	2.205	Pounds

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Appendix 1: Training, Field Protocols, Equipment, and Supplies

This appendix includes information, documents, forms, and explanations.

Details from the 2013 Wisconsin FIA East Lichen Elemental Indicator Pilot Study

Recommended changes are included here; appendix 3 contains original crew feedback on the training and field season. In this appendix, changes recommended from crew feedback are shown in italic type, and changes recommended from data evaluation or author suggestions have gray backgrounds.

A1.1. Training

Pretraining: read two-sentence rationale (on first page of app. 2) for the pilot study and the draft copy of protocols. Follow links to online images of focus species and lookalikes.

These pretraining materials should be supplemented by links to PDFs of background reading that remain available during the field season.

Note: The lichen species used during the entire pilot study were referred to as "target species." However, reviewers for earlier manuscripts noted discomfort with the term and sometimes misinterpreted it, so in most published papers (including the body of this one), the studied lichen species are called "focus species." We did not change the wording in a few original pilot study documents in appendices, but we recommend using "focus species" in all future instances.

Training day and site—

Wednesday September 11, 9 am to 4 pm, U.S. Forest Service, Northern Research Station, Institute for Applied Ecosystem Studies, Rhinelander, Wisconsin. A large training/laboratory room plus a laptop and projector for presentations were arranged by Supervisory Forester Peter Koehler. Training field sites were in wooded parts of the extensive grounds of the institute; Forester John Benaszeski collaborated in site selection.

The Institute for Applied Ecosystem Studies at Rhinelander was an excellent training site, with an indoor workroom of adequate size, ample wooded sites including both conifers and hardwoods within easy walking distance, and moderate abundance of most of the focus lichen species. Nearby forested land allowed two rounds of sample collection followed by indoor examination of specimens;

these steps facilitated rapid instruction for identifying focus species and distinguishing them from lookalikes. We thus recommend that a future all-day training include a very brief introduction (rationale plus overview of focus species and protocols) followed by intensive identification practice with actual lichen specimens and iterative field collection using protocols and reviews of success. Proximity of a [semi-]natural forest with most focus species abundant is a high priority in selection of a training site, to facilitate this hands-on approach to training.

Training schedule (revised from that presented at training)—

1. PowerPoint™ Presentation (see app. 2): Background—lichen tissue element concentrations are better proxies for air quality at plot than modeled regional and local point source estimates—5 min.

In the future, include one example from the literature and present simple correlations as well as a very simple diagram or map; make available reference PDFs for optional reading.

In the original pilot study documents, field staff were referred to as “crew,” but confusion from reviewers of papers about whether a crew had one or two people led us to substitute “staff” in papers and revise to use “staff” throughout this report. “Staff” apparently does not invoke in readers the assumption that it always means two or more people working together. In a few instances, the term “1-person crew” was used Also note: for the pilot study training a PowerPoint™ presentation (app. 2) was used; other types of presentations could serve the same purpose .

2. Presentation: Review five focus species and field protocol (wear gloves; wipe off tools with alcohol) to reduce contamination to the sample from outside the site (not to protect the collector). Lichen concentrations of some elements are in parts per million, so it is important to exclude contamination, to keep the strongest signal from what was at the site and the least noise in the final dataset—5 minutes.
3. Presentation questions—total presentation time 20 minutes or less.
4. Hands-on training in lab: Practice distinguishing five focus species in training room with specimens, focusing on aids to distinguish from other lookalike species; use hand lenses with dissecting microscope available— about 1 hour.
5. Hands-on training in lab: Hand out and discuss equipment and supplies used for lichen collection; address questions—20 minutes.
6. Hands-on training in field: Practice field protocol 1: take equipment and supplies to field; practice as a group finding and collecting focus species. Use clean collection protocol; training samples will be measured as part of analysis dataset—30 to 45 minutes.
7. Break for lunch—30 minutes.

8. Hands-on training in field: Practice field protocol 2: each trainee practices fully rigorous protocol alone: choose a sample location, find and collect focus species, label bag. Training samples will be measured as part of analysis dataset—1 to 1.5 hours.
9. Hands-on training in lab: Trainees display lichen samples; trainer evaluates field samples for quality and species recognition; all use rigorous lab protocols. All discuss field issues. Repackage field specimens; give to trainer for lab measurement. Discuss post-field handling and mailing of specimens to expert. Trainer answers questions. Make sure all field season supplies are transferred to crews—1 to 1.5 hours.

FIA lichen indicator advisor Sarah Jovan (sarah.jovan@usda.gov) possesses the training Powerpoint file, plus all training and field season files and documents. In addition, she has the field reference focus species recognition guide, including lichen samples; a complete example site kit (including bags, gloves, pencils, and markers); and knife with 3-inch (7.5-cm) blade, with cover, used for sample collecting.

Training equipment, materials, and techniques—
Training equipment included a laptop computer and projector provided by the research station, and a dissecting microscope for occasional examination of lichens to see useful characters in more detail. Training equipment also included all the field equipment needed in the field (detailed below). All nonstandard equipment, and field supplies needed by FIA field staff for sample collection and handling for the entire season, were handed out at the beginning of training and were used during training, as were protocol documents, forms, and the field lichen identification guide. The trainer also had and used the required equipment and supplies.

The introductory presentation could have been even shorter and simpler.

Trainer notes: Although a digital presentation might still be useful for a large group, a brief oral presentation of rationale and introduction to species and protocols with support only of paper handouts and specimens might be quite adequate with no more than four to five trainees.

Training materials included many specimens of focus species and non-focus lookalike species pre-organized in groups of focus species paired with lookalikes. Cleaned samples of each focus species that were larger than minimum desired weight and clearly from six+ different individuals were available to help learn the size needed for a good sample.

FIA field staff said working with actual lichen samples was the most help learning species ID, and seeing the size of a final good sample helped them know how much biomass to collect.

Based on results illustrating staff ID success, the combination of lichen color and size plus presence of apothecia vs. not appeared to be key characters supporting success of Phyaip ID. Lack of discrimination in the field on thallus lobe shape and/or presence/absence plus location of soredia vs. isidia appeared to underlie problems with ID of Parsul and Punrud as opposed to several other non-focus gray foliose lichens. Staff had appeared to learn and distinguish these characters during training with immediate feedback, but only one of the four appeared to recall and use these successfully in the field. Few medium/large gray foliose specimens with apothecia were collected. When a similarly difficult-to-distinguish gray foliose lichen is required as a focus species in a future implementation, more intensive training focus and time on distinguishing characters for this species should be included. Rapid field season feedback via email on distinguishing Parsul or Punrud did not appear to help; an in-season refresher on a plot and with specimens brought by the trainer might help—to be triggered by a staff request and/or receipt of mislabeled specimens.

Training techniques included a low trainer:trainee ratio—one trainer for four trainees plus a supervisor who took care not to intrude too much on trainee interaction. Training techniques were mostly intensive hands-on experience and interactive exchange between trainer and trainees that included piecemeal demonstrations of techniques by the trainer.

FIA field staff suggested, as the first field experience, the trainer should demonstrate a complete sequence: decide on a site, then collect and label one good field sample. This would be a good addition to future trainings.

Pilot study results showed very good elemental data quality from most FIA staff samples, with data interpretation meeting all the objectives of the study. Most samples of Evernia, Flacap, and Phyaip had good quality data that were retained for analyses. While a higher proportion of Parsul and Punrud samples were excluded for poor data quality, data for retained samples were as good as for other species. Authors concluded from these results that training of the sampling and handling protocols was adequate to generate data suitable for elemental biomonitoring at the desired level. Data quality problems were mostly linked to ID issues with some species, rather than to problems using the fairly rigid sampling protocols. No additional revisions to training techniques for the field protocols are recommended.

A1.2. Protocols and Documents

Hard copies of the field and shipping protocols on the next pages were handed out in training; digital copies were sent as backup.

Focus species in the pilot project:
Priority 1 (roughly in order of commonness in Wisconsin):

1. *Flavoparmelia caperata,* code name "Flacap"
1. *Punctelia rudecta*, code name "Punrud"
1. *Evernia mesomorpha,* code name "Evemes"

Priority 2 (in order of desirability):

2. *Parmelia sulcata,* code name "Parsul"
2. *Physcia aipolia/stellaris,* code name "Phyaip"

Comments by authors: For the pilot study we provided common names because they are easier to understand, and often quirky and interesting. However, we think that staff should use the six-letter species code name (from genus and species) for all labeling and always think in terms of it when in the field. In the pilot study, FIA staff mostly labeled samples by abbreviated common names and never used the scientific names or six-letter species code names (see app. 6). Sometimes the abbreviated common names were quite difficult to decipher on field specimen labels. Training in future should emphasize and insist on labeling with the six-letter species code nane; the common name of the lichen should not be included in the field recognition guide.

Focus species for implementation—
See "Results and Discussion" on page 11 and "Recommended Elemental Bioindicators" on page 26.

Field protocol: choose area (revised from pilot project handouts)—

1. Locate sample area—Do not collect within the FIA permanent plot area (lichen plot; ring connecting centers of outer subplots). Focus lichens all prefer well-lighted areas; the collection criterion is a forest opening or edge with 20 to 50 percent canopy cover. Check isolated single trees only if no focus species are found in more forested areas, and make note of that on the sample bag.
2. First, look for a forest opening or edge within sight of the permanent plot. Avoid edges with actively farmed fields, tended lawns, or well-used roads. Quickly survey an appropriate area for the presence of focus lichen species.
3. Take note of any likely lichen sample areas on the way to the plot; return to that area if better than near the plot and do a quick survey.

4. Choose first an area with lichens visible on trunks or branches from a distance, if available. Try to keep the sample area within 0.25 mi (0.4 km) of the plot, although it can be farther between the plot and vehicle if necessary (note that on sample bag). If you have searched for 20 to 30 minutes near the plot and then have found no suitable area on route back to or near the vehicle, it is okay to give up and not collect a lichen sample.

5. **Added to training and field guidelines for implementation, based on project sample data quality**—Examine lichens with a hand lens to confirm they are a focus species. Consult your field recognition guide for characteristics; individuals with ≥20 lobes/branches have the distinguishing characteristics. Do not select an area, prepare to sample, label a sample bag, and begin to sample until at least one focus species has been confirmed on at least three different substrates in a given sample area.

Field protocol—sample goal (revised from pilot project handouts)—

1. Only one person collects lichens at the site.
2. Primary goal for the pilot project—Collect one sample each of two focus species. Best: collect any two of the three priority 1 species; next best: any one of the priority 1 species + one of the priority 2 species; next best: any one or two of the five focus species. Primary goal for implementation—Collect 1 sample each of two priority 1 species, two samples of one priority species, or include the priority 2 species.
3. This protocol element was for the pilot project; it will probably not be part of the implementation protocol.
   For about one fifth of the sites collected by one staff member, collect two samples of as many focus species as are seen. It should be obvious when to try this—the focus species appears to be quite common even before you observe it with a hand lens.
4. This entry was notably revised based on project sample data quality.
   A good sample of a focus species gives about 1.5 to 2 g (0.05 to 0.07 oz) of dry, large pieces of lichen biomass after substrate removal, estimated visually (examples in training)—this translates to a cloth collection bag in the field more than half full of lichens plus some substrate. Lichens should be collected from at least six **different** trees or other natural woody substrates like saplings, shrubs, or standing dead snags. Samples should be collected from 0.5 m (1.5 ft) above ground level or higher. Tree trunks are the preferred substrate for all focus species except Phyaip, whose preferred collection substrate

is low branches of trees or shrubs. If Phyaip is found only on canopy branches from a fallen crown, then take a sample only from interior branches well back from crown tips, to maintain the criterion of 20 to 50 percent canopy cover over lichens.

Field protocol—prepare to sample (revised from pilot project handouts)—

1. Once minimal abundance of the probable focus lichen species has been confirmed, pull out equipment to begin sampling. Arrange to your convenience.
2. Next, inside the carry bag, open the site kit and find the bag with gloves. Shake cuff of a glove to near opening, open the bag, pull out glove, and put the glove on touching only the cuff; put on the second glove the same way. Do **not** reach into the bag or touch other gloves with your bare hand; do not allow gloves or sample bags to touch the ground or your person. The goal of the rigorous protocol steps is to keep lichen samples from contact with the ground or anything from offsite.
3. With gloves on, shake one alcohol wipe to the top of bag, open the bag, and take out one wipe. Tear open, discard pack in trash bag, wipe shears and knife with the wipe (including handles). Wipe inside of cover/case(s) with alcohol or rinse with alcohol from bottle. Return knife and shears to cover/case(s) and discard wipe.
4. Pull out one or two cloth sample bags, carry in gloved hand, and avoid contact with ground or anything from offsite (sweat or insect repellent on hands, face, clothing, surfaces of carry bag, etc.).

Field protocol—sample (revised from pilot project handouts)—

1. First label the cloth bag tag in either pencil (always use when damp) or marker with the official FIA ST-CO-Plot code in your plot information, the date, your name, the **species code** (see “Focus Species” above), and a very brief description of the sample area and proximity to plot. For example: 55-97-3122, 9/12/13, Will-Wolf, Flacap, gap 25 yd (22.9 m) NE of plot (or “forest edge 100 yd SE of plot, route back to vehicle”). Write in blank spaces any way it fits.
2. Collecting from a dead substrate is okay, as long as it is standing under 20 to 50 percent canopy, not fully in the open and not lying on the ground.
3. Collect individuals that look healthy—with few/no bleached/brownish/dead/otherwise discolored spots.
4. Collect whole individuals as large as possible up to palm-size; when individual is palm-size or larger, take only part of individual up to a palm-size single piece. If the individual is the only one on that tree or other substrate,

take only half. **Goal is ≥ six individuals per sample from different trees, etc.,** with approximately equal amounts from each tree; **start collecting only after species is confirmed on at least three different trees**. You can roam up to 500 m (1,640 ft, 0.3 mi) to find enough separate trees.

5. Evemes can be collected with the gloved hand. Collect other large lichens with the knife; include a thin upper layer of bark or wood to keep individual intact. Avoid cutting through bark to living cambium. For larger species, completely fill a cloth bag loosely with individuals plus only as much bark as needed to keep individuals intact.
6. Collect Phyaip mostly with pruning shears. For this species, fill a cloth bag with short segments of twigs/branches or bark pieces as heavily covered as possible with Phyaip.

Field protocol—post-sample handling (revised from pilot project handouts)—

1. During collection, you can have the (1-gal/3.8-L) sample-protecting plastic bag open in the carry bag, slip the cloth bag in when not collecting. This facilitates collecting two different species on a single tree when convenient.
2. After collection is completed and while wearing gloves, check the cloth bag tag and complete labeling if necessary. Put cloth bag into the (1-gal) sample-protecting plastic bag; **one species** per plastic bag. If two separate composite samples of the **same** species were collected, you can put both in the same plastic bag.
3. Still with gloves on, shake out one desiccant packet into the (1 gal) sample-protecting plastic bag, but **outside** the cloth collecting bag(s). Leave the plastic bag protected, but unsealed until reaching the car and cooler. If the lichen sample is very damp or it is raining, add two desiccant packets.
4. **Now** remove the gloves, put them in your trash bag. If the chosen sample area was very poor and not enough lichen was collected, take off gloves carefully by pulling them inside out so they can be reused.
5. If you feel not enough was collected of a species for an adequate sample, observe as you walk back toward vehicle. If while within 0.24 mi (0.4 km) of the plot you see any other likely places to search for the focus species, put the gloves back on to sample. Wipe gloves and equipment again with alcohol. Sample more of the same species, following all the protocols; add to the current cloth sample bag(s) for **that species**. If you see an adequate amount of a different target species, use a new cloth bag, etc., but keep the original sample until you have two other adequate samples. It can always be thrown away later.
6. Back at vehicle, seal all plastic bags with samples and desiccant packs; place them into the cooler with ice packs.

7. Before leaving the area, fill out a plot sheet (the shipping form is fine for this) or otherwise make notes about sampling details. Especially mention if an edge with less than ideal features (like barely adequate canopy, etc.) was the only available sample area, or if samples were strung out along a long route, or if sample did not meet the goals for size or number of substrates. When filling out the shipping form, use one row per FIA plot. List the focus species collected by their **codes**, and the number of samples per species. Write brief notes about any issues or questions you encountered with the lichen sampling or the area sampled. These notes are especially important for this pilot study, though they are also helpful to evaluate sample quality during routine indicator implementation.

Post-field handling and mailing—

1. If you are on the road and have an air-conditioned motel at night, or it is cold out and dry and warm in the motel room, dry out any samples that were collected very damp. Open the plastic sample bag and prop it against the wall. **Do not** touch or remove the cloth sample bags or the desiccant pack(s). Allow lichens to dry overnight, then reseal and repack bags in cooler the next morning. Check samples in the morning from outside the plastic sample bag by gently squeezing. If the lichens are still very pliable and not stiff, add another desiccant pack before sealing.
2. If there is a refrigerator in the motel room, put any samples that do not clearly need drying into the refrigerator. Refreeze cold packs overnight if possible. If not, add some free ice the next morning when repacking all samples into the cooler. If there is no refrigerator, add some free ice to the cooler as soon as you reach the motel room; replace the ice the next morning before leaving.
3. If you return home, do the equivalent of steps 1 and 2, choosing a room without food or any solvents or chemicals to dry very damp specimens as necessary. Leave dried and sealed collected samples in your refrigerator until returning to the office.
4. At the end of the week, deliver all samples to your office; store dry samples in a refrigerator until mailing if possible. Otherwise, store in very dry location in the office. Open samples for further drying in the office before mailing if they are still pliable by feel from the outside.
5. As soon as possible, mail the samples from a single week to Susan Will-Wolf at the address below. Include a copy of the completely filled out shipping form (fig. 14).

LICHEN ELEMENTAL SAMPLE SHIPPING FORM

Please enclose a copy of this form when samples are mailed. Keep a copy for your records.

FIELD CREW TO LICHEN SPECIALIST: To: Susan Will-Wolf
317 Birge, Dept. of Botany, Univ. of Wisconsin
430 Lincoln Drive
Madison, WI 53706-1381

Date: ____________________

Sent by: ____________________________

Sender's general comments: ____________________

Received: _______________ Comments: ____

CONTENTS

State-County-Plot number	Date	Collector	Sample duration	Sample notes (species code , sampling issues, storage issues, etc.)

Figure 14—Lichen elemental sample shipping form.

Shipping address—

This was for the pilot study: Susan Will-Wolf, University of Wisconsin–Madison, Department of Botany, 317 Birge Hall, 430 Lincoln Drive, Madison, WI 53706-1381.

Field Lichen Identification Guide

Field Protocol Summary: This summary of field protocol was included in the field reference focus species recognition guide:

Focus Species (for pilot study):

- Priority 1: Flacap, Punrud, Evemes
- Priority 2: Parsul, Phyaip

  Replace with focus species recommended for the region in pilot study results and discussion.

Sample area:

1. Just outside permanent plot (first choice) or along route to plot (second choice).
2. Look for well lit forest opening or edge, 20 to 50 percent canopy cover. Avoid edges with roads, tended fields, or lawns.
3. Search one-half hour near plot and en route back before giving up.

Samples:

4. Collect, wearing gloves, one sample each of two focus species, about every fifth plot two samples each, 1 to 2 species.
5. Collect cloth bag one-half or more full of focus species, plus some substrate, **one species per bag**.
6. Collect each species from six **different** trees, 0.5 m (1.6 ft) above ground level. Collect large and healthy individuals if possible.
7. Tree trunks/snags are preferred for most species; branches are preferred for Phyaip.

Field protocol:

1. Hand lens, knife, pruning shears handy. Rigorous technique: gloves first, wipe knife and pruning shears with alcohol second, extract cloth sample bag(s) third, collect samples fourth. Samples **do not touch** anything from off site.
2. Label cloth sample bag tag only after presence of target species is confirmed: Plot number, ST, CO, date, crew name, **species code**, area description.
3. Wearing gloves, place labeled cloth bag(s) with complete sample into sample-protecting plastic bag; **one species** per bag. One (2) 5 g desiccant pack into sample-protecting plastic bag, **outside** cloth bag(s).
4. Supplement small samples on the way back to the vehicle if necessary.
5. At the vehicle, seal the sample-protecting plastic bags with samples and desiccants, then place into the cooler with ice packs. On the mailing form, write notes about samples and area before leaving.

Color images of target species and lookalikes: These were included in the pilot study Field Identification Guide.

FIA staff did not find them helpful so they should ***not*** *be included for an implemented indicator.*

Information on target species to accompany specimens: The following pages have bullet lists for characteristics of target lichens and lookalikes not to be collected, in two-column format. "1" lichens were primary target species in the pilot study; "2" lichens were secondary target species. Format is suitable to clip and include in a field notebook of 9- by 12-inch plastic sheets with four picture pockets, two species per sheet. Organization: a right pocket includes a sample of the target species showing both front and back, the matching left pocket includes clipped paper sheet with characteristics of target species on front and lookalikes on back.

Revise to reflect recommended focus species. Code:… should be the first line for a focus species.

1. CODE: Flacap

(*Flavoparmelia caperata)*

- Flat, leafy growth, lobes one-fourth to one-third inch across
- Individuals to 10 to 12 inches (~25 to 30 cm) or more across
- On tree trunks and larger branches
- Pale yellowish green above
- Upper surface smooth to wrinkled, pale powdery granules more dense at center
- Underside black, brown at edges, rootlike fibers visible

Flacap lookalikes—**do not collect**

- Pale powdery granules along ruffled edges
- Tiny dark finger-like projections on surface
- Upper surface darker green and less yellowish
- Gray-yellowish rather than greenish, grayish
- Surface with tiny white dots

1. CODE: Punrud

(*Punctelia rudecta*)

- Flat, leafy growth, lobes one-fourth to one-third inch across
- Individuals to 10 to 12 inches (~25 to 30 cm) or more across
- On tree trunks and larger branches
- Dark greenish gray to blue-gray above
- Upper surface with tiny white dots
- Tiny dark finger-like projections on surface, more dense toward center
- Underside pale to med brown, rootlike fibers visible

Punrud lookalikes—**do not collect**

- Pale powdery granules on upper surface
- Upper surface pale bone gray or brown
- Upper surface without tiny white dots
- Lower surface black or dark brown
- Lower side without rootlike fibers

1. CODE: Evemes
(*Evernia mesomorpha*)
- Narrow stringy lobes in tufts to ~4 inches (~10 cm) long
- Mostly on twigs and small branches
- Pale greenish; multiple-branched
- Branches irregular, flabby
- Powdery granules along ridges
- No clear underside, no rootlike fibers

Evemes lookalikes—**do not collect**
- Branches clearly rounded, with clear sharp branching
- Sometimes long stringy lobes
- Branches flat, strap-like with upper and lower sides

2. CODE: Parsul
(*Parmelia sulcata*)
- Flat, leafy growth, lobes to one-fourth inch (0.6 cm) across
- Individuals to 10 to 12 inches (~25 to 30 cm) or more across
- Gunmetal gray above
- On trunks to large and small branches
- Narrow strap-shaped lobes, squared off at ends
- Lobes crossed by small ridges with pale powdery granules, more dense toward center;
- Underside black, rootlike fibers visible
- Often has reddish patches with age

Parsul lookalikes—**do not collect**
- Tiny dark finger-like projections on surface
- Upper surface bone gray or very brownish
- Lobes rounded rather than squared off
- No ridges on surface
- Lower surface not black

2. CODE: Phyaip
(*Physcia aipolia/stellaris*)
- Flat growing with narrow lobes to one-eighth inch (0.3 cm) wide
- Growing in rosettes 2 inches (5.1 cm) or more across
- Mostly on twigs and small branches, trunks only in open, mostly on hardwoods
- Gray to pale bone gray above, not shiny, convex and thick-looking
- No powdery granules or finger-like projections
- Fruit cups present, margins pale, center dark or with powdery surface
- Underside pale

Phyaip lookalikes—**do not collect**
- Lobes very tiny
- Lobes very flat, pressed close to bark
- Brownish gray or dark gray
- Powdery granules or tiny dark finger-like projections on surface
- Underside dark

A1.3. Pilot Study Field Supplies and Equipment—Summary and Organization

1. Lichen collection kit: carry sack with one full site kit and sometimes a partially used site kit (use first), plus reusable equipment.
   A. **Site kit** (single-use supplies)—Only the gallon zipper-lock bag to put cloth sample bags in must be heavyweight plastic; all other bags can be mediumweight plastic.

      Note: For a fully implemented indicator the site kit for a single standard site needs disposable supplies for collecting only two full lichen samples: two gloves, two cloth sample bags, two to three alcohol wipes, one heavy-duty plastic zipper-lock gallon bag for filled cloth sample bags. All necessary supplies will probably fit into one zipper-lock gallon bag. Reusable supplies and equipment include pencils, markers, knife, hand lens, and clippers (the latter two are standard staff equipment), stored separately. Extra disposable supplies should be available in case of accidents.

      - Zipper-lock gallon bag of eight gloves.
      - Zipper-lock gallon bag of 10 cloth sample bags, each with write-on tag.
      - Zipper-lock quart bag of 10 heavyweight plastic sample zipper lock bags to put cloth bags in.

        For the pilot study, 6- by 13-inch heavyweight plastic sample bags were used. **For implementation, use heavyweight plastic zipper-lock gallon bag of standard shape (~12 by 13 inch) to put cloth bag(s) in, as suggested by FIA staff; they found the narrower mouth bags inconvenient to use.**
      - Zipper-lock pint bag of ten 5 g desiccant packets, to go inside plastic sample bag, outside cloth bag(s). Also one or two 10 g desiccant packets, for a really wet day.

        In future, include only one size of desiccant packet, probably 10 g packets. Consider increasing the number of desiccant packets to include.
      - Zipper-lock pint bag with 10 alcohol wipes.
      - *In future, supply more alcohol wipes and also supply a bottle of rubbing alcohol, to be used to rinse out knife cover. Depending upon the knife and cover chosen for implementation, wrapping the knife blade with the alcohol wipe before returning it to the cover might be an option.*

B. **Reusable Equipment**
   - Zipper lock gallon bag holding 3-inch-blade shaft knife for sample collecting, with cover, plus pencils, and markers.
     Shaft knife needs higher quality case than the version provided for the pilot study. Both crew and the expert found that the quick-release mechanism began to fail before the end of the pilot field season. Add to field protocol instructions to rinse the knife cover between sites, to avoid cross-contamination.
   - Trash bag for used gloves and alcohol wipes.
   - Hand lens and pruning shears: standard crew equipment. Standard crew equipment folding knife as backup.

2. Cooler with icepacks, spare site kits, remain in vehicle.
   For implemented indicator, a small 5-gal cooler is large enough.

Field Supplies and Equipment—Detailed Information on Equipment and Sources

1. **Gloves:** Should be medium-weight, unpowdered, chemically clean nitrile single-use gloves (finest weight/thickness not sturdy enough for field work); purchase in packages of 100, or 50 for XL size. Consult with crew about size needed; gloves should not fit too tightly. Carried by many scientific and medical vendors; XL size carried by fewer. Each crew should receive extra gloves of the size they need, kept clean in a zipper lock bag (partial box in zipper lock bag is fine). Reasonably good-quality gloves are recommended to avoid splitting in the field. These are widely available.
2. **Desiccant packets:** for the fall season pilot study, one 5-g packet was good for normal days; a few 10-g packets were more convenient for wet days. The field staff should receive extras. These are carried by many scientific and medical vendors. The cheapest is okay. Widely available.
   Increase both size and number of desiccant packs to better help dry samples quickly.
3. **Cloth sample bags:** Bags must be sturdy, chemically clean, and certified as containing low sulfur and heavy metals. Spun-bonded polyester meets these specifications; some other materials do not. The recommended bags are certified free of metal contaminants for collection of ore samples (see website below). Each has a write-on tag and is quite sturdy. Larger bags are not needed. These are available from few sources.
   - 01121 5 by 7 inch New Sentry (Hubco)—PE Sample Bag Bundle of 100—$38.91 (2013 price)
   - Legend, Inc. Sparks, NV. http://www.lmine.com/hubco-sentry-sample-bags-c-4_125_126/. (March 2017)

The breathable cloth bag facilitates evaporation of water.

Lichen specimens must be dried as fast as possible and kept relatively cool to retard deterioration, especially during a summer collection season. Other vendors for cloth bags might be okay; research them to make sure other bags are sturdy, chemically clean, have a convenient write-on tag and are easy to open/close. It is recommended to field test bags from other vendors before mass purchase.

4. **Markers and pencils:** Standard permanent markers (black preferred) need to have extra-fine point. Mechanical pencils are a reliable backup for very wet days. The field staff should receive extras of both. Widely available.
5. **Sample collecting knife:** A 3-inch fixed-blade diving knife with plastic handle and quick-release hard plastic sheath was provided to staff. All field staff preferred this knife to the folding pocket knife provided as standard equipment to FIA crews. The 3-inch blade was long enough; a longer blade would likely not be as efficient. The fixed blade was sturdy for cutting through bark, etc. The saw teeth on the back of the blade were not useful, and sometimes interfered with pushing the knife through bark. The bright yellow handle made the knife easy to find if dropped. The rigid cover protected the knife, reduced contamination, and could be attached to a belt—a convenience noted by field staff. The quick-release feature of the cover was appreciated while it worked; it allowed one-handed release and locking. The blade was stainless steel, adequate for normal elemental measurement.

   Knife purchased: Blue Reef ™ 3-inch mini knife 420 SS—yellow—18.95 (2013 price)

   The knife purchased for the pilot study was quite cheap; knife blade and handle quality were fine but the quick release mechanism of the cover broke down before the end of the field season and became a liability. Knives were supplied tied to the cover with synthetic cord to deter misplacement, and with a long cord to hang the cover from the neck. Some staff did not like the pre-rigged knife with cords. In future, include two long lengths (at least ~1 m/yd each) of synthetic cord with equipment; staff can rig the knife and cover as they prefer.

Recommendation:
A higher quality fixed-shaft knife of the same dimensions—3-inch blade—is needed, with a cover that can go on a belt. Cover is necessary; rigid plastic cover facilitates cleaning, while leather cover would foster cross-contamination. Diving knife style is not essential; the saw teeth on the back of the knife blade were not useful and sometimes interfered with cutting. A stainless-steel blade is probably adequate for implementation; element measurement with adequate precision and low enough variability for data analysis were obtained in the pilot study for most elements including mercury.

A titanium or ceramic blade with demonstrated low "shedding" of metal ions is much more expensive, but could be considered if funding is adequate and use for several years can be anticipated. A titanium or ceramic blade would be required if measurement of elements in extremely low concentrations were required. Both kinds of knives are available from several vendors; investigate quality and cost of either option in advance of implementation.

6. The cooler provided in the pilot study was an inexpensive cooler with plastic outer and interior liner: about 2.5-ft long, 1.5-ft high, 1.5-ft wide, with a lift-off cover and no lock.

   Some field staff recommended a smaller cooler. Most likely a cooler half that volume would be adequate for an implemented indicator, and staff suggested that a rudimentary "lock" mechanism would be useful. Refreezable cold packs were convenient and were used by at least two field staff.

   For collection of lichens for element analysis in warm and humid summer months, cooling in the vehicle is an important step to retard deterioration of the samples.

Appendix 2: Training Introduction Presentation

2013 training introduction presentation (some terms revised 2019)

FIA LICHEN BIOMASS ELEMENT INDICATOR PILOT STUDY

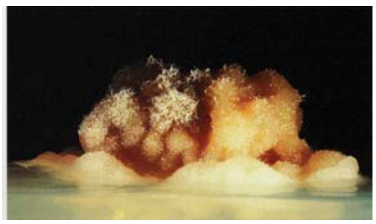
Susan Will-Wolf, University of Wisconsin-Madison, FIA lichens cooperator
Sarah Jovan, FIA lichens indicator advisor, US FS Portland Forestry Sciences Lab, OR
Mike Amacher, Research Soil Scientist, RMRS, US FS, Logan UT

Purpose for the indicator – use element concentrations in lichen biomass as an index for air pollution load at an FIA plot
Purpose for the pilot study – evaluate eastern USA lichen species for this indicator, evaluate use of protocol by FIA staff

BACKGROUND
EASTERN USA FOCUS LICHEN SPECIES
SUPPLIES AND PROTOCOL FOR LICHEN SAMPLE COLLECTION
FIELD PRACTICE
EVALUATION AND QUESTIONS

Lichen Biology and Ecology

- Lichens are a symbiosis



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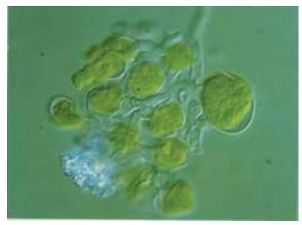

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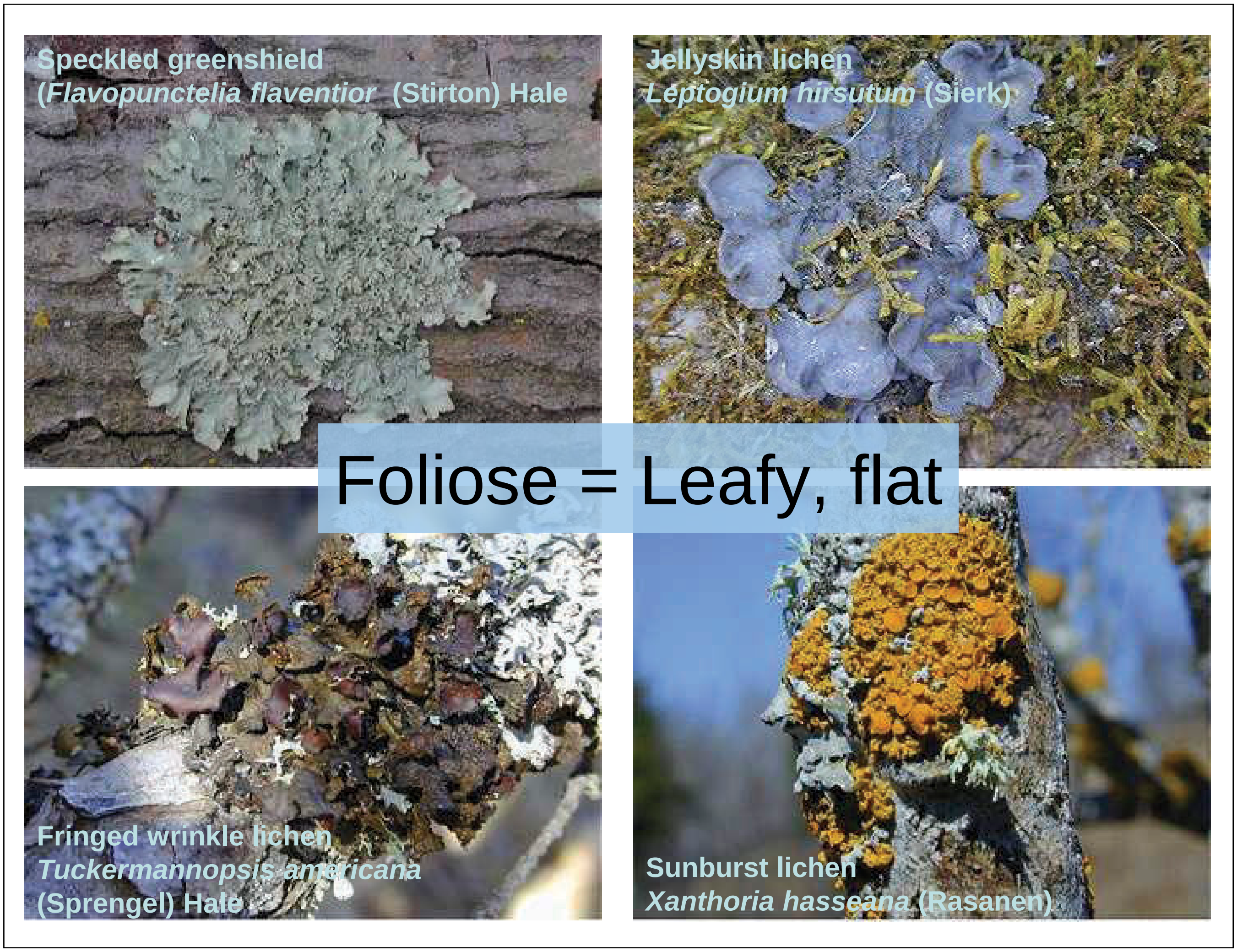
Purvis, 2000

- Lichens grow where vascular plants don't.

- 3 major growth forms of lichens - 2 used in study.


Speckled greenshield
(Flavopunctelia flaventior (Stirton) Hale
Jellyskin lichen
Leptogium hirsutum (Sierk)
Foliose = Leafy, flat
Fringed wrinkle lichen
Tuckermannopsis americana
(Sprengel) Hale
Sunburst lichen
Xanthoria hasseana (Rasanen)

Fruticose = 3-D stalked or tufted

Boreal oakmoss lichen
Evernia mesomorpha Nyl.

Sinewed Ramalina
Ramalina americana Hale

Mealy pixie-cup
Cladonia chlorophaea
(Flörke ex Sommerf.) Sprengel

EASTERN USA FOCUS LICHEN SPECIES

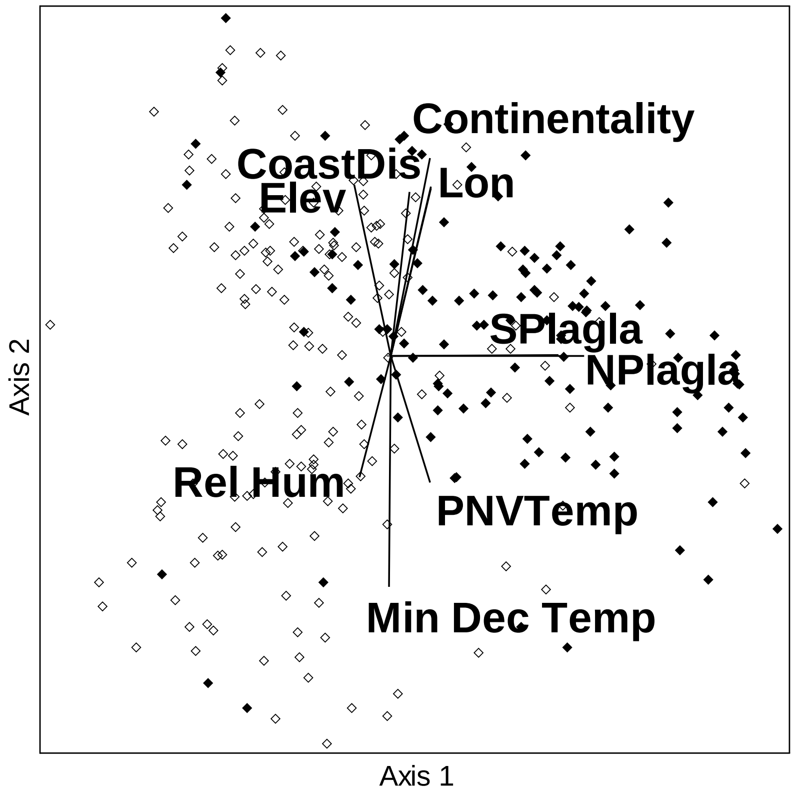
Priority 1:

Common greenshield lichen (*Flavoparmelia caperata*)
code: greenshield or Flacap
Rough-speckled shield lichen (*Punctelia rudecta*)
code: roughshield or Punrud
Boreal oakmoss lichen (*Evernia mesomorpha*)
code: oakmoss or Evemes

Priority 2:

Hammered shield lichen (*Parmelia sulcata*)
code: hammershield or Parsul
Hoary rosette lichen (*Physcia aipolia/stellaris*)
code: rosette or Phyaip

Shield and rosette lichens - common throughout eastern North America, except the SE and Gulf coastal plains.
Oakmoss lichen - Northern Hardwoods region and at higher elevations along the Appalachian chain - easiest to collect!



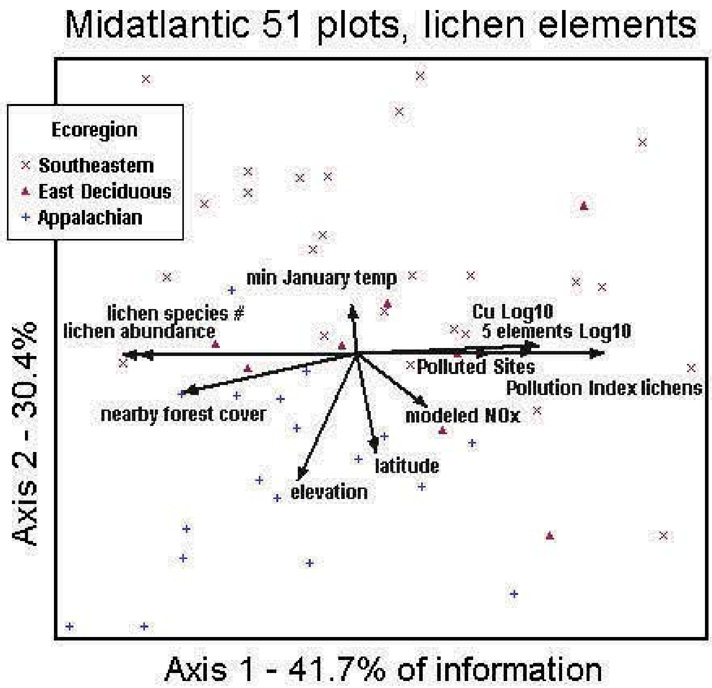
Pacific Northwest Lichen Community Model

◊ Plot: 'clean'
◆ Plot: 'polluted'

Plots close together - similar lichen communities.
Plots far apart - different communities.
West halves OR & WA

Geiser & Neitlich 2006

Lines on graph illustrate correlations of environmental factors with lichen community composition. SPlagla and NPlagla are amount of Sulfur and Nitrogen In lichens. They are the only factors correlated with Axis 1, the pollution axis.

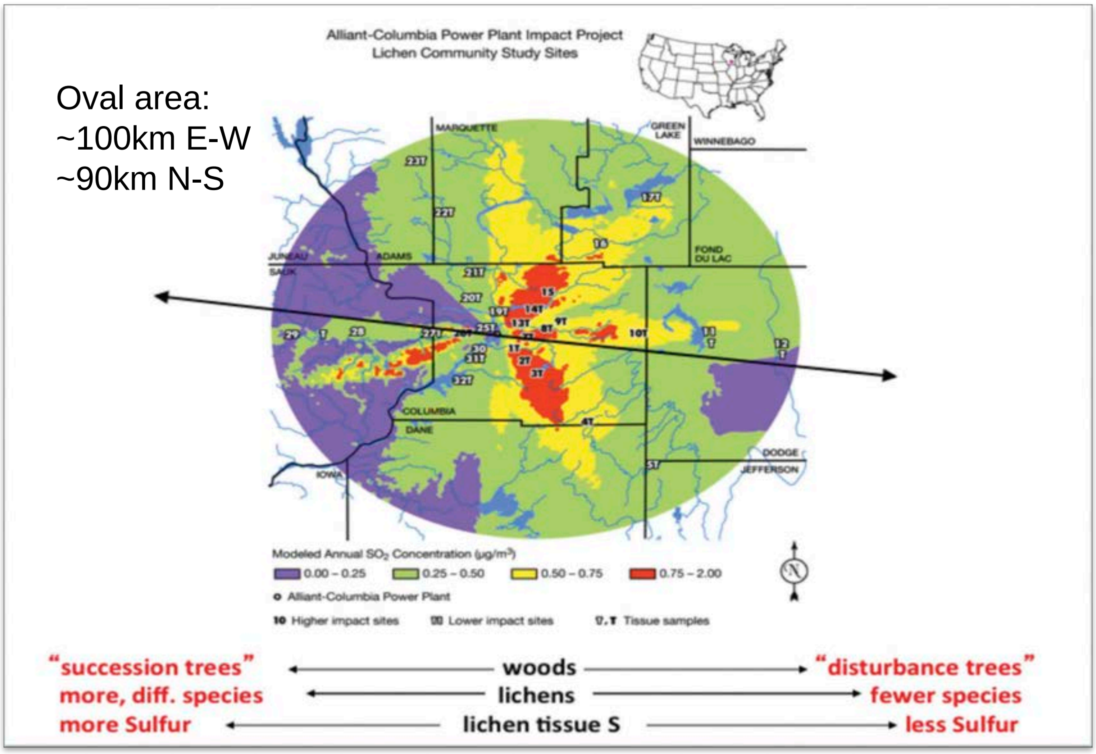


Plots close together - similar lichen communities.
Plots far apart - different communities.
More polluted sites to the right on the graph.
5 states covered.

Combined lichen element factor 5 elements Log10 is the 2nd strongest factor positively correlated with air pollution level.
14 elements from greenshield and rough-shield lichens validated.

Will-Wolf et al. 2017 Soil, Wat. Air Polln

Lines on graph illustrate correlations of environmental factors with lichen community composition. Factors Cu Log10 and 5 elements Log10 are concentrations of elements in lichens. Conversion factors between lichen species needed for 2 of 5 pollution elements.



Colors on map illustrate pollution concentration from the power plant. 14 elements from greenshield and roughshield lichens validated (12 same as MidA). Arrows and red type represent other factors important to lichens.

5 elements (4 same as MidA) strongly correlated with power plant emissions.

Eastern Deciduous ecoregion group: Pearson correlations between selected pollution risk and "forest stress" indexes. Correlation coefficients first, probability second. A p<0.01 is considered significant; a 0.01<p<0.1 is considered marginally significant. The r^2 in parentheses indicates percent of variation involved.

"Forest stress" indexes		Pollution risk indexes	
	N = 80	**LichenAirNE-B**	**2 x LichenAirNE-B +OzoneIBI**
AvgDBK		0.240 p=0.032 (r^2=0.06)	0.205 p=0.068 (r^2=0.04)
%BA-DbkVgr		0.341 p=0.002 (r^2=0.12)	0.284 p=0.011 (r^2=0.08)
%BA-DbkVgrM		0.328 p=0.003 (r^2=0.11)	0.273 p=0.014 (r^2=0.07)
%Ct-Stress		0.280 p=0.017 (r^2=0.08)	0.233 p=0.038 (r^2=0.05)
%BA-Stress		0.270 p=0.016 (r^2=0.07)	0.228 p=0.042 (r^2=0.05)

Will-Wolf, S.; Jovan, S. 2008. Lichens, ozone, and forest health - exploring cross-indicator analyses with FIA data. In: McWilliams, Will; Moisen, Gretchen; Czaplewski, Ray, comps. 2008. 2008 Forest Inventory and Analysis (FIA) Symposium; October 21-23, 2008; Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

EASTERN USA FOCUS LICHEN SPECIES

Priority 1:

Common greenshield lichen (*Flavoparmelia caperata*)
code: greenshield or Flacap
Rough-speckled shield lichen (*Punctelia rudecta*)
code: roughshield or Punrud
Boreal oakmoss lichen (*Evernia mesomorpha*)
code: oakmoss or Evemes

Priority 2:

Hammered shield lichen (*Parmelia sulcata*)
code: hammershield or Parsul
Hoary rosette lichen (*Physcia aipolia/stellaris*)
code: rosette or Phyaip

Shield and rosette lichens - common throughout eastern North America, except the SE and Gulf coastal plains.

Oakmoss lichen - Northern Hardwoods region and at higher elevations along the Appalachian chain - easiest to collect!

Proportion of FIA P3 plots with focus lichen species (as of 2006)

	SE	SE%	MidA	MidA%	NE	NE%	NC	NC%
total plots	409		846		880		249	
any					774	87.95	212	85.14
either of top two	347	84.84	737	87.12	693	78.75	187	75.10
Flacap	233	56.97	665	78.61	552	62.73	160	64.26
Punrud	304	74.33	531	62.77	524	59.55	94	37.75
Evemes					439	49.89	135	54.22
both of top two	190	46.45	461	54.49	384	43.64	68	27.31
all					186	21.14	38	15.26

SUPPLIES AND PROTOCOL FOR LICHEN SAMPLE COLLECTION

- Standard equipment: hand lens, pruning shears, folding knife. Other supplies and equipment provided.
- Choose sampling area – near, not on, plot and/or on route back.
- Clean sampling protocol to reduce contamination from off site, i.e. from the field technician and equipment.
- Collect a composite sample from several different trees to average across within-site variability. Collect duplicate samples once in a while to estimate within-site variability.
- Label immediately. Handle samples to dry as fast as possible, keep clean and healthy for mailing to specialist.

FIELD PRACTICE

- Learn to identify focus species with specimens.
- Practice distinguishing focus species from lookalikes with specimens.
- Practice finding focus species in field.
- Practice collecting protocol in field.
- Practice full protocol in field: choose a sample area, find focus species, collect adequate samples, handle appropriately.

EVALUATION AND QUESTIONS

- Examine field-collected specimens using clean technique to evaluate their adequacy, remove any lookalikes.
- Training specimens collected using clean protocol will be analyzed as official samples to compare with the Rhinelander monitoring station.
- Hand out site kits for the field season - supplies for 50 composite samples.
- Each field technician will collect 50 composite samples, or until the snow comes, whichever comes first.
- Questions????

Appendix 3: Pilot Study 2013 Post-Season Crew Feedback

FIA Eastern U.S. Lichen Element Indicator Pilot Study—Wisconsin 2013

The original post-season feedback form sent to the four participating FIA Northern region field staff is presented below with text in black type. Three returned the form; their responses—in italics—are interspersed after each question. See appendix 1 for training outline, revised protocol documents, and lists of equipment and supplies with notes on changes recommended based on field season experience and crew feedback. See appendix 2 for the pilot study training introduction. The most important points from field staff feedback are:

Training—
Most of the 6-hour training was considered valuable. Hands-on training for focus species recognition with actual specimens plus demonstrations and guided field practice of all protocols were most important. Hands-on practice is critical. Some explanation of the rationale (but not as much as was provided in app. 2) was appreciated.

Equipment and supplies—
A field reference guide with actual focus species specimens plus text on identification aids was very important; pictures were not good substitutes for specimens. A 3-inch fixed-blade knife with case was the preferred collecting tool. Other equipment was mostly good and well-organized, with one exception. The provided bag was mostly not used: too big, too clumsy, and did not fit within the standard backpack. A thin, light, simple carry bag for lichen collecting equipment and supplies, that would fit in the standard field backpack, was recommended.

Field and shipping protocols—
Responders thought they performed protocols well and mostly collected adequate samples. Protocols were considered reasonable and mostly not too onerous, though some suggestions were made for minor improvements. Responses should be evaluated with these protocol aspects unique to the pilot study in mind: (1) Field staff had the option to skip lichen collection if weather or time was too limiting for any reason; this would not be an option for an implemented indicator. (2) Lichen collection for the pilot was done in the fall season. Lichens were to be collected before Thanksgiving, but because of furloughs resulting from a government shutdown, lichen collection went later into very cold weather. For an implemented indicator, collection might be mainly in the summer; there will likely be more problems with

collecting in hot weather and problems drying lichens, and few to no problems with wearing nitrile gloves in cold weather.

Indicator implementation—

Responding staff thought there would be time constraints to fit collecting of lichens for elemental bioindication into a P3 schedule with a one-person crew, this would be easily feasible with a two-person crew. It is likely that for implementation, collecting focus lichens would be included as part of the P3 schedule. Field staff thought suggestions for training certification and QA evaluation were generally reasonable but required more thought.

Note: The original questionnaire word usage and staff feedback are included below, not the revised word usage used in the body of the report and most of its appendixes.

Training

1. Background information:

Too much?

There was a visual with a graphic that I could not understand and would need significantly more time to figure out. It was a star-like graphic with different elements… I think that one likely went over all our heads and we would all need significant time to understand what it represented. It can likely be left out.

Generally, the field crew won't need much background other than the fact that lichens can provide information on pollutants. Providing a list of references for those with an interest to read more would suffice.

Too little?

See "what else…" below.

General:

The background information during training was good. It let us know why lichens were being collected.

I enjoyed the background information, especially the visual of elements collected from lichen in the output of a power station (?). That was very cool.

What else might you want to know?

I would enjoy a little more focus on what can be pulled from the lichens (if I remember correctly Nitrogen was a main one, but I felt a little more time on this and past studies would be cool.) Knowing our crew though, I can't guarantee that anyone other than myself would be interested in that information.

2. Five target species training: Was enough time spent teaching to identify and distinguish the five target species?

It seemed like we all pretty much had a handle on the species ID by the time we left. The folder with actual species was really critical for reminders throughout the season.

Training was good on the five target species. I did have a problem distinguishing between rough speckled and hammered [Punrud and Parsul]. I still don't know if I really know. Unfortunately, I didn't work in the area we did the training in. But you did give me a good idea of what to expect to find in my area.

What were the most useful parts of the species identification training?

The microscope was very handy to have around so that we could look at things up close. Even though we wouldn't be using it for actual collections, it gave me a better idea about what I was looking for. All the samples you had in the room were very helpful, but some of them did get mixed around which made it a little confusing at times. If I recall correctly you explained the proper procedure and had us do it as you described it. I always find it helpful to watch the procedure first (in its best form) and then try to duplicate it. Your review of our individual samples that we took alone was very useful. A little more time for this review would be great.

Hands-on is the only way to quickly train identification. Having samples like you did was great.

Having actual lichens to look at, not just pictures, helped in identification. Having everyone at the training interacting with each other helped. Hearing others talk about how they identify the lichens or what they see also helped.

What were the least useful parts?

The pictures and descriptions could not give a sense of size and what would appear in the field.

I don't feel there really were any, this was all new.

3. Field protocol training:

Was enough time spent indoors explaining the protocol?

Yes there was enough time explaining the protocols.

Yes.

Yes, I think so. I do recall being uncertain about whether it was more important to get the samples out within the about a week timeframe or make sure that they were fully dried before sending them to you.

Was enough time spent outdoors practicing the protocol?

Yes.

Yes, but more is better.

Yes, I think so.

Suggestions to improve protocol training?

None that I can think of.

More time outdoors practicing the protocol is better.

Only what I mentioned above about watching you do clean technique first. I always find it helpful to watch the procedure first (in its best form) and then try to duplicate it.

4. Suggestions to improve the overall training?

No responses.

Equipment and Supplies

5. ID aids for the five target species:

Photos ID aid—useful?

Honestly, I'd have to look at this again to recall if I used it. I think I always referred to the actual specimens.

Only of limited use, the accompanying descriptions were helpful.

They were useful with specimens ID aid.

Size—would half-size images be ok?

Yes.

Perfect size.

Specimens ID aid—was this notably more help beyond the photos leaflet?

*This was **notably** more helpful. It felt critical.*

Oh yes. Being able to look at the sample specimens with the magnifier was important when determining the species in the field.

These worked well for a quick reference, and well with the photo ids.

Would a smaller booklet with just specimens and name/code be just as useful?

I think the booklets were well done.

Would **only** the photos ID aid booklet be adequate?

No—I don't think so.

Not for me.

It seems in my experience that for the identification of species, having them there is a big help. Photos don't really help that much sometimes.

6. Collecting tools and equipment:

Was the shaft knife more useful than the standard folding knife?

Yes, the shaft knife was more useful, mainly because it was really sharp. The only problem was that the sleeve the knife was in started to get dirty toward the end. It was filling with debris from previous cuttings. I had a feeling that, for clean sampling practices, this wasn't good.

Yes, it was firm and rigid when needed to remove samples from stubborn sources.

*I loved the diving knife once I attached it to my belt so that I could release it one-handed. This ability to release it one-handed seemed critical while trying to hold samples and other materials and walk between trees. An easy release made it more likely that I would put the knife away while walking between trees (**much** safer). Unfortunately, by the end of the season, the knife quit releasing without two hands to strongly push on the case release. I could barely get it out of there.*

How often did you use the standard folding knife, either by choice or necessity?

I never used the folding knife.

I did not use the folding knife, by choice. Why, when I had the shaft knife?

Didn't have one I don't think, and didn't use one.

Would a different kind of shaft knife be preferred? If so, what specific features should be different?

The only problem I had with the knife was the sleeve filling with gunk. I don't know if this could be fixed since it is needed for safety reasons.

Same style of knife, with a better release.

How often did you use the pruning shears?

I used the pruning shears for hoary rosettes quite a bit.

Only when collecting the rosette species on twigs and small branches.

Rarely. I generally used the knife and my thumb to pull moss-type lichens away from the tree at their base.

Cooler:

I really didn't use the cooler.

Too big?

Maybe

Perfect size.

Too small?

No responses.

Insulation adequate?

Yes.

Seemed good.

Cooling packs useful?

Initially.

Definitely, but a little difficult to remember to pull them from my freezer at home to take them to work and into the field.

Ice available?

No responses.

How often were you unable to keep specimens cool in your vehicle? Reminder to readers; the pilot study was conducted in mid- to late-fall: outside temperatures were moderate to very cool.

Every hotel I stayed at had a fridge or it was cold enough to leave them in my vehicle.

I did all sampling from the office, only cooled specimens during drive back to office.

Rarely to never.

7. Collecting supplies: evaluate each of the collecting supplies used—mention any problems and possible solutions (other than abandoning the "clean" technique!).

Gloves;

If we carry late into the season again, a supply of larger gloves to fit over liners would be good. I found my hands got ***really*** *cold* ***really*** *fast in just rubber, but my liners didn't really fit underneath.*

The gloves were ok to use but I did have to touch things like my pants, face, hair and other things that I had worn the day before. Unsure if this was a clean practice or not? Maybe alcohol sanitizer would be just as good.

Alcohol wipes:

They were easy to use. Thought maybe alcohol sanitizer might be easier.

Cloth sample bags:

I did have to set them down a couple times but were easy to use.

Plastic zipper lock sample bags:

Something with a bigger opening would be handy. I found I had to manhandle the samples sometimes to get them in those tall skinny bags. Standard quart ziplock bags or similar would be perfect.

They fit the sample bags great.

Desiccant packets:

Seemed to work well.

Carry sack:

Hmmm… perhaps a thin, but large sack that we could put our lichen equipment for the day into, stuff that inside our standard field pack with our other field equipment, and then use to lay out on the ground to work on. I had a bit of a difficult time finding what I needed when trying to dig through that bag while keeping everything inside it and off the ground.

I used a Forest Service backpack that I had in the office. The handles on the provided carry sack were not long enough to put on shoulder while walking through the woods.

I used my everyday pack to carry my equipment. It was easier to do this in the field. I didn't use [the provided carry bag].

Organization and packing of site kits and equipment:

Loved the separated packs of ten. It was good to "start fresh" at the beginning of each pack. Otherwise I am certain my "clean technique" would have been a little less clean.

Good.

It was nice to have site kits made up for us. I could easily grab a new kit when I exhausted the last one.

Field and Shipping Protocols

8. Field protocol elements: For each of the field protocol elements listed, list problems you had, suggestions for better explanation, alternative actions, etc.

Find area to sample:

Marshy areas had fewer species to choose from.

Decide if target species present, choose two to sample:

I did a lot of scouting while going to and from the plot area, carrying only my hand lens. By the time I was ready to collect lichens, I had mapped a suitable area in my mind and knew what species were available.

Sometimes the areas I was sampling were near fields or the woods weren't that big of an area. Sometimes the best area was actually on my survey area. The area I surveyed the trees, was sometimes pretty nasty so I really wasn't looking forward to walking around in it, which made it hard to find samples.

Find multiple trees/other substrates to sample:

Variable by site.

I did notice what trees to look for that would have the lichens on them. Cherries were good along with hickories. Fresh downed oaks were the best. But if certain tree species weren't available, it became hard to find the lichens.

Follow clean protocol:

*It was **very** hard to keep things clean on rainy/wet days. Everything stuck to everything.*

It became second nature after a while.

Occasionally take two samples per target species:

If you are in the right place sometimes the lichens would be all over. Other times it was hard to find them.

Label cloth bags:

Would be nice to be able to label the site details, etc., on the outside of the bag so as to have to juggle the pen less while trying to keep things clean.

I labeled the best I could, sometimes changing them because I found a better lichen species to collect. Not sure if that was alright?

Fill out shipping form at the vehicle with summary of target species and sampling issues:

Because I was incorporating the collection with P2 work, I made notes on my plot sheets and transferred to the shipping form at the office. I used the electronic copy of the shipping form directly.

I filled out the shipping form before being sent out, not in my vehicle.

Store samples in cooler:

Due to the furlough, most of the sampling was during cooler weather. I did keep the samples in the cooler in the office, but without freezer blocks.

Didn't do.

How much time was spent collecting lichen tissue samples?

On average?

About one hour for two samples. Scouting the site was absorbed in P2 plot time.

One hour.

Half hour.

Maximum?

1½ to 2 hours.

1 hour.

Minimum?

One half hour, samples very close to vehicle/road.

One half hour.

15 minutes.

What time of day was collecting done? Was light adequate? If not, solutions?

There were a few times the weather affected light. It could affect identifying appropriate species for me.

I didn't collect if it was getting late. This was usually not an issue though.

I collected them during the daytime, sometime in the middle of our tree survey, but mostly at the end of our tree surveys.

How often did you collect what you thought might be inadequate samples?

I think only once or twice I collected inadequate samples.

For these times, how often was the issue limited availability of a target species?

Maybe got desperate to finish collecting. We were getting later in the season and sunlight was fading earlier.

I believe limited availability was the issue.

Half of the time availability of the species was a problem, especially in the farm/plains states (Illinois, central Minnesota).

How often was the issue limited time available from other inventory tasks?

Spending time with lichens may have affected my ability to do a second P2 plot when I was working alone. When I had a partner, not lichen trained, I was able to complete two P2 plots in one day.

Not really an issue, but the flexibility to not collect all the time made this more reasonable. Sometimes the field work took too long to collect lichens afterwards and sometimes non-work schedule items meant that I had time to do complete normal field work, but not collect lichens samples.

I managed the time for collection well.

How often were you able to collect duplicate samples of a focus species?

Several times; I don't recall how many.

A couple of times when I found a lot of one, mostly Green Shield [Flacap].

Was this as often as recommended?

I think it was close to what was recommended.

Yes.

If not, was lichen availability or time availability the more limiting?

Both of these factors restricted how often I would collect duplicate samples. Less lichen availability meant more time and I often couldn't spend more than 1½ to 2 hours on it.

9. Procedures after field collection:

Overnight drying:

I just put the bags in my office opened and that seemed to work.

Overnight cooling, storage—how often were you unable to keep specimens cool overnight during a field week?

Always able to do this.

Not an issue, in office sitting near air conditioning vent.

Weekend sample handling—drying and cooling:

Left the samples in my office where it was cool, out of sunlight, and dry.

I shipped after the samples had more time in the office, usually after the weekend.

Shipping:

I stuffed them in a box. I tried not to crush them. I figured they were no good if smashed.

Went allright—I could usually fit specimens into a UPS box that would fit into a drop box.

How often did you ship specimens not fully dry, to keep on a weekly schedule?

I guess once, but after that I held onto wet ones for a while.

A few times I think (twice maybe)?

N/A.

Indicator Implementation

10. Comments about how the procedure might fit into a P3 crew schedule, as opposed to a P2 crew schedule.

I usually take an entire day to do our P3 plots, of course depending per plot. Adding this probably would add an extra hour at the most I would think. But it does seem that I do most of my P2 during the winter so working in the cold is sometimes trying not to work long in the cold. This would be a survey to do in the summer months.

Mixed feelings. The workload for P3 is enough to keep a one person crew busy for a full day. Adding another protocol to P3 and what we refer to as P2+ (P3 without soils protocol) may tip the scales and drive us to two-man crews more than we work now. This is not a bad thing, but requires more scheduling as most of our offices have one person. I think lichens are better done during the *growing season, so how will lichen plots be selected? The P3 schedule crowds our summer season already.*

I think it would be tight and frustrating. More equipment into the field, more time required than already required. I believe it may be difficult to maintain sample quality in that situation.

11. Training, quality assurance (QA) evaluation:
There need to be training and QA evaluations for crews with an implemented FIA indicator. Your comments on useful evaluation criteria for future training certification and quality assessment would be helpful.

Training certification might be based on a test of how many of a set of lichen specimens can be correctly identified as target or nontarget species, plus a checkoff of whether adequate samples of two target species were collected and appropriately labeled. QA would probably be conducted by having a lichen specialist revisit selected sites in a region, make collections of 2 target species and notes on others, then evaluate the crew sample based on the specialist sample: did crew collect the higher priority available species, were samples large enough for the target species, in good shape, labeled fully, etc.

That seems reasonable.

[For QA:] One might find species in one place, collect them. QA person collects them from somewhere else. I guess the question is how long do you want someone to look for them before they sample them.

21. Any other comments about the indicator, the training, the procedures, or the field season.

Sometime the only place I found good samples was on our acre tree survey area. I wasn't always able to find any other outside this area.

I wasn't always able to find two species.

[Collecting the samples with clean practices made sense but I feel alcohol sanitizer could replace the glove.

While collecting samples, I did cut off of live trees and sometimes left some scars because of their thin bark. This put a frown on my face. Sometime I collected the only sample of the species in the area, basically took the only one there.

Thank you for your participation; your contributions are invaluable for development of this indicator.

—Susan Will-Wolf (FIA lichens cooperator) and
Sarah Jovan (FIA lichens indicator advisor)

Appendix 4: Laboratory Protocols and Equipment

Summary of protocols and equipment: revisions based on pilot project results are included.

Notes about what was done differently in the pilot study have a gray background.

A4.1 Recommended Laboratory Protocols for Sample Handling and Measurement

1. **Qualifications of laboratory personnel:** The lichen specialist must be well trained to evaluate specimens for adequate quality and prepare them for measurement—determining that a sample is a correct bioindicator species that meets established field sample criteria, removing damaged thallus pieces, removing substrate and other unwanted material, or training suitable technicians to perform these tasks. The lichen specialist is responsible for the final decision of whether to send a finished sample for measurement.
2. **Each lichen sample should be given a unique laboratory tracking number upon receipt.** Write this number on the tag of the cloth sample bag and enter into a sample tracking spreadsheet as soon as possible. Transcribe all sample tag information and any notes on the shipping form to the tracking spreadsheet. Record in the tracking spreadsheet date of receipt plus any other general notes about the sample, including drying state, sample size, species ID, and other field sample quality factors. Give immediate feedback to field staff about the last four items, describing problems and suggesting solutions as needed to improve specimen collecting. Throughout residence of sample in the laboratory: Record date of substrate removal and any additional notes on sample size, species ID, and quality; record air-dry weight of sample after substrate removal; record date sent for laboratory measurement.
3. **Samples should be quickly examined immediately upon receipt from FIA staff.** Samples should be re-dried as necessary in the lab, then are stored dry and cool until preparation. Will-Wolf samples for the project were handled similarly in the laboratory, following either rigorous protocols or more relaxed protocols as indicated by the expert's field collection protocols (Will-Wolf et al. 2017b).
4. **Evaluation for measurement:** Each full sample is examined just before preparation to confirm target species and discard any pieces of non-target species. Any discolored or otherwise unhealthy-looking pieces of the target species are also removed at this stage. Next evaluate whether the remaining composite sample meets field criteria of apparently from ≥6 separate substrates and of sufficient quantity to support measurement. Laboratory

notes relevant to field sample quality are recorded by sample. If at this stage material of a target species is clearly insufficient for measurement, the sample should be discarded and a note made of the reason. Any sample not meeting the minimum field sample quality criteria below should be discarded at this point.

Samples not meeting full field sample quality criteria but with enough available biomass had elements measured for the pilot study, to facilitate evaluating impact of field sample quality on subsequent data quality.

Minimum field sample quality criteria for bioindicator species samples to be measured: Revised based on Will-Wolf et al. (2017a, 2017b) results.

- No specimen with any visible evidence of contamination with extraneous substances should be measured.

Attempts to sufficiently reduce contamination of specimen by brushing or rinsing were unsuccessful.

- No sample that clearly fails to meet the criterion of being from ≥6 separate substrates should be measured, no matter how large.

Many samples of any species that were marked as failing this criterion were measured but were subsequently excluded because of multiple data anomalies.

- A sample that passes both these criteria but is clearly too small to meet the species-specific minimum prepared air-dry weight listed after step 5 should not be prepared for measurement.

5. **Preparation for measurement:** Substrate, any other substances, and any other lichens are removed from the composite sample of the focus species. Samples are not rinsed, to avoid element leaching; see main text. During this process, any further damaged thallus pieces and non-focus species are discarded. Fully remove substrate, etc. (≥99 percent removed as viewed under dissecting microscope), using chemically clean gloves and alcohol-wiped tools, platforms, and containers. Reclean everything before starting with each new sample. Leave lichen specimens as intact as possible after substrate removal. The emptied cloth field sample bag should be shaken to remove any particles. Lichen samples not reduced to small flakes during substrate removal should be returned to their original cloth field sample bag stored in a plastic zipper-lock bag, kept dry and cool. For samples of species like Phyaip that are reduced to small flakes during substrate removal, place sample flakes in a new chemically clean bag, with original cloth bag tag taped to the outside. Record notes about apparent sample quality and size during the process, and weigh the air-dry sample before returning it to

the sample bag. If the sample fails to meet the minimum species-specific weight below, do not send it for measurement. Recording of cleaning time is optional, but could be useful to support budgeting.

Project samples had either "Full" or "Partial" removal of substrate (about 5 percent of substrate left on a sample, as judged by the unaided eye) before measurement (see Will-Wolf et al. 2017b). For the pilot study cleaning time was recorded for samples and prepared air-dry samples were weighed for estimation of cleaning rate. Small samples were measured for the pilot project.

Minimum species-specific air dry prepared sample weight:
Revised based on Will-Wolf et al. (2017b) results. Low-weight samples were measured for the pilot study.

- Prepared air-dry samples of Evemes, Flacap, or Phyaip that otherwise meet all field collection criteria but weigh ≥0.6 g can be sent for measurement. Mark these samples in your spreadsheet for additional thorough data screening.
- Prepared air-dry samples of Parsul or Punrud that meet field collection criteria and weigh ≥1 g should be sent for measurement; samples weighing <1 g should not be sent for measurement even if they otherwise meet field collection criteria.
- Low-weight samples of Evemes, Flacap, or Phyaip should not provide more than 1 to 2 percent of the elemental data analysis data set for analysis. Some of them might well have failed the criterion of ≥six different substrates even though not noted by collector nor apparent from sample appearance, so a high proportion of low-weight samples would likely reduce data quality and bioindicator usefulness. Also, low-weight samples require much more time to remove substrate (see text); a high proportion of these would greatly increase the cost of sample preparation for measurement.

6. Species-specific sample preparation notes: Phyaip preparation requires additional care and different techniques for substrate removal. Because this species has a small and tightly appressed thallus, it is seldom possible to remove large pieces of thallus. Instead, sample material is often scraped from the surface of thalli on twigs or bark pieces. This process leaves mostly many small flakes. A scalpel held at a moderately steep angle to lichen thalli is the most efficient scraping tool. Take care to avoid scraping off the substrate as well. This is usually done in a wide glass bowl to catch as many of the small thallus scrapings as possible. After scraping is

complete and before weighing, examine flakes and remove any interspersed pieces of substrate with tweezers. The prepared sample of Phyaip scrapings is placed in a new chemically clean solid plastic/composition bag about 5 by 6 inches. The tag on the cloth field sample bag is cut off and taped to the new solid sample bag after it is sealed.

7. Pilot study analyses: Only samples collected and handled using the most rigorous protocols (rigorous cleanliness protocols and "Full" removal of substrate) were used to evaluate field sample quality impact on data quality. Substrate removal rate was calculated for "Full" removal of substrate from samples handled with the most rigorous field and lab cleanliness protocols, and also for "Partial" removal of substrate regardless of field and lab cleanliness protocols.
8. Prepared samples should be sent to a Forest Service analysis lab (or similar facility for other organizations conducting a study) for measurement. Intersperse standard and reference samples with study samples; ~3 to 5/100 study samples measured. Aluminum (Al), calcium (Ca), heavy metals, nitrogen (N), sulfur (S), and strontium (Sr) plus lithium (Li) if possible (useful for Will-Wolf et al. 2018a) are important metals to measure. Priority should be N, S, Al, heavy metals, then other elements as desired.

   Pilot project prepared samples were sent to the Soil and Water Analysis Lab (SWAL), U.S. Forest Service Rocky Mountain Research Station, Forestry Sciences Laboratory, Logan, Utah, for measurement. Elements are listed using their standard codes (IUPAC 2014). Under the supervision of Michael C. Amacher, samples were oven dried (40 °C), mill ground (high-rpm rotary mill with dry ice snow added to help shatter lichen tissue and avoid sample overheating), and reweighed. After grinding, several large samples were divided by Amacher as laboratory splits. The entire 500 g bulk Flacap collection was mixed after grinding to homogenize it before subdividing to evaluate repeatability of element measurement procedures. Part of each sample was first chemically digested using concentrated nitric acid plus 30 percent hydrogen peroxide, followed by inductively coupled plasma optical emission spectrometry (ICP-OES) to measure Al, arsenic (As), boron (B), barium (Ba), Ca, cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), phosphorus (P), lead (Pb), S, selenium (Se), silicon (Si), sodium (Na), Sr, and zinc (Zn). See Gatziolis et al. (2016) for details of SWAL measurement procedures. If enough sample remained, Carbon (C) and N, then mercury (Hg), and finally S were measured with combustion analysis. Note S was measured by both procedures if enough sample was available. Samples of a certified external standard and the internal reference bulk Flacap material (three to four samples each) were interspersed with each batch of about 90 field samples submitted. The external standard was IAEA-336, preground Evernia prunastri from rural Portugal (IAEA 2017), certified for Al, Cd, Co, Cr, Cu, Fe, K, Mn, Na, P, Pb, and Zn (Heller-Zeisler et al. 1999) that were also measured by SWAL. For small samples, measurement priority was digestion/ICP followed by combustion analysis of S, C, and N, then Hg. During indicator implementation, priority for the two procedures should be the same: first chemical digestion and then measurement by ICP/OES, followed by combustion analysis of C and N, then Hg, then S if the sample is large enough.

A4.1.1 References

Heller-Zeisler, S.F.; Zeisler, R.; Zeiller, E.; Parr, R.M.; Radecki, Z.; Burns, K.I.; De Regge, P. 1999. Report on the intercomparison run for determination of trace and minor elements in lichen material IAEA-336. Vienna, Austria: International Atomic Energy Agency. https://nucleus.iaea.org/rpst/ReferenceProducts/ReferenceMaterials/Trace_Elements_Methylmercury/IAEA-336.htm. (March 2017).

International Atomic Energy Association [IAEA]. 2017. Materials characterized for trace elements and methyl mercury. http://nucleus.iaea.org/rpst/ReferenceProducts/ReferenceMaterials/Trace_Elements_Methylmercury/index.htm. (March 2017).

A4.2. Laboratory Equipment and Supplies

This equipment is needed by the lichen specialist and technicians who receive field staff specimens and prepares them for measurement of elements.

1. Air-conditioned laboratory space is important; additional cool-temperature facilities for air-drying lichens are useful. An air-flow fume hood is useful; a specimen-drying cabinet is acceptable if it has a low-enough temperature; a drying oven should probably not be used unless <100 °F or 37 °C. Space is needed to store samples after receipt and substrate removal, before mailing to a laboratory for measurement.
2. The lichen specialist or technician wears clean nitrile gloves whenever handling lichen specimens; specimens should touch no surface nor object that is not chemically clean. **Note:** sterility is not necessary, and does not guarantee that a specimen is chemically clean. Gloves as specified above for field collectors meet all requirements for handling samples in the lab as well.
3. A dissecting microscope, plus chemically clean containers and work surfaces are needed. Multiple 6- to 15-inch glass plates or dishes (large glass petri dishes, for instance, for the smaller range) or those of other chemically inert materials that are smooth and amenable to cleaning are needed when removing substrate and other unwanted material from specimens. The smaller sizes are needed under the dissecting scope. Necessary tools include fine forceps and medical scalpels with large disposable stainless steel blades. A sharp stainless steel (or other mostly inert metal) knife can be substituted if it can be completely and thoroughly cleaned. Specimens must be weighed (in clean weighing pans) after substrate removal on a scale accurate to two decimals in the 0.01 to 10 g range.
4. Additional new chemically clean bags at least 5 inches wide by 6 inches long need to be available for samples reduced to small flakes during removal of substrate. If these are used, field collecting bag tags/labels should be taped to the new bags as explained in section A4.1.5 of laboratory protocols above. A chemically clean bag with a self-closure would be most convenient. Check before ordering to make sure that the type of solid bag is acceptable to the measurement laboratory for receipt of specimens.
5. Opaque chemically clean Silverpak™ bags were used for this purpose in the pilot study; other suitable alternatives are available from scientific supply companies. The bags used for the pilot study had no closure; the tops were folded and taped for shipment.

Appendix 5: Procedures for Validation of Lichen Elemental Data

Detailed Procedures

Raw data were first screened, and extremely high outlier values (more than five times the average of remaining values, notable gap from the next higher value) for an element were removed as likely being due to measurement error. Excluded far-outlier values were replaced with remeasured values when possible, unless the remeasured value was >50 percent of the original value. In the latter case, original and remeasured values were averaged for the dataset. Sulfur (S) was measured with both methods. S from chemical digestion, then inductively coupled plasma optical emission spectrometry (ICP-OES), had notably lower variability for all replicates of our field-collected lichen samples than did total S from combustion (table 5 below), and the latter had more missing values, so S values from ICP-OES represented S in all subsequent analyses. Method minimum detection limit (MDL) (see table 5) was from Gatziolis et al. (2016) for ICP-OES measurements and from Amacher (pers. comm.) for measurements from combustion. Validation of screened data was based on the number of values noted as below detection level (BDL) and on variability of replicates. Variation of replicates was calculated as the relative standard deviation (rSD): ratio of the sample standard deviation (sd) σ to the absolute value of the mean μ expressed as a percentage (Gailey and Lloyd 1986) (equivalent to the coefficient of variation (CV) (Halleracker et al. 1998) when the mean is positive:

$$\text{rSD as percentage} = \sigma/|\mu| \times 100$$

Elements listed in table 5 with >5 percent of samples BDL or rSD >25 percent (these values in are boldfaced type) for any sets of replicates, including external standards and internal reference material, were excluded from further analyses. Maximum rSD (=CV) values for validated elements range from 10 to 50 percent in the literature (e.g., Frati et al. 2005, Loppi et al. 2002). The IAEA-336 *Evernia prunastri* (L.) Ach. certified lichen reference product (IAEA 2017) is an appropriate external standard for lichen-based studies. The Flacap bulk internal reference sample (handling details are in app. 4) was also useful; a similar internal bulk reference sample should be included in future studies to help assess measurement variability. Total samples for calculation of percent BDL included project lichen samples from all species and reference samples from both the bulk Flacap and the IAEA-336 standard. For elements not excluded from further analyses, values below the MDL for each element (BDL) were replaced for data analysis by one-half the

Table 5—Project lichen elemental data validation results

Analysis method and type of element	Element	Units[a]	Detection limit[b]	Number of BDL samples/ total samples	rSD for IAEA-336 external standard; n = 7 to 8 samples	rSD for Flacap internal reference; n = 8 samples	Mean rSD for Flacap field replicates; n = 9 to 12 sets	Mean rSD for lab splits, 5 species; n = 10 to 13 sets	Elements to retain for further analysis
			mg/kg[c]			- - - - - - *Percent*	- - - - - -		
Combustion:									
Important nutrients and/or pollutants	C	Percent	0.352[c]		3.5	3.6	3.0	1.2	C
	Hg	mg/kg	0.03		10.8	9.5	10.3	9.4	Hg
	N	Percent	0.52%[c]		5.2	2.1	9.3	5.2	N
	S	Percent	0.06%[c]		8.9	8.6	11.4	7.9	S
ICP-OES:									
Plant macronutrients	P	Percent	0.283[c]		3.8	5.0	13.2	6.3	P
	K	Percent	0.255[c]		6.9	3.1	8.6	6.6	K
Plant secondary nutrients	Mg	Percent	0.002[c]		4.3	3.9	10.4	6.1	Mg
	Ca	Percent	0.001[c]		4.3	2.9	18.3	8.9	Ca
	S	Percent	0.111[c]		14.4	3.9	8.0	7.3	S
Plant micronutrients	Mo	mg/kg	0.056	54/283	195.8	16.7	58.8	36.2	
	Mn	mg/kg	0.011		3.5	7.1	23.4	13.5	Mn
	Fe	mg/kg	0.040		9.6	11.8	10.9	9.0	Fe
	Ni	mg/kg	0.115	3/283	8.6	13.6	17.8	15.2	Ni
	Cu	mg/kg	0.118	2/283	7.0	13.8	10.9	7.0	Cu
	Zn	mg/kg	0.030		3.6	5.9	16.7	9.9	Zn
	B	mg/kg	NA		19.4	29.7	13.4	9.6	

Table 5—Project lichen elemental data validation results (continued)

Analysis method and type of element	Element	Units[a]	Detection limit[b]	Number of BDL samples/ total samples	rSD for IAEA-336 external standard; n = 7 to 8 samples	rSD for Flacap internal reference; n = 8 samples	Mean rSD for Flacap field replicates; n = 9 to 12 sets	Mean rSD for lab splits, 5 species; n = 10 to 13 sets	Elements to retain for further analysis
			mg/kg[c]			- - - - - - *Percent* - - - - - -			
Soil mineral elements	Na	mg/kg	0.090	3/283	4.4	18.2	23.8	13.8	Na
	Sr	mg/kg	0.002		2.8	3.9	14.3	8.9	Sr
	Ba	mg/kg	0.009		77.1	6.4	16.8	16.3	
	Al	mg/kg	0.076		6.3	9.8	12.0	8.8	Al
	Si	mg/kg	NA		25.7	39.8	24.6	12.9	
	Cr	mg/kg	0.043		10.8	8.5	9.7	11.4	Cr
Environmental trace elements	Co	mg/kg	0.058	3/283	10.5	8.2	14.3	16.8	Co
	Cd	mg/kg	0.0095	13/283	16.7	10.9	15.3	20.7	Cd
	Pb	mg/kg	0.225	2/283	5.7	6.5	19.9	13.9	Pb
	As	mg/kg	0.237	67/283	38.1	58.3	173.7	77.8	
	Se	mg/kg	NA	161/280	189.9	99.3	49.1	172.7	

Elements: Al = aluminum As = arsenic; B = boron; Ba = barium; C = carbon; Ca = calcium; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; Mo = molybdenum; N = nitrogen; Na = sodium; Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; Se = selenium; Si = silicon; Sr = strontium; Zn = zinc.

BDL = below detection level; rSD = relative standard deviation. Elements with >5 percent of samples BDL or rSD >25 percent are shown in boldfaced type.

ICP-OES = inductively coupled plasma optical emission spectrometry.

[a] Unit was determined by measurement method.

[b] See text for sources of method minimum detection limits. NA = not available.

[c] Units in this column are milligrams per kilogram (mg/kg) unless identified as percentages. Some elements are footnoted because units are reported in percent by weight, and detection limits are reported in mg/kg. For these elements, the smallest reported value was >100 times the detection limit in mg/kg.

MDL (this avoids problems of missing data). Although not considered optimal (e.g., Helsel 1990), such a data-censoring approach is commonplace. In our case, because only 26 of more than 5,600 data records (only five for important pollution elements) were replaced by one-half the MDL, this had no material effect on the data analysis or interpretations. Similar screening and validation procedures should be performed on any data for lichen elemental concentrations.

Our measured values for the IAEA-336 lichen standard were 75 to 80 percent of the certified values for aluminum (Al), iron (Fe), potassium (K), and phosporus (P) (Heller-Zeisler et al. 1999), while measured chromium (Cr) was 150 percent of the certified value. Our values for IAEA-336 cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), sodium (Na), and zinc (Zn) did not differ significantly from the certified values (averages within 1.96 sd of the certified value). No high outlier values were found for any element from standards. The IAEA-336 lichen standard was not measured for mercury (Hg), and certified values were not reported for nitrogen (N), nickel (Ni), lead (Pb), and S (summarized from Will-Wolf et al. 2017a, Supplementary Document 3). The IAEA-336 standard was pre-ground much more finely than our mill-ground project lichen samples and certified element concentrations were measured with a different method (neutron activation analysis); these could account for some of the significant differences (pers. comm. Amacher, June 2014) between certified values and our results. These results and the more general issue of variability linked to grinding and measurement specifications for different studies should be taken into consideration when comparing our absolute element values with those from other publications, as was done in Will-Wolf et al. (2017b). Similar comparisons and caveats should be reported for future studies.

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Appendix 6: Post-Validation Evaluation of Sample Data

This appendix covers screening of entire samples, to identify and exclude from further analyses those samples that do not reliably reflect their site's elemental status. This contrasts with appendix 5 procedures to screen for data on individual elements that should be excluded because their measurement appeared to be inaccurate, often from measurement error. Most samples recommended for exclusion from further data analyses had identified sample quality problems as potential causes for the data problems (table A6.1; see "Results and Discussion/Data Evaluation" section in body of report) (Will-Wolf et al. 2017b).

1. Screening to identify entire problem samples should precede analysis of a set of validated elemental data. Any sample with ≥ four excluded high outlier values (>5 times the average of remaining values; see app. 5) even after remeasurement, especially for important elements (for instance, aluminum (Al), calcium (Ca), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), strontium (Sr), or sulfur (S) important for bioindication or further sample screening), should be excluded from further analyses.
2. Any sample with an already excluded high outlier value of any element should be examined for moderate outlier values (2 to 5 times the average for remaining values) of other elements. Any sample with ≥4 additional moderate outlier values (especially for elements important for bioindication or further sample screening) should be remeasured if possible (and not already done) and its data replaced, or averaged if remeasured elemental value >50 percent of original value. If remeasurement is not possible, the sample should be excluded from further analyses.
3. Evaluate the remaining samples for moderate outlier values (2 to 5 times the average for remaining values) and locally odd values (1.5 to 2 times higher or 25 to 50 percent lower than other samples at that or nearby sites). Criteria for values to be flagged are from Will-Wolf et al. (2017b). Sorting the sample by elemental values in a spreadsheet first by focus species, then by site latitude and longitude (or another site value that groups plots by proximity or similar environmental status such as general pollution load) facilitates such evaluation. Because this screening precedes most data analyses, the sort criteria must be general.
4. Any sample should be flagged that has ≥ 4 to 6 elemental values identified from steps 1 through 3 as any combination of excluded high outlier values, moderate outlier values, and/or locally odd values. Most of these samples should be excluded from all further data analyses. Such a sample should be retained only after very careful evaluation. Field crew notes

or laboratory observation notes may help suggest causes for the problem data, but even samples with no identified cause for the data problems should probably be excluded.

5. Samples should also have data screened for a pattern of unusually high values of Ca or Sr coupled with unusually (for the general location) low values of the pollution elements Al, Co, Cr, Cu, Fe, N, and S. This proposed signal for soil dust contamination (Will-Wolf et al. 2017a) should not trigger exclusion of a North Central region sample unless the sample also meets the criteria in item 4 above. The pattern should be evaluated further before wide application, since it may be linked to soils high in Ca (southern Wisconsin soils, for instance). It may not apply to all of the North Central region or to other Eastern U.S. FIA lichen regions.
6. Multispecies scatterplots of elemental data against a general pollution ranking for sites (as in figs. 7 through 12) is useful to identify moderate outlier and locally odd elemental values and entire samples that could weaken models for conversion between species and/or general patterns of bioindication. Clear reasons should be identified before excluding such samples from analyses

Appendix 7: Logistic Regression Models

Logistic regression model specification and data description details are in section A7.1; description and interpretation details for final logistic regression models are in sections A7.2, A7.3, and A7.4. References not listed in the body of the report are included at the end of this appendix.

A7.1: Details of Methods

Logistic regression identifies the strongest (binary, ordinal, or continuous) predictor variables to explain or predict a binary response variable (Hosmer and Lemeshow 2005). Preliminary logistic regression models were developed in SPSS® Statistics (IBM Corporation 2015) for collection (1) vs. not (0) of Flacap or Phyaip samples (site environmental data from app. 8; species sample presence from app. 9) at 83 sites; samples of either or both species were collected at all but three sites. Separate logistic regression models (also called presence/absence models) were developed for each of the two species. We also developed models for Evemes samples. Two of three sites lacking samples of either Flacap or Phyaip had Evemes samples; Evemes also had the strongest evidence of all indicator species, for sample limitation by pollution. Models were developed by three classes: Model 1—with nearby forest cover and a pollution factor; Model 2— without a pollution factor, and Model 3—with a single explanatory variable. Model 2 excluded a pollution factor because our elemental Pollution Indices were available only after project data analyses; not for project planning. Data for the other environmental variables from external sources could be available during planning in other regions. The NE, MidA, and SE regions for which we recommend elemental bioindicator species each have site Pollution Indices based on lichen community response (see “Conclusions” in main text) to help evaluate bioindicator species distribution for planning; another E region would not. Most environmental factors were relatively independent of each other (pairwise correlation $r^2 < 0.4$), with some exceptions. Latitude and all temperature variables were strongly collinear (pairwise correlation $r^2 = 0.86$-0.97), while Lichen Pollution Index N + S and Lichen Index 5 metals were moderately collinear (pairwise correlation $r^2 = 0.44$). Only one factor of each pair was entered in a model. No more than three explanatory variables were entered into a single logistic regression model, to avoid overfitting. For each species the strongest model in each class was determined based on model statistical strength and prediction success from SPSS Statistics (IBM Corporation 2015) runs along with single correlations of environmental variables with species sample presence. This step was taken to reduce to nine the number of models subjected to thorough statistical evaluation. Only five environmental factors (table 6) appeared in at least one of the nine selected strong models, to be described in the results sections.

Table 6—Explanatory variables used in logistic regression models

Variable code	Description	Value range
ForCov	Forested land cover: the percentage of pixels within a 1-km radius of the site that have been coded as forested	0.78 to 100 percent
Latitude	Latitude of the site in decimal degrees	41.2832 to 46.7717° N
Temp	Average maximum temperature	9.9 to 15.7 °C
Precip	Annual average precipitation	773 to 944 mm
PollnNS	Pollution Index N + S: site air pollution index from nitrogen and sulfur concentrations in lichen samples collected from the site. Calculations are in table 3.	0.4429 (low pollution) to 2.6389 (high pollution)

All are continuous variables; see appendix 8 for sources.

To more appropriately evaluate model strength and ascertain for each species which if any of the three selected models was optimal, further analysis was conducted in R following Freeman and Moisen (2008a, 2008b). The first step is to create a validation set for a selected species. There are several ways to do this; for a dataset with only 83 entries, it is recommended to use leave-one-out cross validation. The protocol for leave-one-out cross validation is this: (1) first remove one site from the 83-site dataset for the selected species, and build a binary logistic regression model for the remaining 82 sites using the set of explanatory variables in Model 1 for that species; (2) use the model from step 1 to make a prediction using the values of the independent variables at the excluded site from step 1; (3) repeat steps 1 and 2 for the remaining 82 sites; (4) the process returns a three-variable dataset with the 83 entries having columns "Site," "Observed," and "Model 1," where the Model 1 column contains the predicted value. Repeat steps 1 through 4 with Model 2 and then Model 3. Finally, merge the three datasets into a five-column dataset—table 7 with three rows is an example. The full table is our validation dataset for that species, its form dictated by the PresenceAbsence package (Freeman and Moisen 2008b) for R (R Core Team 2017) used to conduct the evaluation analyses described next. The process is repeated for each of the other species giving three validation datasets, one for each species.

Table 7—Example validation data set excerpt, illustrating its structure

Site	Observed	Model 1	Model 2	Model 3
27	1	0.935743025	0.934816554	0.936700747
28	1	0.736737345	0.73153677	0.735129772
29	0	0.607222814	0.58322717	0.603028932

A graph of three accuracy measures (sensitivity, specificity, and Kappa) as a function of the threshold was produced for each of the models, from the validation dataset for each species. Sensitivity is the proportion correctly predicting presence, specificity is the proportion correctly predicting absence, and Kappa is a measure of the proportion of all possible cases of presence or absence that are predicted correctly after accounting for chance effects. These measures are used for initial evaluation of relative accuracy of the three models.

The receiver operator characteristic (ROC) curves and associated area under the ROC curve (AUC, a threshold-independent measure of model quality) were calculated for each validation dataset. For presence/absence models, the AUC is considered a reliable measure of relative model strength than the more familiar Akaike information criterion (AIC). Models with AUC above 0.70 are considered useful; those above 0.90 are considered highly accurate (Manel et al. 2001, Swets 1988). Using methods based on DeLong et al. (1988) and implemented using the Splus ROC library from the Mayo Clinic (Atkinson and Mahoney 2004) incorporated as R functions (R Core Team 2017), the AUC for the three models was tested for statistical significance to indicate whether strengths of models differed. The functions provide both an overall test for equality of areas, as well as pair-wise comparisons between each model.

The next step was to determine an optimal threshold for each of the models. The threshold is used to determine the presence/absence prediction. When predicted likelihood is greater than the threshold, the site is classified as species sample predicted present = 1; when predicted likelihood is less than the threshold, the site is classified as species sample predicted absent = 0. Freeman and Moisen (2008b) presented 10 methods to determine an optimal threshold, based on the criterion selected for determination. The criterion we used was that model sensitivity (proportion correctly predicting presence) should equal specificity (proportion correctly predicting absence). The rationale for this choice was that when predicting the presence or absence of an indicator species to support choices of which species best cover a geographic area, the two types of predictions should be considered equally important.

The final step was to select the model to be used along with the threshold to predict presence or absence at future sites. The leave-one-out process created 83 potential models. Rather than picking one of the 83 leave-one-out models, it is considered best to use the model built from using all 83 sites (Fielding and Bell 1997).

A7.2: Flacap Results

Predictor variables for each of the Flacap models are provided in table 8. The three accuracy measures are graphed in figure 15 as functions of the threshold for each of the models. Kappa differs slightly between models; for model 2 Kappa stays at higher values over a greater range, but for model 3 Kappa reaches a greater maximum. Specificity and sensitivity graphs are very similar for all models, with sensitivity and specificity equal (the two curves cross) at ~0.8 for a threshold equal to 0.7. The ROC curves for the three models (fig. 16) and the associated AUC are also similar. All three models have moderate model quality (Manel et al. 2001, Swets 1988) and have equal AUC to two digits (overall test for equality of AUC Chi-square, 2 df, = 0.4777, p = 0.7875 for null hypothesis of no difference in AUC; DeLong et al. 1988); pairwise results are in table 9.

Because the models were not statistically different, we selected the most parsimonious Model 3 with the single predictor "percent nearby area in forested land cover" for interpretation. Flacap Model 3 parameter coefficients for prediction and optimal threshold (summarized in table 4) were intercept -2.1033, nearby forest cover 0.0504; the threshold optimized for "sensitivity equals specificity" was 0.7. At the optimized threshold of 0.7, sensitivity of 47 (correct predicted presence) /57 (observed presence) = 0.81, and specificity of 20 (correct predicted absence)/25 (observed absence) = 0.80.

Table 8—Predictor variables for selected Flacap models, listed left to right by decreasing strength in model

	Flacap model predictor variables		
Model 1—with pollution	ForCov ↑	PollnNS ↓	
Model 2—no pollution	ForCov ↑	Temp ↑	Precip ↓
Model 3—single factor	ForCov ↑		

Table 6 has full names of predictor variables. 70 percent of sites had Flacap samples (observed = 1).
Arrows indicate that likelihood of a Flacap sample either increased or decreased as the value of the explanatory factor increased.

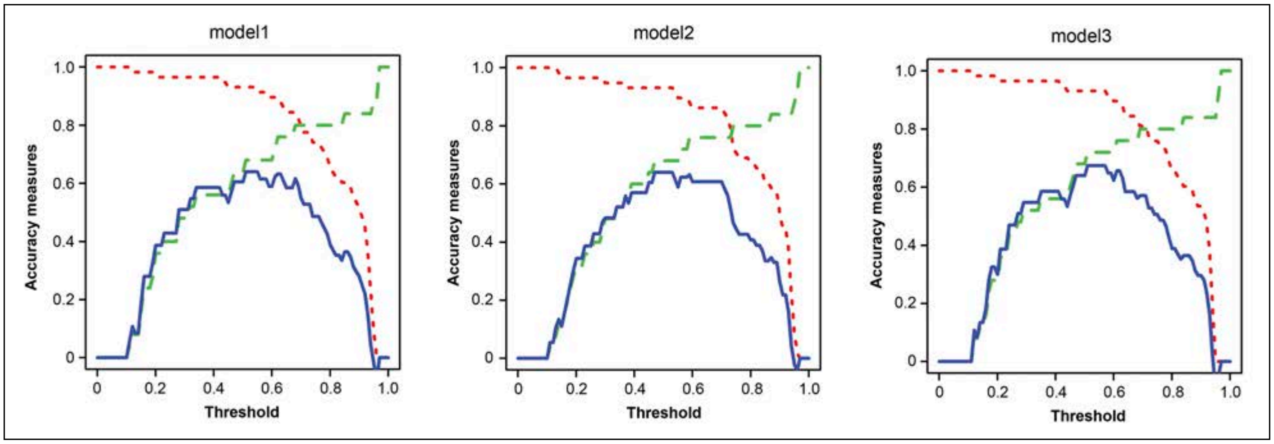

Figure 15—Accuracy measures for selected Flacap models, plotted as functions of the threshold for each model. Red dotted lines = sensitivity; green dashed lines = specificity; blue solid lines = Kappa.

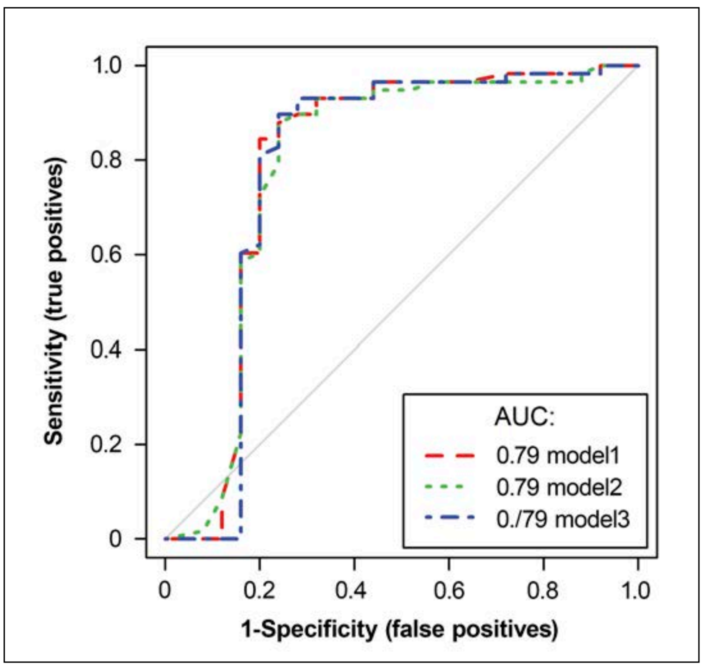

Figure 16—Receiver operator characteristic curves for selected Flacap models, and the associated area under the curve (AUC).

Table 9—Pairwise comparisons of area under curve for selected Flacap models, two-sided tests

	Area 2nd model	Area 1st model	Area difference	Probability	Lower .95	Upper .95
Model 2—model 1	0.7924	0.7917	0.0007	0.9555	-0.0240	0.0250
Model 3—model 1	0.7890	0.7917	-0.0028	0.5188	-0.0110	0.0060
Model 3—model 2	0.7890	0.7924	-0.0034	0.7717	-0.0270	0.0200

A7.3: Phyaip Results

Predictor variables for each of the models are provided in table 10. The three accuracy measures are graphed in figure 17 as functions of the threshold for each of the models. The curves of three accuracy measures are very similar; model 3 stands out slightly as Kappa stays at higher values over a greater range. The ROC curves for the three models (fig. 18) and the associated AUC are again quite similar. All three models have statistically equivalent near to high model quality (Manel et al. 2001, Swets 1988), with models 1 and 2 having equal AUC to two digits, slightly higher than model 3 (overall test for equality of AUC Chi-square, 2 df, = 0.5474, p = 0.7605 for the null hypothesis of no difference in AUC) (DeLong et al. 1988); pairwise results are in table 11. Again, models were not statistically different, so we selected the most parsimonious Model 3 with the single predictor "percent nearby area in forested land cover" for interpretation. Phyaip Model 3 parameter coefficients for prediction and optimal threshold (summarized in text table 4) are intercept 3.234, nearby forest cover -0.0558; threshold optimized for "sensitivity equals specificity" was 0.36. At the optimized threshold of 0.36, sensitivity of 25/34 = 0.74, and specificity of 36/49 = 0.73.

Table 10—Predictor variables for selected Phyaip models, listed left to right by decreasing strength in model

	Phyaip model predictor variables		
Model 1—with pollution	ForCov ↓	PollnNS ↑	Latitude ↓
Model 2—no pollution	ForCov ↓	Latitude ↓	
Model 3—single factor	ForCov ↓		

Arrows indicate that likelihood of a Phyaip sample either increased or decreased as the value of the explanatory factor increased.
Table 6 has full names of predictor variables. Forty-one percent of sites had Phyaip samples (observed = 1).

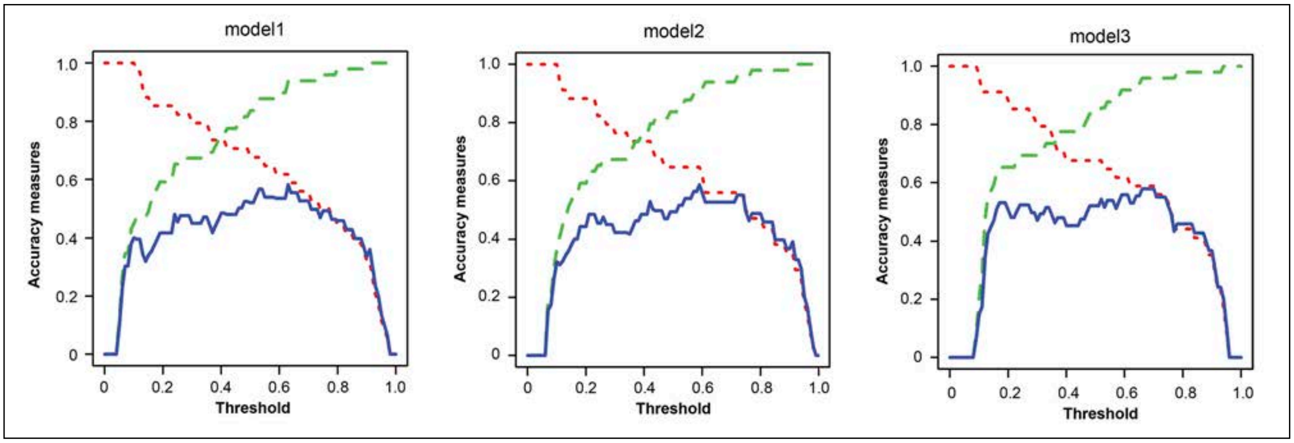

Figure 17—Accuracy measures for selected Phyaip models, plotted as functions of the threshold for each model. Red dotted lines = sensitivity; green dashed lines = specificity; blue solid lines = Kappa.

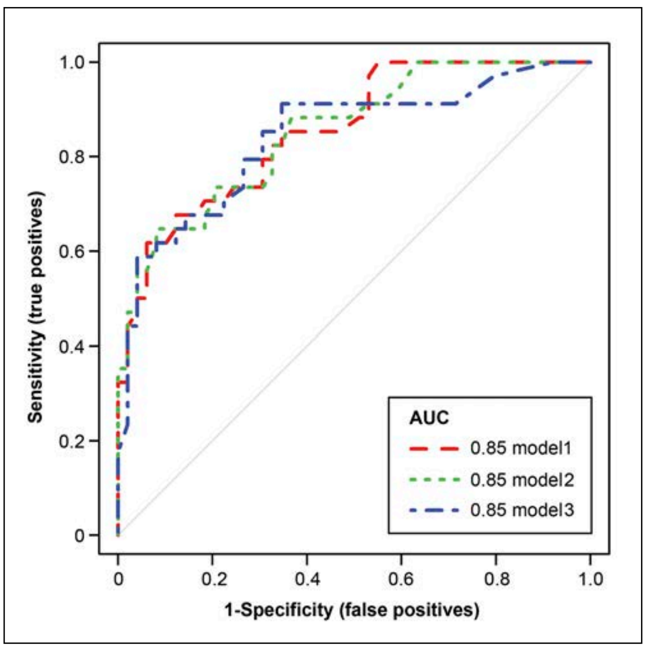

Figure 18—Receiver operator characteristic (ROC) curves for selected Phyaip models, and the associated area under the curve (AUC).

Table 11—Pairwise comparisons of area under curve for selected Phyaip models, two-sided tests

	Area 2nd model	Area 1st model	Area difference	Probability	Lower .95	Upper .95
Model 2—model 1	0.8547	0.8541	0.0006	0.9517	-0.0190	0.0200
Model 3—model 1	0.8427	0.8541	-0.0114	0.5761	-0.0510	0.0290
Model 3—model 2	0.8427	0.8547	-0.0120	0.4694	-0.0450	0.0210

A7.4: Evemes Results

Table 12 has the predictor variables for each of the Evemes models. The three accuracy measures are graphed in figure 19 as functions of the threshold for each of the models. The curves of three accuracy measures are very similar; model 3 again stands out slightly as Kappa stays at higher values over a greater range. Specificity and sensitivity graphs are quite similar, with sensitivity and specificity above 0.8 where their curves cross for all three models, but with thresholds where equality occurs varying from less than 0.4 to above 0.4, in contrast to Flacap and Phyaip models where the thresholds for equality are very similar. The ROC curves (fig. 20) for the three models and the associated AUC are again very similar. All three statistically equivalent models are near to high model quality (Manel et al. 2001, Swets 1988), with models 1 and 2 having equal AUC to two digits, slightly higher than model 3 (overall test for equality of AUC Chi-square, 2 df = 2.1607, p = 0.3395 for the null hypothesis of no difference in AUC) (DeLong et al. 1988); pairwise results in table 13. Because the models were not statistically different, we selected the most parsimonious Model 3 with the single predictor "average maximum temperature" for interpretation. Evemes model 3 parameter coefficients for prediction and optimal threshold (summarized in text table 4) are intercept 15.1745, average maximum temperature -2.9740, and the threshold, optimized for "sensitivity equals specificity," was 0.425. At the optimized threshold of 0.7, sensitivity of 16/18 = 0.89, and specificity of 56/65 = 0.86 for model 3.

Table 12—Predictor variables for selected Evemes models, listed left to right by decreasing strength in model

	Evemes model predictor variables		
Model 1—with pollution	Temp ↓	PollnNS ↓	ForCov ↑
Model 2—no pollution	Temp ↓	Precip ↓	ForCov ↑
Model 3—single factor	Temp ↓		

Arrows indicate that likelihood of an Evemes sample either increased or decreased as the value of the explanatory factor increased.
See table 6 for full names of predictor variables. 21.7 percent of sites had Evemes samples (observed = 1).

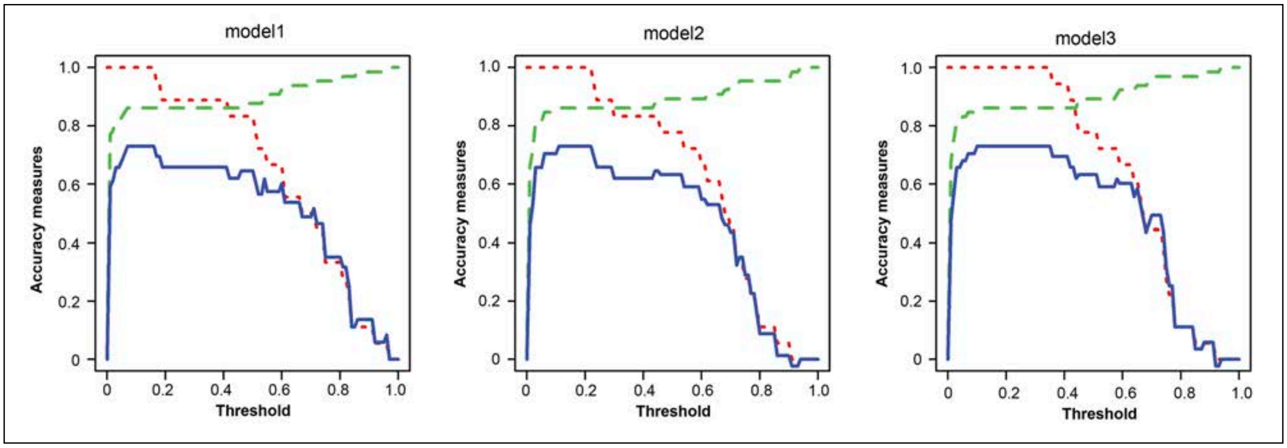

Figure 19—Accuracy measures for selected Evemes models, plotted as functions of the threshold for each model. Red dotted lines = sensitivity; green dashed lines = specificity; blue solid lines = Kappa.

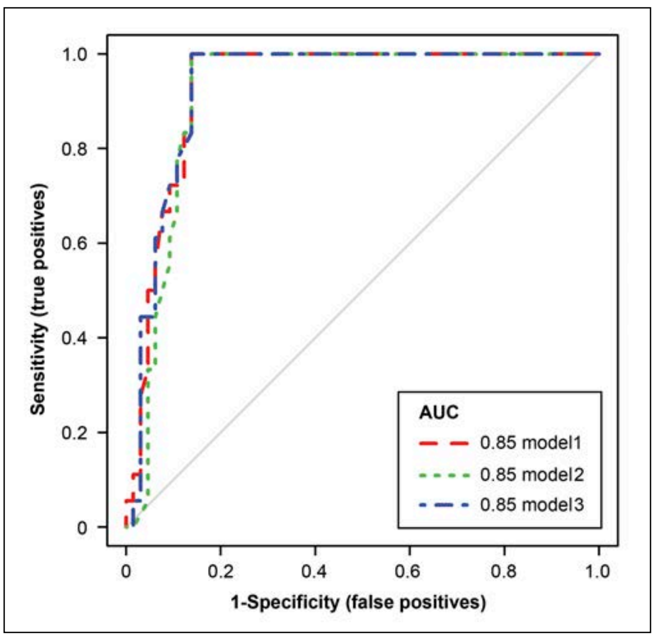

Figure 20—Receiver operator characteristic (ROC) curves for selected Evemes models, and the associated area under the curve (AUC).

Table 13—Pairwise comparisons of area under curve for selected Evemes models, two-sided tests

	Area 2nd model	Area 1st model	Area difference	Probability	Lower .95	Upper .95
Model 2—model 1	0.9188	0.9316	-0.0128	0.3398	-0.0390	0.0140
Model 3—model 1	0.9316	0.9316	0.0000	1.0000	-0.0230	0.0230
Model 3—model 2	0.9316	0.9188	0.0128	0.1460	-0.0040	0.0300

References

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Appendix 8: Lichen Sample Site Information and Environmental Data

This appendix includes information and environmental data for lichen sites in this project; site locations are from FIA databases or were measured for the project and most environmental data were extracted from public databases—see “Methods” section on page 3 and Will-Wolf et al. (2017a) for details. Table 14 includes site location and lichen data summary information; table 15 has site variables for climate; table 16 has site variables for air pollution; table 17 has site variables for nearby land cover. The lichen analysis site code orders sites by latitude north (1) to south (83). Table 14 includes special use sites; tables 15 through 17 include only sites with standard lichen elemental samples from the most rigorous field and laboratory protocols. Site climate, air pollution, and land cover values for tables 15 through 17 were extracted from publicly available geographic information system coverages; climate and pollutant deposition models are encoded in variable names.

Table 14—Lichen site location and lichen elemental data summary

Lichen site code	Location name	FIPS state code	FIPS county code	FIA PLOT_ PUBLIC	Ecoregion	FIA ELEV_ PUBLIC	FIA LAT_ PUBLIC	FIA LONG _PUBLIC	Number on map	Number of lichen species	Replicates Y N	Protocol variants Y N
						Feet	*North latitude*	*West longitude*				
1	FIA plot	55	7	20746	1	1,263	46.7717	-91.0363		2	N	N
2	FIA plot	55	7	20718	1	939	46.7383	-90.9368		2	N	N
3	FIA plot	55	7	20707	1	1,196	46.7091	-91.2810		2	Y	N
4	FIA plot	55	7	20788	1	1,321	46.6694	-91.2495		3	N	N
5	FIA plot	55	7	20344	1	1,373	46.6666	-91.2029		2	N	N
6	FIA plot	55	7	20108	1	1,225	46.6237	-91.3485		3	Y	N
7	FIA plot	55	7	29053	1	1,158	46.5983	-91.0839		3	Y	N
8	FIA plot	55	7	20711	1	1,319	46.5740	-91.1412		1	N	N
9	FIA plot	55	7	20461	1	1,187	46.5645	-91.4029		2	Y	N
10	FIA plot	55	7	20716	1	865	46.5266	-91.0050		2	N	N
11	FIA plot	55	7	20759	1	1,278	46.4372	-91.5093		2	Y	N
12	FIA plot	55	7	20038	1	1,421	46.3228	-91.3168		2	N	N
13	FIA plot	55	7	29043	1	1,525	46.3143	-91.2871		2	N	N
14	FIA plot	55	7	20424	1	1,455	46.2938	-91.2590		2	N	N
15	FIA plot	55	7	20048	1	1,409	46.2852	-91.4218		2	N	N
16	FIA plot	55	7	20440	1	1,469	46.1684	-91.1607		2	N	N
17	FIA plot	55	99	20626	1	1,550	45.8949	-90.2125		2	N	N
18	FIA plot	55	113	20610	1	1,495	45.8464	-91.4309		1	Y	N
19	FIA plot	55	99	20591	1	1,611	45.7855	-90.1921		2	Y	N
20	FIA plot	55	99	20556	1	1,732	45.7289	-90.1961		2	Y	N
21	NRS Rhinelander	55	85		1	485	45.6417	-89.4664	1	5	Y	Y
22	FIA plot	55	41	20091	1	1,536	45.6391	-88.5672		2	Y	N
23	FIA plot	55	99	20442	1	1,698	45.6297	-90.1908		2	N	N
24	Wabikon Lake	55	41		1	513	45.5671	-88.7973	2	5	Y	Y
25	FIA plot	55	69	20259	1	1,523	45.4783	-89.8477		2	N	N
26	FIA plot	55	99	20416	1	1,651	45.4693	-90.2647		2	N	N
27	Jerry Lake	55	119		1	442	45.2225	-90.5886		4	Y	Y
28	FIA plot	55	19	20380	1	1,254	45.0174	-90.7145	3	1	N	N

Table 14—Lichen site location and lichen elemental data summary (continued)

Lichen site code	Location name	FIPS state code	FIPS county code	FIA PLOT_ PUBLIC	Ecoregion	FIA ELEV_ PUBLIC	FIA LAT_ PUBLIC	FIA LONG _PUBLIC	Number on map	Number of lichen species	Replicates Y N	Protocol variants Y N
						Feet	*North latitude*	*West longitude*				
29	FIA plot	55	19	20194	1	1,294	44.8735	-90.4495		1	N	N
30	FIA plot	55	19	20592	1	1,124	44.7558	-90.7626		1	N	N
31	FIA plot	55	73	20804	1	1,276	44.7501	-89.5441		1	N	N
31.5	Mead State Wildlife Area	55	73		1	355	44.7020	-89.8623	12	1	Y	N
32	FIA plot	55	19	20021	1	1,118	44.6946	-90.8538		1	N	N
33	FIA plot	55	19	20219	1	1,108	44.6300	-90.8716		2	N	N
34	FIA plot	55	19	20212	1	1,004	44.6283	-90.7196		1	Y	N
35	FIA plot	55	97	20218	1	1,094	44.6186	-89.5407		1	N	N
36	FIA plot	55	19	20411	1	1,145	44.5923	-90.7985		2	Y	N
37	FIA plot	55	19	20408	1	1,004	44.5522	-90.5676		2	N	N
38	FIA plot	55	19	20595	2	1,040	44.5268	-90.8232		1	N	N
39	FIA plot	55	19	20052	1	1,063	44.4856	-90.4241		2	N	N
40	FIA plot	55	19	20490	2	983	44.4693	-90.7571		2	N	N
41	FIA plot	55	141	20124	1	986	44.4034	-90.2846		2	Y	N
42	FIA plot	55	53	20007	2	1,117	44.3804	-91.1509		1	N	N
43	FIA plot	55	53	20516	2	955	44.3479	-91.0683		2	Y	N
44	FIA plot	55	141	20384	1	1,007	44.3167	-90.1226		2	N	N
45	FIA plot	27	157	20311	2	698	44.2941	-92.1273		2	N	N
46	FIA plot	55	141	20263	2	982	44.2793	-90.1555		2	N	N
47	FIA plot	55	141	20407	2	978	44.2618	-90.0686		2	N	N
48	FIA plot	55	141	20303	2	966	44.2540	-90.0329		2	N	N
48.5	Gilbert Lake	55	137		2	289	44.2161	-89.1615	13	2	Y	Y
49	FIA plot	55	53	20197	2	1,028	44.2022	-91.0297		2	N	N
50	FIA plot	27	157	20036	2	1,114	44.2016	-92.4130		1	N	N
51	FIA plot	27	109	20102	2	1,141	44.1337	-92.4117		1	N	N
52	FIA plot	27	169	20304	2	1,114	44.0702	-92.0053		1	N	N
53	Perrot State Park	55	121		2	211	44.0155	-91.4755	4ab	3	Y	N
54	FIA plot	27	109	20313	2	1,200	44.0146	-92.5457		2	Y	N

Table 14—Lichen site location and lichen elemental data summary (continued)

Lichen site code	Location name	FIPS state code	FIPS county code	FIA PLOT_ PUBLIC	Ecoregion	FIA ELEV_ PUBLIC	FIA LAT_ PUBLIC	FIA LONG _PUBLIC	Number on map	Number of lichen species	Replicates Y N	Protocol variants Y N
						Feet	*North latitude*	*West longitude*				
55	FIA plot	27	109	20195	2	1,154	43.9796	-92.4744		1	N	N
56	Mayville Lions Park	55	27		2	292	43.4892	-88.5429	5	2	Y	N
57	Horicon southeast	55	27		2	2,71.5	43.4720	-88.6179	5	4	Y	N
58	Ledge County Park	55	27		2	320	43.4688	-88.5839	5	2	Y	N
59	Baxter's Hollow	55	111		2	278	43.3807	-89.8015	6	5	Y	Y
60	FIA plot	55	23	20278	2	897	43.3686	-90.7523		2	N	N
61	FIA plot	55	23	20279	2	1,121	43.3667	-90.9375		3	N	N
62	FIA plot	55	23	20014	2	1,070	43.2867	-91.0321		2	N	N
63	FIA plot	55	43	20324	2	1,009	43.1571	-90.5164		3	Y	N
64	FIA plot	55	43	20558	2	1,085	43.1429	-90.6662		2	N	N
65	Madison Sandburg Park	55	25		2	297	43.1369	-89.3068	7	2	Y	Y
66	FIA plot	55	23	20282	2	1,112	43.1317	-91.0115		4	N	N
67	FIA plot	55	23	20218	2	1,059	43.1304	-91.0789		2	N	N
68	Madison Hiestad Park	55	25		2	287	43.1042	-89.3079	7	3	Y	Y
69	FIA plot	55	43	20171	2	1,022	43.0743	-90.7227		2	N	N
70	FIA plot	55	43	20433	2	626	43.0614	-90.9311		2	Y	N
71	Milwaukee Hansen Park	55	79		2	209	43.0557	-88.0358	9	1	Y	N
72	FIA plot	55	43	20308	2	897	43.0540	-90.5230		1	N	N
73	FIA plot	55	43	20290	2	1,002	43.0475	-90.7583		2	N	N
74	Milwaukee Prospect Park	55	79		2	190	43.0439	-87.8978	8ab	2	Y	N
75	Milwaukee Kosziusko Park	55	79		2	199	43.0056	-87.9235	8ab	1	Y	N
75.5	Milwaukee Mitchell Park	55	79		2	200	43.0273	-87.9420	8ab	1	Y	N
76	FIA plot	55	43	20345	2	1,105	42.9939	-90.4424		2	N	N
77	FIA plot	19	43	20071	2	915	42.9318	-91.3863		1	N	N

Table 14—Lichen site location and lichen elemental data summary (continued)

Lichen site code	Location name	FIPS state code	FIPS county code	FIA PLOT_ PUBLIC	Ecoregion	FIA ELEV_ PUBLIC	FIA LAT_ PUBLIC	FIA LONG _PUBLIC	Number on map	Number of lichen species	Replicates Y N	Protocol variants Y N
						Feet	*North latitude*	*West longitude*				
78	FIA plot	19	43	20135	2	806	42.9270	-91.5250		2	N	N
79	FIA plot	19	43	20110	2	1,043	42.8513	-91.2036		2	N	N
80	FIA plot	19	43	20141	2	1,034	42.7675	-91.5620		2	N	N
81	FIA plot	17	11	20149	3	723	41.4466	-89.5409		1	N	N
82	FIA plot	17	161	20007	3	713	41.3702	-90.8861		1	Y	N
83	FIA plot	17	131	20027	3	785	41.2832	-90.7596		1	N	N

The lichen site code orders sites by latitude north (1) to south (83). This table includes a reference site 31.5 and sites 48.5 and 75.5 used only to evaluate variations in field and handling protocols. Number on map (fig. 1) is either the number for the site itself or the number of the instrument monitor site near that lichen site. Column titles that include FIA are official FIA database variables.

FIA = Forest Inventory and Analysis; FIPS = Federal Information Processing Standards; N = no; NRS = U.S. Forest Service Northern Research Station; Y = yes.

Table 15—Lichen site variables for climate

Lichen site code	Minimum temperature, PRISM	Maximum temperature, PRISM	Mean temperature, PRISM	Precipitation, PRISM
	- - - - - - - - - - - -	°C - - - - - - - - - - - -	-	*Millimeters*
1	-1.4	9.9	4.3	827.1
2	-0.4	10.5	5.0	815.5
3	-1.3	10.7	4.7	798.1
4	-1.2	10.9	4.8	822.8
5	-1.1	10.9	4.9	828.7
6	-1.2	10.9	4.9	802.4
7	-0.8	10.9	5.1	793.5
8	-1.0	10.9	4.9	815.9
9	-1.3	11.1	4.9	807.7
10	-0.6	11.0	5.2	773.4
11	-1.3	11.2	5.0	816.3
12	-0.9	11.3	5.2	870.4
13	-0.8	11.3	5.3	873.5
14	-1.0	11.3	5.2	873.0
15	-0.9	11.3	5.2	839.1
16	-1.4	10.8	4.7	837.4
17	-1.2	10.5	4.7	804.4
18	-1.2	11.3	5.0	897.6
19	-1.2	10.5	4.7	799.9
20	-1.5	10.3	4.4	798.7
21	-1.2	10.7	4.7	798.2
22	-1.3	10.9	4.8	776.9
23	-1.4	10.4	4.5	794.1
24	-1.0	10.5	4.7	794.7
25	-1.1	10.9	4.9	801.6
26	-1.4	10.5	4.6	784.9
27	-0.8	11.1	5.1	818.6
28	0.3	11.5	5.9	824.8
29	0.5	11.6	6.1	837.0
30	0.7	12.1	6.4	832.1
31	0.6	11.7	6.2	816.5
32	0.7	12.2	6.5	840.2
33	0.7	12.2	6.4	847.0
34	0.5	12.5	6.5	843.8
35	0.9	12.2	6.6	816.0
36	0.6	12.2	6.4	847.5
37	0.4	12.5	6.5	844.7

Table 15—Lichen site variables for climate (continued)

Lichen site code	Minimum temperature, PRISM	Maximum temperature, PRISM	Mean temperature, PRISM	Precipitation, PRISM
	- - - - - - - - - - - - °C	- - - - - - - - - - - - -		*Millimeters*
38	0.6	12.5	6.6	853.4
39	0.7	12.7	6.7	837.6
40	0.4	13.1	6.7	864.2
41	0.8	13.0	6.9	831.1
42	0.2	12.4	6.3	864.7
43	0.7	13.1	6.9	865.7
44	0.9	13.0	6.9	829.6
45	2.1	13.4	7.8	860.4
46	0.9	13.0	6.9	832.0
47	1.0	13.0	7.0	832.0
48	1.0	13.0	7.0	830.7
49	0.7	12.8	6.8	871.8
50	1.6	12.6	7.1	853.9
51	1.7	12.5	7.1	854.9
52	2.3	12.6	7.5	862.2
53	2.6	13.4	8.0	854.7
54	1.4	12.6	7.0	849.3
55	1.7	12.4	7.1	851.4
56	2.4	13.0	7.7	840.1
57	2.6	13.2	7.9	842.6
58	2.1	12.8	7.4	842.8
59	2.6	13.3	7.9	874.0
60	1.9	13.1	7.5	871.8
61	2.0	12.7	7.4	879.0
62	2.6	13.3	7.9	871.7
63	2.3	13.7	8.0	897.5
64	2.3	13.4	7.8	880.3
65	2.6	13.5	8.0	889.0
66	2.5	13.1	7.8	888.8
67	2.8	13.5	8.2	882.5
68	2.6	13.5	8.1	891.0
69	2.4	13.4	7.9	884.0
70	2.8	14.4	8.6	865.6
71	3.9	13.9	8.9	859.4
72	2.5	13.9	8.2	900.0
73	2.5	13.4	7.9	883.2
74	4.5	13.4	9.0	853.8

Table 15—Lichen site variables for climate (continued)

Lichen site code	Minimum temperature, PRISM	Maximum temperature, PRISM	Mean temperature, PRISM	Precipitation, PRISM
	- - - - - - - - - - - - °C	- - - - - - - - - - - - -		*Millimeters*
75	4.5	13.5	9.0	869.2
76	2.5	13.6	8.1	912.8
77	2.6	14.0	8.3	897.7
78	2.6	14.2	8.4	903.6
79	2.9	13.8	8.4	888.3
80	2.2	13.7	7.9	943.6
81	4.3	15.5	9.9	933.1
82	5.0	15.7	10.3	930.8
83	4.7	15.5	10.1	932.9

PRISM = parameter-elevation relationships on independent slopes model.
Source is encoded in the name of a modeled variable.

Table 16—Lichen site variables for air pollution

Lichen site code	N deposition 2013, NADP	NH_4 deposition 2013, NADP	NO_3 deposition 2013, NADP	SO_4 deposition 2013, NADP	Hg deposition 2013, NADP	S total deposition 2013, CMAQ	N total deposition 2013, CMAQ	Lichen Pollution Index, N (nitrogen) + S (sulfur)	Lichen Pollution Index, 5 metals
	Kilograms per hectare								
1	5.839419	5.032639	8.594849	6.25047	8.32483	3.558049	8.73602	0.60	0.81
2	5.889709	5.073699	8.67642	6.329259	8.54708	3.54952	8.565899	0.78	0.75
3	5.608459	4.862189	8.155659	5.87024	7.575709	3.42364	8.638179	1.42	1.63
4	5.729899	4.970789	8.320739	5.98816	7.76878	3.45718	8.837599	0.82	0.86
5	5.81743	5.04816	8.44289	6.08123	7.965089	3.49236	8.91559	0.74	0.93
6	5.6785	4.94705	8.17381	5.847599	7.57482	3.15503	8.433099	1.15	1.21
7	5.87721	5.10644	8.50749	6.1363	8.23552	3.55167	8.821869	0.94	0.96
8	5.91472	5.14798	8.53079	6.138249	8.19071	3.507689	9.02875	1.07	1.13
9	5.74455	5.02288	8.205559	5.84948	7.651629	3.28975	8.726599	1.46	1.27
10	5.8708	5.09916	8.50395	6.17114	8.414299	3.271759	8.655699	0.74	0.88
11	5.569349	4.912769	7.80622	5.51444	7.41201	3.213289	8.83469	0.90	1.36
12	5.944859	5.251239	8.307939	5.90914	8.14887	3.439929	9.5375	0.94	0.79
13	5.94047	5.24347	8.315239	5.923389	8.17284	3.439929	9.5375	0.73	1.43
14	5.91893	5.22581	8.280469	5.905749	8.186519	3.455389	9.5555	0.76	0.73
15	5.75504	5.10654	7.963329	5.63176	7.841229	3.1614	8.91096	0.80	0.92
16	5.914879	5.23528	8.22961	5.913829	8.306139	3.62086	9.80663	0.51	0.66
17	5.75052	4.97684	8.393119	6.335999	8.87851	3.663209	9.46175	0.81	1.42
18	6.216	5.62622	8.219889	5.764689	8.702449	3.304229	10.3232	0.93	1.06
19	5.696909	4.94674	8.25792	6.2761	8.68651	3.680569	9.523429	0.77	0.84
20	5.786409	5.03981	8.334119	6.36985	8.71745	3.772109	10.3296	0.83	0.93
21	5.31047	4.53863	7.946149	5.956449	8.74145	3.749119	8.21131	1.10	1.03
22	4.898029	4.11601	7.56992	5.474669	8.662759	3.775969	8.083709	0.79	0.81
23	5.966969	5.22409	8.499979	6.58161	8.77546	3.855999	11.057	0.93	1.11
24	5.905469	4.964789	9.11421	6.595349	10.227499	4.13353	9.002059	0.89	0.69
25	5.508379	4.787909	7.96497	6.15349	8.493909	3.92545	10.4391	1.11	1.53
26	6.273479	5.555109	8.719969	6.915569	8.71827	4.146299	12.8528	0.95	0.82
27	7.777309	7.0022	10.414699	8.55198	9.65968	4.4477	16.298999	1.18	1.19
28	6.690959	5.993249	9.06468	7.367919	8.855839	3.807389	13.514599	1.33	1.39

Table 16—Lichen site variables for air pollution (continued)

Lichen site code	N deposition 2013, NADP	NH_4 deposition 2013, NADP	NO_3 deposition 2013, NADP	SO_4 deposition 2013, NADP	Hg deposition 2013, NADP	S total deposition 2013, CMAQ	N total deposition 2013, CMAQ	Lichen Pollution Index, N (nitrogen) + S (sulfur)	Lichen Pollution Index, 5 metals
	Kilograms per hectare								
29	6.257999	5.55916	8.63449	7.02466	9.00883	3.83154	13.463199	1.41	1.44
30	6.13955	5.449059	8.486889	6.80452	9.063899	3.765799	13.2179	1.19	1.44
31	5.292099	4.62094	7.570119	6.506319	8.957989	4.16302	10.440699	1.23	1.42
32	6.118629	5.42529	8.47521	6.75814	9.17105	3.812	12.9757	1.76	2.53
33	6.07601	5.38146	8.43626	6.721519	9.259889	3.951339	12.3781	1.53	1.59
34	6.053229	5.352419	8.435029	6.80689	9.331689	3.799109	12.8781	1.32	2.65
35	5.08754	4.441949	7.27883	6.244959	8.7163	4.03771	10.083	1.30	2.15
36	6.07105	5.372149	8.44591	6.756599	9.35114	3.86554	12.283699	2.54	2.28
37	5.93168	5.23362	8.3036	6.74864	9.372329	3.59763	12.169099	1.05	1.74
38	6.071939	5.367179	8.466609	6.79575	9.478719	3.84591	12.232099	1.24	1.24
39	5.637949	4.962359	7.93273	6.4934	9.21809	3.804719	10.7145	1.22	1.12
40	6.22654	5.4973	8.70374	7.012179	9.91901	3.850569	11.130399	1.37	
41	5.422679	4.764589	7.657479	6.30765	9.101779	3.759949	10.1686	1.37	1.46
42	6.101379	5.40076	8.480099	6.713449	9.607029	3.79021	15.1201	1.52	1.19
43	6.188159	5.47518	8.60855	6.842889	9.837829	3.745209	12.540399	2.01	1.74
44	5.260749	4.613599	7.45795	6.165909	9.06844	4.13807	9.528949	1.52	2.26
45	6.279129	5.56899	8.69007	6.50676	9.63136	3.972739	13.808099	1.71	2.14
46	5.31682	4.665919	7.52647	6.196609	9.197349	4.125889	9.52865	1.50	1.51
47	5.21574	4.57381	7.394999	6.096879	9.104009	5.012259	9.2208	1.25	1.49
48	5.207049	4.56476	7.387599	6.095799	9.105699	5.013179	9.204239	1.35	0.96
49	6.149569	5.439499	8.55838	6.84104	10.076499	3.74791	11.6758	1.26	1.09
50	6.197239	5.49792	8.570659	6.40875	9.794289	3.647089	14.2334	1.01	1.38
51	6.50036	5.76552	8.994239	6.772299	10.3498	3.77378	14.6279	2.53	2.04
52	6.83684	6.063099	9.4624	7.37226	11.003199	4.46256	16.4747	1.84	1.74
53	6.338819	5.615719	8.79137	7.00747	10.252499	4.03376	13.003299	1.59	1.15
54	6.51688	5.78137	9.01259	6.853459	10.47	3.92492	14.7741	2.14	1.72
55	6.74139	5.982989	9.31453	7.207109	10.8421	4.243999	15.482899	1.47	1.60
56	5.65946	4.797239	8.59543	7.549729	10.6176	4.943679	16.858499	1.73	1.81

Table 16—Lichen site variables for air pollution (continued)

Lichen site code	N deposition 2013, NADP	NH_4 deposition 2013, NADP	NO_3 deposition 2013, NADP	SO_4 deposition 2013, NADP	Hg deposition 2013, NADP	S total deposition 2013, CMAQ	N total deposition 2013, CMAQ	Lichen Pollution Index, N (nitrogen) + S (sulfur)	Lichen Pollution Index, 5 metals
	Kilograms per hectare								
57	5.69628	4.832789	8.63634	7.584829	10.7263	4.963099	16.8852	1.40	0.89
58	5.6427	4.785039	8.563019	7.52463	10.616499	4.963099	16.8852	1.97	1.31
59	6.112929	5.33537	8.75341	7.362669	11.727299	4.30167	12.8746	1.50	1.08
60	6.71153	5.948709	9.294239	7.60992	11.875499	4.57526	13.3915	1.10	1.08
61	7.05351	6.258329	9.746829	8.000189	11.946399	4.88766	14.1336	1.15	0.93
62	7.525809	6.689459	10.359399	8.541899	12.3661	5.341219	14.867199	0.97	1.01
63	6.73681	5.94525	9.42103	7.871109	11.7206	4.818439	14.6856	1.68	1.18
64	7.03694	6.223309	9.79561	8.17677	11.9252	4.886079	14.884699	1.44	0.98
65	6.47373	5.523829	9.706669	8.595129	12.466899	5.13661	15.666	1.63	1.04
66	7.928569	7.0559	10.886099	9.073419	12.1982	5.4025	15.4687	1.15	2.50
67	8.07096	7.198979	11.0253	9.144269	12.4027	5.4677	15.766099	1.49	1.83
68	6.427629	5.475319	9.669239	8.573599	12.3877	5.13661	15.666	1.70	1.63
69	7.22278	6.394939	10.029899	8.391579	11.8892	5.09307	16.317699	1.94	1.44
70	7.90392	7.03235	10.857999	9.06674	12.1426	5.429329	16.3448	1.45	1.35
71	5.94222	4.953629	9.310779	8.479319	11.348099	7.5798	16.014799	2.06	2.33
72	6.888559	6.076049	9.645039	8.108169	11.7781	4.97945	16.520799	1.14	1.27
73	7.311079	6.47796	10.136199	8.491279	11.8315	5.169439	16.523599	1.59	1.04
74	5.72558	4.773469	8.970239	8.21362	10.859999	5.875619	7.8318295	2.64	2.37
75	5.871339	4.890389	9.214209	8.437919	11.186699	5.914279	7.90743	2.24	2.23
76	6.820879	6.00399	9.593379	8.11268	11.7129	4.897049	15.9961	1.43	1.01
77	8.681929	7.793059	11.6913	9.73503	12.416099	5.200439	18.1322	2.50	1.55
78	8.7486	7.853089	11.7805	9.809009	12.544799	5.0903	17.921899	2.14	1.12
79	8.21306	7.35339	11.124799	9.294819	12.049599	5.21597	16.856	1.70	1.09
80	8.840149	7.92418	11.942099	9.957839	12.947899	5.322519	19.4328	1.73	1.44
81	5.70332	4.84766	8.62273	8.77873	10.71	5.424149	12.478099	2.10	1.63
82	5.100769	4.39236	7.514969	7.5061	10.279399	5.61517	11.3736	1.12	0.74
83	5.10332	4.39715	7.510479	7.560919	10.3688	5.49454	11.421799	0.44	0.63

Source is encoded in the name of a modeled variable. Hg = mercury; N = nitrogen; NH^4 = ammonium; NO^3 = nitrate; S = sulfur; SO^4 = sulfate. NADP = Atmospheric Deposition Program; CMAQ = Community Multiscale Air Quality.

Table 17—Lichen site variables for nearby land cover, extracted from public state coverages (continued)

Lichen site code	Forested land cover percentage, 100 m buffer	Forested land cover percentage, 500 m buffer	Forested land cover percentage, 1000 m buffer	Open semi-natural land cover percentage, 100 m buffer	Open semi-natural land cover percentage, 500 m buffer	Open semi-natural land cover percentage, 1000 m buffer	Agricultural land cover percentage, 100 m buffer	Agricultural land cover percentage, 500 m buffer	Agricultural land cover percentage, 1000 m buffer	Developed land cover percentage, 100 m buffer	Developed land cover percentage, 500 m buffer	Developed land cover percentage, 1000 m buffer
1	100.0	93.3	94.8	0	0	0	0	0	0	0	6.4	3.5
2	100.0	100.0	100.0	0	0	0	0	0	0	0	0	0
3	100.0	89.9	90.4	0	0	0	0	0	0	0	6.7	6.8
4	100.0	100.0	100.0	0	0	0	0	0	0	0	0	0
5	100.0	100.0	98.3	0	0	0	0	0	0	0	0	0.6
6	100.0	96.6	95.0	0	0	0	0	0	0	0	3.3	4.1
7	100.0	98.5	94.6	0	0	0	0	0	0.9	0	0.9	2.9
8	100.0	99.4	98.8	0	0	0	0	0	0	0	0	0
9	94.3	48.5	53.8	0	0	0	0	0.5	1.1	0	2.9	22.1
10	100.0	79.9	56.7	0	0	0	0	14.5	35.2	0	1.0	3.1
11	100.0	96.0	94.6	0	0	0	0	0	0	0	3.6	4.2
12	100.0	98.2	97.7	0	0	0	0	0	0	0	1.8	2.3
13	100.0	99.0	94.1	0	0	0	0	0.2	0.9	0	0.8	3.8
14	100.0	100.0	99.9	0	0	0	0	0	0	0	0	0
15	100.0	100.0	98.0	0	0	0	0	0	0	0	0	0
16	100.0	92.5	95.6	0	0	0	0	0	0	0	0	0
17	100.0	100.0	95.7	0	0	0	0	0	0	0	0	3.0
18	100.0	96.1	91.7	0	0	0	0	0	0	0	2.7	6.0
19	100.0	100.0	99.4	0	0	0	0	0	0	0	0	0.6
20	100.0	100.0	100.0	0	0	0	0	0	0	0	0	0
21	95.7	76.9	74.1	0	0	0	0	0	0	4.3	10.6	7.7
22	100.0	97.2	98.2	0	0	0	0	0	0	0	2.8	1.4
23	100.0	98.1	93.2	0	0	0	0	0.3	3.9	0	1.6	1.6
24	100.0	86.9	81.0	0	0	0	0	0	0	0	13.1	12.1
25	100.0	97.0	97.0	0	0	0	0	0	0	0	3.0	3.0
26	100.0	99.5	96.1	0	0	0	0	0.4	2.1	0	0	0.1
27	33.3	88.2	95.6	0	0	0	0	0	0	0	3.2	1.8
28	100.0	88.4	62.5	0	0.1	0.6	0	7.9	35.1	0	3.6	1.8

Table 17—Lichen site variables for nearby land cover, extracted from public state coverages (continued)

Lichen site code	Forested land cover percentage, 100 m buffer	Forested land cover percentage, 500 m buffer	Forested land cover percentage, 1000 m buffer	Open semi-natural land cover percentage, 100 m buffer	Open semi-natural land cover percentage, 500 m buffer	Open semi-natural land cover percentage, 1000 m buffer	Agricultural land cover percentage, 100 m buffer	Agricultural land cover percentage, 500 m buffer	Agricultural land cover percentage, 1000 m buffer	Developed land cover percentage, 100 m buffer	Developed land cover percentage, 500 m buffer	Developed land cover percentage, 1000 m buffer
29	83.3	61.6	48.9	0	0	0	16.7	38.4	50.7	0	0	0.4
30	100.0	66.9	72.2	0	1.0	0.4	0	29.0	23.8	0	3.2	3.5
31	100.0	99.9	88.8	0	0.1	0.1	0	0	8.9	0	0	2.1
32	100.0	97.4	97.3	0	0.5	2.1	0	2.1	0.5	0	0	0
33	100.0	99.9	99.8	0	0.1	0.2	0	0	0.0	0	0	0
34	79.4	96.7	94.4	0	0	0.5	0	0	2.5	20.6	3.3	2.6
35	78.1	85.8	68.8	21.9	5.3	3.3	0	6.1	23.4	0	2.8	3.7
36	100.0	94.2	92.8	0	0.2	0.1	0	0	0.4	0	5.7	6.7
37	100.0	76.4	48.4	0	0.2	0.1	0	18.8	40.5	0	4.7	10.8
38	100.0	93.7	93.3	0	0	0.5	0	0	0.4	0	6.3	5.7
39	100.0	93.9	93.8	0	5.3	1.5	0	0	2.1	0	0	2.0
40	97.1	96.5	95.6	2.9	1.1	0.4	0	0	0	0	2.5	4.0
41	100.0	98.5	93.7	0	1.5	4.6	0	0	0	0	0	1.7
42	93.9	76.6	68.6	6.1	5.8	11.1	0	17.0	17.5	0	0.6	2.8
43	89.2	43.1	27.9	0	3.4	2.0	10.8	48.2	64.5	0	5.4	5.5
44	100.0	95.3	88.3	0	1.7	4.7	0	0	0	0	2.9	5.9
45	74.3	59.5	68.0	0	0	0.1	2.9	33.2	25.1	0	0.8	2.6
46	87.9	90.0	87.8	12.1	10.0	9.0	0	0	0	0	0	3.2
47	88.2	92.8	79.6	11.8	4.8	6.8	0	1.3	10.9	0	1.1	2.7
48	71.4	90.4	93.2	28.6	6.3	3.4	0	0	0.6	0	3.3	2.8
49	100.0	64.9	66.6	0	0.6	0.4	0	29.4	29.7	0	5.1	3.3
50	0.0	15.2	20.6	0	0	0	100.0	84.8	76.4	0	0	3.0
51	31.4	11.2	7.8	0	0	0	68.6	69.1	81.5	0	19.5	10.4
52	45.7	41.5	61.0	0	0	0.4	51.4	54.2	32.3	0	3.9	3.3
53	58.0	53.6	52.5	0	1.7	1.9	0	1.7	5.6	17.0	6.7	4.5
54	28.1	19.0	13.8	0	0	0	71.9	75.7	63.0	0	4.9	22.8
55	100.0	60.2	37.3	0	0	0	0	7.9	22.6	0	29.1	37.2
56	1.0	2.2	8.6	0	1.0	3.5	0	8.2	23.1	82.9	76.9	60.4

Table 17—Lichen site variables for nearby land cover, extracted from public state coverages (continued)

Lichen site code	Forested land cover percentage, 100 m buffer	Forested land cover percentage, 500 m buffer	Forested land cover percentage, 1000 m buffer	Open semi-natural land cover percentage, 100 m buffer	Open semi-natural land cover percentage, 500 m buffer	Open semi-natural land cover percentage, 1000 m buffer	Agricultural land cover percentage, 100 m buffer	Agricultural land cover percentage, 500 m buffer	Agricultural land cover percentage, 1000 m buffer	Developed land cover percentage, 100 m buffer	Developed land cover percentage, 500 m buffer	Developed land cover percentage, 1000 m buffer
57	40.0	11.6	9.5	22.9	63.4	70.9	17.1	9.0	7.4	20.0	9.4	6.6
58	57.0	40.3	22.3	7.4	6.6	4.8	12.9	41.2	65.2	22.8	11.8	7.8
59	88.6	90.8	81.8	4.3	3.1	2.3	0	2.5	13.6	7.1	3.6	2.4
60	97.1	66.7	68.1	2.9	1.6	1.1	0	14.9	21.2	0	16.8	9.6
61	32.4	46.4	38.1	0	0.3	0.4	67.6	48.7	58.1	0	3.2	3.1
62	20.6	49.9	57.8	0	0.1	0.3	79.4	45.2	36.2	0	4.8	5.6
63	100.0	81.3	64.6	0	2.1	2.0	0	16.6	32.7	0	0	0.7
64	100.0	80.9	81.0	0	1.1	0.8	0	18.0	16.7	0	0	1.5
65	97.1	17.3	6.7	2.9	4.3	3.2	0	5.7	16.9	0	72.6	73.2
66	50.0	31.9	17.9	5.6	0.6	0.5	44.4	67.5	77.0	0	0	4.6
67	100.0	94.3	71.4	0	0.1	0.6	0	5.6	26.6	0	0	1.4
68	67.6	12.4	4.3	24.3	10.0	4.1	0	9.9	11.2	8.1	67.6	80.4
69	36.1	55.6	49.8	0	2.0	1.7	63.9	35.3	43.4	0	7.2	5.0
70	91.2	71.0	72.9	0	0	0.7	0	0	0.3	0	0	0.8
71	40.0	30.2	17.5	5.7	12.2	5.5	31.4	11.8	12.9	22.9	45.8	64.1
72	66.7	38.0	53.0	0	4.0	3.4	33.3	48.2	36.3	0	9.9	7.3
73	79.4	54.9	60.7	0	0.4	1.4	20.6	38.2	33.0	0	6.6	4.8
74	15.2	3.1	0.8	3.0	0.6	0.2	0	0	0	81.8	85.6	78.2
75	1.0	1.0	1.0	0	0	0	0	0	0	99.0	99.0	99.0
76	21.6	43.0	36.4	8.1	5.3	2.5	70.3	44.9	57.0	0	6.7	4.1
77	16.7	8.1	14.2	0	0	0	72.2	71.5	75.1	11.1	18.8	8.6
78	58.3	53.0	37.9	0	0	0.2	5.6	31.0	46.4	16.7	8.8	5.9
79	100.0	80.5	55.5	0	0.3	0.1	0.0	18.7	41.8	0	0	1.8
80	50.0	49.6	41.2	0	0	0	50.0	44.4	51.1	0	0	3.3
81	52.9	12.5	7.8	0	0	0	47.1	83.7	87.9	0	2.9	4.1
82	61.8	31.0	17.7	0	0	0.1	35.3	61.0	76.4	0	7.0	5.1
83	29.7	36.4	36.2	0	0.6	0.5	70.3	57.7	58.5	0	3.3	3.3

See Will-Wolf et al. (2017a) for sources.

Appendix 9: Original Data for Validated Elements in Lichen Samples Handled With Full Rigorous Protocols

See body of report for details of field collection and sample handling protocols. See appendix 8 for information about each lichen plot. Table 18 has sample information; tables 19A, B, and C have elemental data for samples of target species.

These notes refer to all tables:

- The lichen analysis site code orders sites by latitude north (1) to south (83).
- Sample laboratory codes are the project internal codes for each sample measured for elemental content.
- Sample laboratory codes with a or b following, designate lab splits of a single sample after grinding and before measurement. Sample data for analysis were the average of the two splits.
- Samples with codes and data in italics were excluded from data analysis because of poor data quality (see text).

These notes refer to table 18:

- Lichen species abbreviations:
- Evemes = *Evernia mesomorpha*;
- Flacap = *Flavoparmelia caperata*;
- Parsul = *Parmelia sulcata*;
- Phyaip = *Physcia aipolia* and *P. stellaris* combined;
- Punrud = *Punctelia rudecta*
- Abbreviations: sm = sample < 1 mg after preparation; subs = substrates
- Number on map, figure 1, is either the number for the site itself or the number of the instrument monitor site near that lichen site.

These notes refer to tables 19A, B, and C:

- Data for validated elements aluminum (Al), carbon (C), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), magnesium (Mg), manganese (Mn), nitrogen (N), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), strontium (Sr), and zinc (Zn) are listed in alphabetical order of their official codes.
- Element acronyms preceded by "Total" were measured by combustion analysis; all other elements were measured by ICP-OES. Sulfur (S) was measured by both methods.
- Cells with "high" had extremely high outliers that were excluded before validation.
- Cells with "bdl" had values below detection level.
- Blank cells indicate that element was not measured for that sample.

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
1	WW3076	FIA plot		Evemes	1	1.53		1	Full
1	WW3075	FIA plot		Parsul	1	1.49		1	Full
2	WW3073	FIA plot		Flacap	1	1.87		1	Full
2	WW3074	FIA plot		Flacap	2	2.18		1	Full
3	WW3030a	FIA plot		Evemes	1	2.0		1	Full
3	WW3030b	FIA plot		Evemes	2	2.0		1	Full
3	WW3029	FIA plot		Flacap	1	3.58		1	Full
4	WW3110	FIA plot		Evemes	1	1.63		1	Full
4	WW3111	FIA plot		Flacap	1	3.58		1	Full
4	WW3112	FIA plot		Parsul	1	2.97		1	Full
5	WW3023	FIA plot		Evemes	1	1.95		1	Full
5	WW3024	FIA plot		Parsul	1	2.02		1	Full
6	WW3142	FIA plot		Evemes	1	2.93		1	Full
6	WW3140	FIA plot		Flacap	1	4.09		1	Full
6	WW3141a	FIA plot		Parsul	1	1.5		1	Full
6	WW3141b	FIA plot		Parsul	1	1.5		1	Full
7	WW3014	FIA plot		Evemes	1	2.22		1	Full
7	WW3015	FIA plot		Evemes	2	2.17		1	Full
7	WW3012	FIA plot		Flacap	1	1.64		1	Full
7	WW3013	FIA plot		Flacap	2	1.79		1	Full
7	WW3016	FIA plot		Parsul	1	0.59		1	Full
7	WW3017	FIA plot		Parsul	2	1.15		1	Full
8	WW3022	FIA plot		Parsul	1	2.11		1	Full
9	WW3025	FIA plot		Flacap	1	2.19		1	Full
9	WW3026	FIA plot		Flacap	2	2.15		1	Full
9	WW3027	FIA plot		Parsul	1	1.68		1	Full
9	WW3028	FIA plot		Parsul	2	1.66		1	Full
10	WW3019	FIA plot		Evemes	1	2.03	2 subs	1	Full
10	WW3018	FIA plot		Flacap	1	1.69		1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
11	WW3106	FIA plot		Evemes	1	1.41		1	Full
11	WW3107	FIA plot		Evemes	2	1.52		1	Full
11	WW3108	FIA plot		Flacap	1	2.19		1	Full
11	WW3109	FIA plot		Flacap	2	1.61		1	Full
12	WW3020	FIA plot		Flacap	1	2.0		1	Full
12	WW3021	FIA plot		Parsul	1	1.4		1	Full
13	WW3102	FIA plot		Evemes	1	1.92		1	Full
13	WW3103	FIA plot		Flacap	1	3.35		1	Full
14	WW3079	FIA plot		Evemes	1	2.18		1	Full
14	WW3078	FIA plot		Flacap	1	1.93		1	Full
15	WW3104	FIA plot		Flacap	1	2.59		1	Full
15	WW3105	FIA plot		Parsul	1	2.09		1	Full
16	WW3144	FIA plot		Evemes	1	2.66		1	Full
16	WW3143	FIA plot		Flacap	1	3.81		1	Full
17	WW3126	FIA plot		Evemes	1	3.63		1	Full
17	WW3125	FIA plot		Flacap	1	2.46		1	Full
18	WW3071	FIA plot		Flacap	1	2.17		1	Full
18	WW3072	FIA plot		Flacap	2	2.09		1	Full
19	WW3128a	FIA plot		Evemes	1	1.6		1	Full
19	WW3128b	FIA plot		Evemes	1	1.6		1	Full
19	WW3127	FIA plot		Flacap	1	3.74		1	Full
20	WW3058	FIA plot		Flacap	1	1.63		1	Full
20	WW3059a	FIA plot		Parsul	1	0.8		1	Full
20	WW3059b	FIA plot		Parsul	1	0.8		1	Full
21	WW143	NRS Rhinelander	1	Evemes	1	3.34		1	Full
21	WW148	NRS Rhinelander	1	Evemes	1	1.52		1	Full
21	WW149	NRS Rhinelander	1	Evemes	1	3.27		1	Full
21	WW144	NRS Rhinelander	1	Flacap	1	7.72		1	Full
21	WW145	NRS Rhinelander	1	Flacap	1	3.52		1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
21	WW150	NRS Rhinelander	1	Flacap	1	3.87		1	Full
21	WW151	NRS Rhinelander	1	Flacap	1	6.18		1	Full
21	WW152	NRS Rhinelander	1	Flacap	1	5.51		1	Full
21	WW153	NRS Rhinelander	1	Flacap	1	3.55		1	Full
21	WW154	NRS Rhinelander	1	Flacap	1	6.52		1	Full
21	WW146	NRS Rhinelander	1	Parsul	1	1.98		1	Full
21	WW155	NRS Rhinelander	1	Parsul	1	1.17	<6 subs	1	Full
21	WW208	NRS Rhinelander	1	Phyaip	1	1.42		1	Full
21	WW209	NRS Rhinelander	1	Phyaip	1	1.23	<6 subs	1	Full
21	WW163	NRS Rhinelander	1	Punrud	1	2.54		1	Full
22	WW3124	FIA plot		Evemes	1	2.08		1	Full
22	WW3123a	FIA plot		Flacap	1	1.9		1	Full
22	WW3123b	FIA plot		Flacap	1	1.9		1	Full
23	WW3057	FIA plot		Evemes	1	2.25		1	Full
23	WW3056	FIA plot		Flacap	1	1.8		1	Full
24	WW215	Wabikon Lake	2	Evemes	1	0.83		1	Full
24	WW216	Wabikon Lake	2	Evemes	2	0.8		1	Full
24	WW211	Wabikon Lake	2	Flacap	1	1.87		1	Full
24	WW212	Wabikon Lake	2	Flacap	2	2.5		1	Full
24	WW217	Wabikon Lake	3	Parsul	1	1.55		1	Full
24	WW218	Wabikon Lake	3	Parsul	2	1.74		1	Full
24	WW219	Wabikon Lake	2	Phyaip	1	2.08		1	Full
24	WW220	Wabikon Lake	2	Phyaip	2	1.22		1	Full
24	WW213	Wabikon Lake	2	Punrud	1	3.67		1	Full
24	WW214	Wabikon Lake	2	Punrud	2	3.76		1	Full
25	WW3003	FIA plot		Flacap	1	1.37		1	Full
25	WW3004	FIA plot		Parsul	1	2.13	(Soil particles)	1	Full
26	WW3032	FIA plot		Flacap	1	2.23		1	Full
26	WW3033	FIA plot		Parsul	1	1.11	<6 subs	1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
27	WW123	Jerry Lake	3	Evemes	1	4.1		1	Full
27	WW124	Jerry Lake	3	Evemes	2	3.46		1	Full
27	WW126	Jerry Lake	3	Flacap	1	6.43		1	Full
27	WW127	Jerry Lake	3	Flacap	2	5.05		1	Full
27	WW128	Jerry Lake	3	Flacap	3	4.0		1	Full
27	WW136	Jerry Lake	3	Parsul	1	2.83		1	Full
27	WW137	Jerry Lake	3	Parsul	2	1.75		1	Full
28	WW3036	FIA plot		Flacap	1	2.16		1	Full
29	WW3038	FIA plot		Phyaip	1	1.0		1	Full
30	WW3037	FIA plot		Phyaip	1	0.79	Small, <6 subs	1	Full
31	WW3134	FIA plot		Flacap	1	2.31		1	Full
32	WW3093	FIA plot		Flacap	1	2.37	Damp	1	Full
33	WW3095	FIA plot		Flacap	1	2.66	Damp	1	Full
33	WW3096	FIA plot		Parsul	1	0.22	Damp, small, <6 subs	1	Full
34	WW3101a	FIA plot		Phyaip	1	0.6		1	Full
34	WW3101b	FIA plot		Phyaip	1	0.6		1	Full
35	WW3135	FIA plot		Flacap	1	1.62		1	Full
36	WW3100	FIA plot		Flacap	1	1.28		1	Full
36	WW3099a	FIA plot		Phyaip	1	0.85	Dusty	1	Full
36	WW3099b	FIA plot		Phyaip	1	0.85	Dusty	1	Full
37	WW3089	FIA plot		Flacap	1	1.46		1	Full
37	WW3090	FIA plot		Punrud	1	1.26		1	Full
38	WW3094	FIA plot		Flacap	1	2.46	Damp	1	Full
39	WW3039	FIA plot		Flacap	1	2.51		1	Full
39	WW3040	FIA plot		Phyaip	1	1.16		1	Full
40	WW3097	FIA plot		Flacap	1	1.99		1	Full
40	WW3098	FIA plot		Parsul	1	0.83	Sandy	1	Full
41	WW3091a	FIA plot		Flacap	1	1.35		1	Full
41	WW3091b	FIA plot		Flacap	1	1.35		1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
41	WW3092	FIA plot		Phyaip	1	0.98		1	Full
42	WW3133	FIA plot		Flacap	1	2.21		1	Full
43	WW3130	FIA plot		Phyaip	1	1.19		1	Full
43	WW3129a	FIA plot		Punrud	1	0.85		1	Full
43	WW3129b	FIA plot		Punrud	1	0.85		1	Full
44	WW3034	FIA plot		Flacap	1	1.47		1	Full
44	WW3035	FIA plot		Punrud	1	1.7	(Unidentified)	1	Full
45	WW3113	FIA plot		Flacap	1	0.29	Damp, small, 3 subs	1	Full
45	WW3114	FIA plot		Phyaip	1	1.03	damp	1	Full
46	WW3136	FIA plot		Flacap	1	1.97		1	Full
46	WW3137	FIA plot		Punrud	1	1.46		1	Full
47	WW3138	FIA plot		Flacap	1	1.72		1	Full
47	WW3139	FIA plot		Parsul	1	1.4		1	Full
48	WW3001	FIA plot		Flacap	1	1.8		1	Full
48	WW3002	FIA plot		Parsul	1	1.21		1	Full
49	WW3131	FIA plot		Flacap	1	1.61		1	Full
49	WW3132	FIA plot		Phyaip	1	0.85		1	Full
50	WW3115	FIA plot		Phyaip	1	1.19	Damp	1	Full
51	WW3116	FIA plot		Phyaip	1	0.57	Small, less clean	1	Full
52	WW3118	FIA plot		Flacap	1	2.48	Damp	1	Full
53	WW225	Perrot State Park	4ab	Flacap	1	1.2		1	Full
53	WW226	Perrot State Park	4ab	Flacap	2	1.03		1	Full
53	WW229	Perrot State Park	4ab	Phyaip	1	1.47		1	Full
53	WW230	Perrot State Park	4ab	Phyaip	2	1.68		1	Full
53	WW227	Perrot State Park	4ab	Punrud	1	1.89		1	Full
53	WW228	Perrot State Park	4ab	Punrud	2	1.15		1	Full
54	WW3085	FIA plot		Phyaip	1	0.99		1	Full
54	WW3086	FIA plot		Phyaip	2	0.52	Small, <6 subs	1	Full
54	WW3087	FIA plot		Punrud	1	0.24	Small, <6 subs	1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
55	WW3117	FIA plot		Phyaip	1	0.41	Damp, small, <6 subs	1	Full
56	WW116	Mayville Lions Park	5	Flacap	1	0.22	Small, <6 subs	1	Full
56	WW204	Mayville Lions Park	5	Phyaip	1	6.53		1	Full
57	WW114	Horicon southeast	5	Flacap	1	0.18	Small, <6 subs	1	Full
57	WW115	Horicon southeast	5	Parsul	1	1.45	<6 subs	1	Full
57	WW201	Horicon southeast	5	Phyaip	1	2.4		1	Full
57	WW202	Horicon southeast	5	Phyaip	2	2.17		1	Full
57	WW203	Horicon southeast	5	Phyaip	3	2.87		1	Full
58	WW206	Ledge County Park	5	Phyaip	1	1.61		1	Full
58	WW207	Ledge County Park	5	Phyaip	2	1.53		1	Full
58	WW117	Ledge County Park	5	Punrud	1	5.53		1	Full
58	WW118	Ledge County Park	5	Punrud	2	3.84		1	Full
59	WW238	Baxter's Hollow	6	Flacap	1	1.49		1	Full
59	WW239	Baxter's Hollow	6	Flacap	2	1.37		1	Full
59	WW240	Baxter's Hollow	6	Flacap	3	1.36		1	Full
59	WW253	Baxter's Hollow	6	Parsul	1	0.5		1	Full
59	WW251	Baxter's Hollow	6	Phyaip	1	1.36		1	Full
59	WW252	Baxter's Hollow	6	Phyaip	2	1.75		1	Full
59	WW248	Baxter's Hollow	6	Punrud	1	1.9		1	Full
59	WW249	Baxter's Hollow	6	Punrud	2	1.86		1	Full
59	WW250	Baxter's Hollow	6	Punrud	3	2.08		1	Full
60	WW3069	FIA plot		Flacap	1	1.09		1	Full
60	WW3070	FIA plot		Phyaip	1	0.35	Small, <6 subs	1	Full
61	WW3080	FIA plot		Flacap	1	0.92		1	Full
61	WW3081	FIA plot		Punrud	1	1.05		1	Full
62	WW3083	FIA plot		Flacap	1	0.49	Small, <6 subs	1	Full
62	WW3084	FIA plot		Phyaip	1	0.13	Small, <6 subs	1	Full
63	WW3046	FIA plot		Flacap	1	1.26		1	Full
63	WW3047	FIA plot		Flacap	2	1.57		1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
63	WW3050	FIA plot		Phyaip	1	0.96		1	Full
63	WW3048	FIA plot		Punrud	1	1.71		1	Full
63	WW3049	FIA plot		Punrud	2	1.87		1	Full
64	WW3061	FIA plot		Flacap	1	1.07		1	Full
64	WW3062	FIA plot		Punrud	1	0.92		1	Full
65	WW269	Madison Sandburg Park	7	Phyaip	1	1.4		1	Full
65	WW270	Madison Sandburg Park	7	Phyaip	2	1.42		1	Full
65	WW273	Madison Sandburg Park	7	Punrud	1	1.26		1	Full
65	WW274	Madison Sandburg Park	7	Punrud	2	1.07		1	Full
66	WW3063	FIA plot		Flacap	1	1.23		1	Full
66	WW3064	FIA plot		Punrud	1	0.33	Small, <6 subs	1	Full
67	WW3067	FIA plot		Flacap	1	2.12		1	Full
67	WW3068	FIA plot		Punrud	1	1.28	(Soil particles)	1	Full
68	WW268	Madison Hiestad Park	7	Parsul	1	0.1	Small, 1 subs	1	Full
68	WW264	Madison Hiestad Park	7	Phyaip	1	2.28		1	Full
68	WW265	Madison Hiestad Park	7	Phyaip	2	1.24		1	Full
68	WW267	Madison Hiestad Park	7	Punrud	1	0.31	Small, 1 subs	1	Full
69	WW3051	FIA plot		Flacap	1	1.45		1	Full
69	WW3052	FIA plot		Punrud	1	1.53	(Unidentified)	1	Full
70	WW3053	FIA plot		Flacap	1	1.78		1	Full
70	WW3054	FIA plot		Flacap	2	1.67		1	Full
70	WW3055a	FIA plot		Punrud	1	0.9		1	Full
70	WW3055b	FIA plot		Punrud	1	0.9		1	Full
71	WW262	Milwaukee Hansen Park	9	Phyaip	1	2.31		1	Full
71	WW263	Milwaukee Hansen Park	9	Phyaip	2	2.02		1	Full
72	WW3045	FIA plot		Flacap	1	0.96		1	Full
73	WW3041	FIA plot		Flacap	1	1.28		1	Full
73	WW3042	FIA plot		Punrud	1	0.78	Small, 3 subs	1	Full
74	WW260a	Milwaukee Prospect Park	8ab	Parsul	1	0.9		1	Full

Table 18—Information for lichen samples handled with fully rigorous protocols (field collection code = 1) (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory sample preparation code
						Grams			
74	WW260b	Milwaukee Prospect Park	8ab	Parsul	1	0.9		1	Full
74	WW261	Milwaukee Prospect Park	8ab	Phyaip	1	0.53		1	Full
75	WW256	Milwaukee Kosziusko Park	8ab	Phyaip	1	0.93		1	Full
75	WW257	Milwaukee Kosziusko Park	8ab	Phyaip	2	0.89		1	Full
75.5	WW258	Milwaukee Mitchell Park	8ab	Phyaip	1	1.22	(Degraded)	1	Full
75.5	WW259	Milwaukee Mitchell Park	8ab	Phyaip	2	1.1	(Degraded)	1	Full
76	WW3043	FIA plot		Flacap	1	0.41	Small, 1 subs	1	Full
76	WW3044	FIA plot		Phyaip	1	0.71	Small, <6 subs	1	Full
77	WW3011	FIA plot		Phyaip	1	1.03		1	Full
78	WW3010	FIA plot		Phyaip	1	1.01		1	Full
78	WW3009	FIA plot		Punrud	1	0.76	Small	1	Full
79	WW3006	FIA plot		Phyaip	1	1.11		1	Full
80	WW3008	FIA plot		Phyaip	1	0.87		1	Full
80	WW3007	FIA plot		Punrud	1	0.25	Small, 1 subs	1	Full
81	WW3121	FIA plot		Phyaip	1	0.57	Damp, small	1	Full
82	WW3119a	FIA plot		Phyaip	1	0.5		1	Full
82	WW3119b	FIA plot		Phyaip	1	0.5		1	Full
83	WW3120	FIA plot		Phyaip	1	0.62	Small	1	Full

FIA = Forest Inventory and Analysis; subs = substrate.
Number on map (fig. 1) is either the number for the site itself or the number of the instrument monitor site near that lichen site.

Table 19A—Lichen samples handled with fully rigorous protocols: data for elements Al through Cu

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
1	WW3076	192.9	49.13	0.353	0.220	0.105	0.415	2.190
1	WW3075	340.5	50.11	0.622	0.570	0.330	0.600	5.230
2	WW3073	138.9	41.34	7.024	0.860	0.115	0.410	2.475
2	WW3074	132.9	38.43	8.594	1.080	0.115	0.385	2.230
3	WW3030a	330.2	46.61	0.534	0.185	0.240	0.685	1.855
3	WW3030b	287.8	47.04	0.572	0.175	0.190	0.565	1.840
3	WW3029	396.0	45.37	2.692	0.645	0.280	0.665	2.730
4	WW3110	200.8	47.04	0.777	0.395	0.175	0.415	2.045
4	WW3111	243.4	41.97	4.619	0.505	0.185	0.420	2.485
4	WW3112	292.1	46.75	0.540	0.230	0.215	0.535	3.945
5	WW3023	321.1	47.33	0.192	0.135	0.185	0.550	2.165
5	WW3024	358.9	46.35	0.533	0.320	0.245	0.600	3.980
6	WW3142	233.1	48.55	0.459	0.105	0.165	0.415	2.130
6	WW3140	353.0	46.91	2.314	0.535	0.240	0.560	3.320
6	WW3141a	318.9	47.88	0.938	0.260	0.270	0.635	3.775
6	WW3141b	302.2	48.61	0.775	0.255	0.255	0.610	3.435
7	WW3014	348.8	45.22	0.420	0.230	0.200	0.575	2.495
7	WW3015	326.8	45.83	0.356	0.200	0.190	0.660	2.265
7	WW3012	250.7	43.81	3.620	1.125	0.200	0.490	2.785
7	WW3013	151.7	40.41	6.109	1.395	0.105	0.340	2.030
7	WW3016	367.0		0.411	0.305	0.285	0.625	4.615
7	WW3017	317.1	46.72	0.424	0.285	0.265	0.550	4.460
8	WW3022	395.9	46.73	0.313	0.600	0.330	0.690	4.805
9	WW3025	293.6	42.18	6.429	0.880	0.185	0.610	3.160
9	WW3026	282.8	42.48	4.757	0.645	0.180	0.600	3.290
9	WW3027	392.7	48.21	0.441	0.360	0.290	0.655	5.555
9	WW3028	437.7	46.99	0.554	0.380	0.290	0.745	6.205
10	WW3019	263.2	47.37	0.165	0.140	0.230	0.510	1.910
10	WW3018	198.4	43.24	4.228	1.095	0.205	0.420	2.135
11	WW3106	344.7	47.48	0.104	0.135	0.220	0.525	1.915
11	WW3107	415.5	47.83	0.105	0.130	0.215	0.635	2.530
11	WW3108	393.2	43.75	3.030	0.930	0.195	0.495	3.325
11	WW3109	451.3	47.26	2.249	0.685	0.190	0.550	3.965
12	WW3020	139.1	36.78	9.134	1.300	0.100	0.330	2.165
12	WW3021	296.9	46.90	0.768	0.375	0.205	0.520	5.000
13	WW3102	431.6	44.85	0.161	0.230	0.360	0.840	5.230
13	WW3103	299.9	43.34	3.888	0.535	0.215	0.605	2.685

Table 19A—Lichen samples handled with fully rigorous protocols: data for elements Al through Cu (continued)

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
14	WW3079	184.9	44.44	0.344	0.110	0.120	0.410	2.555
14	WW3078	165.0	46.17	3.452	0.530	0.145	0.465	2.405
15	WW3104	179.4	43.47	3.450	0.625	0.145	0.380	3.685
15	WW3105	309.3	47.35	0.522	0.310	0.225	0.535	4.155
16	WW3144	284.9	49.64	0.229	0.070	0.145	0.540	1.585
16	WW3143	117.7	38.62	8.824	0.410	0.115	0.260	1.415
17	WW3126	489.9	48.27	0.405	0.125	0.360	0.775	2.225
17	WW3125	366.1	46.70	2.975	0.465	0.235	0.535	3.055
18	WW3071	199.1	47.13	3.015	0.310	0.125	0.465	2.455
18	WW3072	246.2	45.32	4.109	0.480	0.210	0.530	3.535
19	WW3128a	300.9	47.94	0.269	0.090	0.170	0.530	1.780
19	WW3128b	322.3	48.66	0.250	0.085	0.200	0.610	1.880
19	WW3127	179.2	40.94	6.034	0.245	0.155	0.350	1.930
20	WW3058	141.8	42.66	5.159	0.285	0.175	0.325	2.330
20	WW3059a	418.0	49.27	0.461	0.600	0.340	0.880	3.290
20	WW3059b	366.4	48.84	0.472	0.335	0.225	0.580	3.425
21	WW143	351.5	46.05	0.325	0.180	0.170	0.655	3.010
21	WW148	191.0	45.95	0.438	0.200	0.095	0.395	1.895
21	WW149	346.8	46.84	0.163	bdl	0.175	0.585	3.035
21	WW144	193.8	36.22	9.183	0.845	0.105	0.470	2.375
21	WW145	219.0	38.24	7.663	0.870	0.155	0.440	2.615
21	WW150	256.0	40.21	5.973	0.575	0.145	0.510	3.610
21	WW151	216.2	40.61	5.568	0.760	0.125	0.450	2.285
21	WW152	146.5	38.84	7.328	0.680	0.085	0.325	2.080
21	WW153	262.1	44.26	3.299	0.265	0.130	0.535	3.320
21	WW154	319.7	45.28	2.533	0.675	0.175	0.565	3.260
21	WW146	422.7	45.82	0.663	0.365	0.265	0.845	6.115
21	WW155	567.1	45.79	0.854	0.485	0.500	0.950	8.295
21	WW208	402.2	44.74	0.063	0.215	0.245	0.885	2.645
21	WW209	340.5	43.48	0.069	0.215	0.215	0.795	2.235
21	WW163	273.5	37.67	4.000	0.560	0.135	0.540	2.790
22	WW3124	316.6	47.74	0.517	0.135	0.200	0.520	2.435
22	WW3123a	157.3	40.02	7.689	0.985	0.130	0.380	2.000
22	WW3123b	147.3	37.99	8.484	1.125	0.100	0.385	1.790
23	WW3057	341.9	48.28	0.449	0.170	0.230	0.540	5.065
23	WW3056	249.2	47.20	2.472	1.090	0.205	0.425	2.185
24	WW215	303.8	43.14	0.778	0.120	0.190	0.630	2.145

Table 19A—Lichen samples handled with fully rigorous protocols: data for elements Al through Cu (continued)

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
24	WW216	213.5	46.66	0.582	0.085	0.155	0.480	2.025
24	WW211	191.0	46.60	3.589	0.555	0.125	0.390	2.015
24	WW212	219.8	46.02	3.954	0.585	0.135	0.455	2.255
24	WW217	276.2	46.60	0.866	0.155	0.210	0.515	10.030
24	WW218	314.6	46.02	0.817	0.165	0.210	0.580	8.930
24	WW219	170.1	45.44	0.096	0.125	0.080	0.400	1.800
24	WW220	184.3	43.92	0.105	0.145	0.095	0.440	1.905
24	WW213	150.4	45.44	6.789	0.355	0.105	0.365	1.140
24	WW214	135.3	43.92	7.689	0.345	0.100	0.315	1.035
25	WW3003	327.8	46.18	0.749	0.460	0.225	0.510	5.730
25	WW3004	144.0	38.53	7.239	0.945	0.115	0.340	1.890
26	WW3032	127.6	40.13	6.984	0.610	0.105	0.305	1.885
26	WW3033	368.9	48.27	0.540	0.410	0.265	0.525	4.200
27	WW123	486.3	46.21	0.312	0.110	0.255	0.880	2.685
27	WW124	454.1	45.88	0.267	0.120	0.205	0.780	2.555
27	WW126	255.9	44.24	2.497	0.160	0.180	0.505	3.190
27	WW127	278.7	44.78	2.573	0.215	0.175	0.510	3.440
27	WW128	214.8	44.44	2.581	0.165	0.155	0.390	2.685
27	WW136	429.0	45.61	0.323	bdl	0.230	0.735	3.890
27	WW137	428.8	45.95	0.379	bdl	0.235	0.750	3.380
28	WW3036	314.8	49.46	2.456	0.425	0.200	0.625	3.865
29	WW3038	382.0	46.20	0.139	0.190	0.235	0.730	3.100
30	WW3037	405.6		0.227	0.140	0.270	0.710	2.800
31	WW3134	303.0	45.75	3.567	0.340	0.225	0.420	3.365
32	WW3093	671.3	41.10	4.218	0.655	0.325	1.325	4.800
33	WW3095	462.3	43.41	4.031	0.425	0.235	0.805	3.685
33	WW3096	489.1		0.901	0.350	0.450	0.850	5.550
34	WW3101a	622.3		0.244	0.320	0.420	1.435	6.145
34	WW3101b	610.8		0.229	0.310	0.405	1.480	5.665
35	WW3135	587.4	41.94	5.289	0.735	0.290	0.715	3.590
36	WW3100	576.8	46.17	0.135	0.310	0.305	1.110	4.785
36	WW3099a	224.7	43.60	4.272	1.035	0.135	0.435	3.915
36	WW3099b	215.8	43.23	3.997	0.975	0.150	0.450	3.685
37	WW3089	347.6	39.40	5.244	0.475	0.265	0.910	3.560
37	WW3090	532.9	38.15	5.904	0.410	0.280	1.260	2.885
38	WW3094	272.4	41.78	5.769	0.590	0.175	0.570	3.750
39	WW3039	229.4	43.65	4.363	0.490	0.130	0.435	3.360

Table 19A—Lichen samples handled with fully rigorous protocols: data for elements Al through Cu (continued)

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
39	WW3040	330.2	48.01	0.207	0.265	0.260	0.615	2.650
40	WW3097	898.3	43.59	3.478	1.720	1.200	2.825	8.610
40	WW3098	high	41.32	0.378	0.360	2.525	10.510	11.005
41	WW3091a	317.4	41.44	5.179	0.490	0.190	0.740	3.510
41	WW3091b	270.9	42.31	5.054	0.495	0.150	0.875	3.550
41	WW3092	381.8	45.50	0.165	0.155	0.380	0.725	3.065
42	WW3133	260.1	45.84	3.521	0.270	0.190	0.520	3.420
43	WW3130	370.5	47.29	0.131	0.190	0.250	0.775	2.840
43	WW3129a	659.9		7.244	0.360	0.270	1.215	3.760
43	WW3129b	673.4		6.514	0.310	0.305	1.145	3.750
44	WW3034	720.2	39.79	6.989	1.085	0.330	1.045	3.325
44	WW3035	671.7	40.98	5.724	0.735	0.325	1.260	2.415
45	WW3113	468.0		3.895	0.540	0.470	0.970	3.570
45	WW3114	525.3	43.46	0.242	0.175	0.340	1.095	3.700
46	WW3136	295.5	42.98	4.993	0.555	0.180	0.655	3.930
46	WW3137	505.4	42.12	5.304	0.720	0.225	0.895	3.935
47	WW3138	482.6	45.45	3.237	0.505	0.235	0.800	3.250
47	WW3139	511.4	48.18	0.475	0.255	0.240	0.750	4.610
48	WW3001	240.8	41.10	4.906	0.590	0.150	0.460	2.730
48	WW3002	354.6	45.14	0.628	0.290	0.195	0.585	4.685
49	WW3131	346.0	45.74	3.076	0.210	0.205	0.700	3.255
49	WW3132	219.3	47.59	0.141	0.130	0.140	0.540	2.180
50	WW3115	379.5	44.66	0.212	0.115	0.230	0.745	2.915
51	WW3116	479.4		0.767	0.090	0.340	1.110	3.945
52	WW3118	441.9	45.56	2.392	0.380	0.280	0.715	3.835
53	WW225	218.3	35.54	5.534	0.695	0.125	0.525	3.045
53	WW226	282.1	37.17	4.602	0.640	0.195	0.675	3.275
53	WW229	329.1	41.91	0.217	0.315	0.225	0.720	2.500
53	WW230	296.8	40.52	0.182	0.325	0.280	0.665	2.205
53	WW227	315.9	35.35	6.554	0.640	0.160	0.735	2.875
53	WW228	233.5	37.61	4.861	0.510	0.125	0.605	2.675
54	WW3085	412.3	44.21	0.340	0.125	0.275	0.925	3.690
54	WW3086	430.5		0.309	0.100	0.310	0.820	3.580
54	WW3087	555.2		5.353	bdl	0.550	1.275	2.650
55	WW3117	391.5		0.231	0.230	0.360	0.710	3.090
56	WW116	375.4		6.234	2.350	0.275	0.975	4.875
56	WW204	331.6	42.56	0.348	0.828	0.315	1.280	4.798

Table 19A—Lichen samples handled with fully rigorous protocols: data for elements Al through Cu (continued)

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
57	WW114	273.7		3.874	bdl	0.250	0.700	2.175
57	WW115	365.9	44.66	0.616	0.075	0.215	0.765	4.160
57	WW201	182.6	43.00	0.185	0.095	0.125	0.525	3.540
57	WW202	274.2	41.53	0.227	0.105	0.200	0.695	4.485
57	WW203	207.4	42.82	0.204	0.095	0.125	0.540	2.345
58	WW206	328.5	44.47	0.155	0.130	0.195	0.795	5.390
58	WW207	355.2	44.77	0.146	0.140	0.225	0.850	6.030
58	WW117	313.3	35.60	7.985	0.430	0.155	0.675	3.120
58	WW118	252.9	35.23	7.970	0.420	0.105	0.555	2.680
59	WW238	265.1	41.94	2.712	0.950	0.230	0.510	2.760
59	WW239	272.1	42.84	2.798	1.145	0.225	0.525	2.955
59	WW240	290.4	42.72	2.668	0.935	0.240	0.540	2.955
59	WW253	463.4	43.70	0.717	0.510	0.380	0.860	5.260
59	WW251	271.2	46.67	0.221	0.200	0.170	0.580	2.610
59	WW252	278.7	46.90	0.173	0.195	0.175	0.640	2.645
59	WW248	255.2	45.50	3.377	0.560	0.185	0.555	2.195
59	WW249	233.3	45.90	3.324	0.735	0.140	0.490	2.155
59	WW250	289.6	45.89	3.332	0.800	0.170	0.600	2.445
60	WW3069	204.7	46.62	2.948	0.120	0.125	0.460	3.290
60	WW3070	254.8		0.364	0.130	0.170	1.010	12.000
61	WW3080	171.3	40.61	4.540	0.200	0.165	0.340	1.915
61	WW3081	213.1	43.37	2.771	0.190	0.190	0.530	2.640
62	WW3083	260.9		3.106	0.235	0.170	0.505	1.515
62	WW3084	361.7		0.266	0.400	0.500	0.975	3.525
63	WW3046	285.5	46.69	2.572	0.245	0.235	0.470	3.160
63	WW3047	254.4	45.95	1.591	0.255	0.185	0.445	2.895
63	WW3050	327.0	45.15	0.193	0.190	0.225	0.585	3.595
63	WW3048	298.1	37.30	7.024	0.410	0.150	0.555	2.930
63	WW3049	255.3	43.56	3.476	0.340	0.195	0.485	2.965
64	WW3061	223.0	50.26	1.707	0.270	0.145	0.525	3.135
64	WW3062	174.6	43.44	5.557	0.520	0.150	0.560	2.130
65	WW269	259.8	47.11	0.122	0.160	0.175	0.810	2.950
65	WW270	250.2	46.10	0.325	0.145	0.205	0.740	3.190
65	WW273	193.4	45.61	3.223	0.150	0.170	0.600	2.625
65	WW274	214.7	45.65	3.124	0.140	0.170	0.550	2.585
66	WW3063	590.4	45.55	3.188	0.110	0.395	1.210	4.225
66	WW3064	161.0		9.278	bdl	bdl	0.775	1.925

Table 19A—Lichen samples handled with fully rigorous protocols: data for elements Al through Cu (continued)

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
67	WW3067	448.4	47.05	2.892	0.165	0.275	0.915	3.325
67	WW3068	224.3	42.83	4.976	0.205	0.140	0.495	3.110
68	WW268	61.9		0.229	bdl	0.070	0.135	0.725
68	WW264	377.9	46.31	0.148	0.125	0.265	1.150	5.080
68	WW265	346.5	45.29	0.214	0.135	0.225	0.955	5.735
68	WW267	310.3	40.51	4.605	bdl	0.350	0.975	2.350
69	WW3051	346.8	45.21	2.549	0.270	0.205	0.585	4.035
69	WW3052	285.9	44.26	3.099	0.220	0.170	0.550	2.775
70	WW3053	334.0	45.19	3.156	0.090	0.185	0.595	3.465
70	WW3054	341.1	44.49	3.520	0.100	0.185	0.615	3.300
70	WW3055a	340.8	41.77	4.146	0.130	0.280	0.720	2.370
70	WW3055b	331.2	41.05	4.640	0.100	0.170	0.670	2.635
71	WW262	364.6	46.90	0.188	0.165	0.275	1.720	8.090
71	WW263	385.6	46.79	0.240	0.175	0.285	1.760	8.470
72	WW3045	322.9	46.63	2.786	0.305	0.225	0.565	2.410
73	WW3041	268.5	47.90	1.502	0.160	0.195	0.435	2.535
73	WW3042	216.0		4.378	0.175	0.150	0.425	2.940
74	WW260a	437.9	46.38	0.662	0.255	0.345	2.955	9.600
74	WW260b	502.4	46.29	0.671	0.270	0.340	3.640	10.035
74	WW261	319.4	44.15	0.172	0.230	0.230	2.730	5.960
75	WW256	355.6	44.84	0.261	0.190	0.245	2.260	6.540
75	WW257	340.0	47.08	0.242	0.165	0.210	2.180	6.095
75.5	WW258	616.9	44.81	0.244	1.165	0.640	7.110	high
75.5	WW259	667.4	44.93	0.253	1.195	0.685	7.540	high
76	WW3043	210.2		6.419	0.230	0.130	0.410	2.620
76	WW3044	290.9	48.77	0.439	bdl	0.200	0.610	2.620
77	WW3011	435.0	42.46	0.265	0.110	0.240	0.830	3.435
78	WW3010	398.3	44.83	0.360	0.125	0.160	0.760	4.360
78	WW3009	192.7		6.609	0.055	0.100	0.445	2.220
79	WW3006	295.5	44.16	0.273	0.155	0.165	0.620	3.605
80	WW3008	414.5		0.426	0.145	0.235	0.755	3.320
80	WW3007	193.5		11.162	0.750	0.400	0.625	bdl
81	WW3121	418.7		0.177	0.190	0.230	0.860	4.560
82	WW3119a	277.0		0.201	0.120	0.210	0.600	2.380
82	WW3119b	156.3		0.126	bdl	0.100	0.340	1.430
83	WW3120	206.0		0.095	0.065	0.140	0.350	1.770

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper.

Table 19B—Lichen samples handled with fully rigorous protocols: data for elements Fe through Na

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
1	WW3076	233.5	0.157	0.192	0.040	67.6	1.120	25.55
1	WW3075	405.9	0.076	0.274	0.089	163.8	0.899	23.55
2	WW3073	168.8	0.123	0.278	0.036	161.9	0.813	15.10
2	WW3074	159.1	0.126	0.195	0.037	72.9	0.628	8.25
3	WW3030a	575.6	0.164	0.236	0.040	101.0	1.298	16.90
3	WW3030b	485.7	0.131	0.222	0.037	83.3	1.282	18.25
3	WW3029	602.1	0.134	0.333	0.054	211.1	1.237	23.35
4	WW3110	296.2	0.208	0.282	0.049	166.0	1.327	19.75
4	WW3111	314.0	0.151	0.258	0.043	240.1	0.911	14.70
4	WW3112	415.1	0.103	0.440	0.099	452.5	1.028	25.30
5	WW3023	381.8	0.171	0.256	0.040	67.2	1.284	19.15
5	WW3024	424.9	0.064	0.443	0.103	572.0	0.957	15.40
6	WW3142	351.6	0.114	0.209	0.037	107.7	1.180	23.50
6	WW3140	454.1	0.200	0.308	0.052	257.8	1.557	22.40
6	WW3141a	481.4	0.113	0.293	0.063	367.9	1.075	17.45
6	WW3141b	460.9	0.110	0.308	0.068	283.4	1.135	18.75
7	WW3014	438.6	0.193	0.311	0.050	204.7	1.437	19.25
7	WW3015	407.5	0.200	0.291	0.047	227.2	1.387	25.40
7	WW3012	275.8	0.157	0.338	0.040	591.0	0.986	23.40
7	WW3013	173.4	0.112	0.291	0.030	364.9	0.748	14.15
7	WW3016	437.7		0.398	0.074	793.0		17.55
7	WW3017	388.2	0.087	0.377	0.068	472.2	1.215	15.80
8	WW3022	434.7	0.091	0.440	0.058	370.8	1.385	17.15
9	WW3025	378.5	0.131	0.366	0.057	268.4	1.034	72.00
9	WW3026	381.6	0.135	0.433	0.051	342.8	1.100	97.50
9	WW3027	549.1	0.057	0.481	0.095	323.1	1.390	80.80
9	WW3028	620.1	0.066	0.515	0.091	393.6	1.327	77.05
10	WW3019	338.3	0.132	0.328	0.042	77.2	1.146	22.40
10	WW3018	224.6	0.099	0.386	0.046	305.3	0.804	22.15
11	WW3106	448.0	0.252	0.160	0.029	31.8	1.133	18.45
11	WW3107	517.3	0.257	0.182	0.034	33.1	1.302	27.30
11	WW3108	326.3	0.189	0.237	0.036	64.1	0.977	18.25
11	WW3109	355.4	0.231	0.263	0.040	65.5	1.072	23.00
12	WW3020	157.8	0.116	0.273	0.030	222.0	0.850	15.60
12	WW3021	379.6	0.140	0.490	0.088	203.3	1.226	16.50
13	WW3102	536.8	0.154	0.343	0.052	146.2	1.191	48.85
13	WW3103	347.4	0.104	0.273	0.057	300.3	0.738	26.60

Table 19B—Lichen samples handled with fully rigorous protocols: data for elements Fe through Na (continued)

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
14	WW3079	236.4	0.110	0.288	0.040	83.4	1.188	22.70
14	WW3078	198.4	0.097	0.296	0.050	205.6	0.823	12.90
15	WW3104	213.2	0.109	0.329	0.055	188.9	0.926	18.40
15	WW3105	389.1	0.072	0.394	0.098	366.1	1.107	19.05
16	WW3144	326.9	0.148	0.167	0.031	132.4	0.905	16.50
16	WW3143	141.6	0.075	0.248	0.045	163.9	0.517	22.65
17	WW3126	615.2	0.129	0.235	0.046	47.8	1.173	20.70
17	WW3125	312.4	0.166	0.228	0.032	95.8	0.837	25.30
18	WW3071	233.9	0.121	0.327	0.047	265.8	0.895	17.30
18	WW3072	284.3	0.148	0.329	0.054	206.6	1.054	18.70
19	WW3128a	397.1	0.140	0.133	0.031	34.7	1.218	23.85
19	WW3128b	402.6	0.129	0.136	0.031	30.9	1.176	33.10
19	WW3127	213.6	0.087	0.194	0.029	85.6	0.799	14.25
20	WW3058	171.9	0.072	0.277	0.057	276.8	0.700	18.20
20	WW3059a	505.3	0.087	0.314	0.068	445.3	1.139	21.00
20	WW3059b	453.3	0.078	0.284	0.062	343.7	1.278	21.25
21	WW143	452.9	0.137	0.261	0.043	28.9	1.617	24.45
21	WW148	223.0	0.139	0.319	0.043	141.7	1.141	21.15
21	WW149	445.5	0.180	0.288	0.043	75.2	1.635	18.00
21	WW144	224.9	0.108	0.285	0.033	142.6	0.841	25.95
21	WW145	240.6	0.112	0.246	0.036	102.5	0.865	17.05
21	WW150	283.2	0.147	0.368	0.040	97.8	1.046	23.50
21	WW151	249.8	0.151	0.327	0.039	161.9	0.768	17.45
21	WW152	170.4	0.128	0.285	0.034	173.9	0.663	26.10
21	WW153	301.4	0.147	0.356	0.052	217.8	0.993	19.20
21	WW154	354.5	0.149	0.389	0.042	443.4	0.935	23.95
21	WW146	518.1	0.099	0.491	0.094	111.1	1.448	15.75
21	WW155	703.6	0.124	0.356	0.076	123.0	1.597	19.25
21	WW208	477.9	0.061	0.539	0.076	30.3	2.313	27.20
21	WW209	411.9	0.060	0.464	0.070	26.1	1.896	22.55
21	WW163	342.4	0.125	0.284	0.060	144.7	1.115	24.65
22	WW3124	370.2	0.167	0.235	0.043	57.1	1.227	23.10
22	WW3123a	179.8	0.120	0.201	0.040	77.5	0.693	8.80
22	WW3123b	165.9	0.114	0.191	0.037	82.3	0.637	12.50
23	WW3057	445.9	0.180	0.249	0.045	102.3	1.429	19.30
23	WW3056	264.1	0.142	0.250	0.034	198.6	0.810	22.85
24	WW215	316.4	0.183	0.346	0.058	38.7	1.714	26.75

Table 19B—Lichen samples handled with fully rigorous protocols: data for elements Fe through Na (continued)

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
24	WW216	231.5	0.193	0.345	0.073	33.1	1.649	26.10
24	WW211	209.4	0.118	0.429	0.087	155.5	1.074	28.30
24	WW212	229.8	0.114	0.480	0.101	170.5	1.022	49.20
24	WW217	294.2	0.070	0.528	0.168	48.0	1.108	20.50
24	WW218	325.1	0.075	0.552	0.164	70.3	1.111	18.95
24	WW219	182.3	0.036	0.758	0.110	14.8	1.547	24.75
24	WW220	195.4	0.038	0.780	0.114	14.2	1.565	21.55
24	WW213	149.3	0.111	0.300	0.076	53.0	0.738	37.00
24	WW214	134.3	0.090	0.254	0.069	48.4	0.671	35.65
25	WW3003	365.8	0.100	0.446	0.103	144.3	1.013	22.90
25	WW3004	155.5	0.070	0.338	0.052	192.7	0.601	22.35
26	WW3032	161.6	0.104	0.288	0.033	163.5	0.698	27.35
26	WW3033	462.4	0.066	0.443	0.082	325.5	1.042	18.20
27	WW123	676.9	0.213	0.209	0.046	44.0	1.800	32.35
27	WW124	633.4	0.217	0.209	0.046	40.5	1.767	24.25
27	WW126	314.6	0.166	0.332	0.063	147.3	1.298	21.70
27	WW127	343.2	0.158	0.346	0.061	125.4	1.590	24.20
27	WW128	266.9	0.175	0.298	0.055	132.7	1.241	18.35
27	WW136	541.1	0.134	0.336	0.086	262.5	1.275	20.60
27	WW137	553.6	0.144	0.284	0.079	307.9	1.180	23.55
28	WW3036	382.6	0.126	0.312	0.051	163.6	1.338	30.10
29	WW3038	556.2	0.044	0.580	0.112	89.4	2.213	19.40
30	WW3037	513.9	0.093	0.680	0.121	46.9		29.70
31	WW3134	584.2	0.131	0.344	0.048	237.4	1.209	19.55
32	WW3093	805.8	0.153	0.289	0.061	263.6	1.785	38.90
33	WW3095	494.3	0.126	0.395	0.062	196.7	1.582	64.90
33	WW3096	601.7		0.442	0.085	542.7		6.25
34	WW3101a	857.3		0.550	0.120	75.7		23.95
34	WW3101b	857.3		0.520	0.123	64.6		23.50
35	WW3135	949.2	0.122	0.311	0.064	309.8	1.283	17.20
36	WW3100	726.8	0.069	0.663	0.120	104.0	2.533	39.50
36	WW3099a	253.3	0.147	0.371	0.054	201.2	1.343	16.10
36	WW3099b	246.6	0.157	0.356	0.053	227.7	1.374	16.60
37	WW3089	428.5	0.096	0.320	0.048	175.7	1.238	5.30
37	WW3090	627.0	0.084	0.257	0.065	69.8	0.989	28.55
38	WW3094	310.9	0.117	0.232	0.055	283.2	1.271	28.70
39	WW3039	264.2	0.138	0.292	0.039	179.2	1.216	20.65

Table 19B—Lichen samples handled with fully rigorous protocols: data for elements Fe through Na (continued)

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
39	WW3040	412.3	0.064	0.498	0.088	65.0	1.917	25.80
40	WW3097	1163.8	0.171	0.243	0.124	50.4	1.344	43.75
40	WW3098	high	0.060	0.354	0.270	157.9	1.604	91.75
41	WW3091a	386.5	0.113	0.313	0.051	342.4	1.514	24.15
41	WW3091b	328.2	0.126	0.323	0.049	332.0	1.373	23.25
41	WW3092	468.4	0.040	0.504	0.098	207.0	2.116	20.85
42	WW3133	298.3	0.127	0.348	0.058	133.7	1.734	18.10
43	WW3130	503.7	0.041	0.541	0.102	52.2	3.075	22.70
43	WW3129a	781.7	0.094	0.190	0.086	99.5		33.55
43	WW3129b	792.2	0.104	0.208	0.088	88.1		25.10
44	WW3034	788.2	0.107	0.417	0.066	91.7	1.193	21.35
44	WW3035	639.7	0.077	0.249	0.065	105.4	0.870	99.20
45	WW3113	712.2		0.444	0.118	157.8		54.20
45	WW3114	758.8	0.062	0.652	0.125	32.4	2.643	42.95
46	WW3136	353.8	0.160	0.352	0.064	195.3	1.379	40.35
46	WW3137	554.2	0.137	0.198	0.056	107.6	1.433	21.85
47	WW3138	566.2	0.126	0.270	0.057	140.1	1.129	19.20
47	WW3139	604.2	0.095	0.334	0.067	140.8	1.486	36.80
48	WW3001	247.8	0.098	0.329	0.058	163.2	1.193	36.20
48	WW3002	386.2	0.063	0.433	0.091	153.5	1.682	20.15
49	WW3131	414.3	0.150	0.302	0.069	59.5	1.610	21.20
49	WW3132	259.9	0.051	0.598	0.114	25.9	2.179	26.80
50	WW3115	513.8	0.049	0.528	0.106	21.9	2.003	41.55
51	WW3116	754.8		0.343	0.095	61.5		27.30
52	WW3118	527.8	0.146	0.445	0.110	123.2	1.983	40.30
53	WW225	276.0	0.135	0.350	0.058	53.3	1.934	21.00
53	WW226	355.6	0.160	0.357	0.070	77.1	2.039	18.00
53	WW229	400.2	0.072	0.638	0.131	95.1	2.476	34.85
53	WW230	337.9	0.135	0.605	0.129	74.2	2.166	29.20
53	WW227	382.0	0.110	0.192	0.060	53.5	1.634	15.45
53	WW228	293.6	0.132	0.239	0.063	53.7	1.583	19.85
54	WW3085	621.5	0.077	0.575	0.105	26.6	3.006	32.65
54	WW3086	668.3	0.059	0.386	0.077	32.9		11.50
54	WW3087	796.7	0.058	0.180	0.066	21.7		bdl
55	WW3117	555.9		0.543	0.114	72.6		69.90
56	WW116	565.1		0.296	0.119	26.8		77.00
56	WW204	496.2	0.092	0.552	0.174	86.6	2.479	52.30

Table 19B—Lichen samples handled with fully rigorous protocols: data for elements Fe through Na (continued)

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
57	WW114	326.9		0.576	0.077	24.7		41.50
57	WW115	468.9	0.092	0.518	0.095	32.3	2.530	20.95
57	WW201	228.3	0.065	0.527	0.124	10.8	2.232	48.25
57	WW202	322.0	0.071	0.557	0.125	14.0	2.319	49.35
57	WW203	246.9	0.059	0.571	0.119	11.0	2.105	26.30
58	WW206	402.0	0.080	0.532	0.106	16.7	2.848	29.05
58	WW207	435.6	0.081	0.524	0.109	17.3	3.047	27.95
58	WW117	413.6	0.103	0.199	0.062	30.4	1.695	35.95
58	WW118	325.6	0.139	0.192	0.056	25.9	1.683	33.70
59	WW238	237.2	0.111	0.404	0.065	65.9	1.632	14.55
59	WW239	247.1	0.160	0.435	0.071	50.7	1.749	12.15
59	WW240	269.5	0.131	0.395	0.066	58.2	1.677	19.60
59	WW253	441.7	0.032	0.487	0.095	107.5	2.038	52.60
59	WW251	296.4	0.060	0.744	0.130	25.7	1.880	10.95
59	WW252	279.5	0.100	0.763	0.130	24.0	1.979	13.55
59	WW248	246.7	0.113	0.315	0.072	72.8	1.481	15.00
59	WW249	229.9	0.131	0.298	0.072	76.9	1.521	10.20
59	WW250	275.8	0.134	0.311	0.073	65.3	1.515	12.50
60	WW3069	235.9	0.082	0.393	0.096	52.0	1.166	13.50
60	WW3070	321.5		0.720	0.132	64.9		6.50
61	WW3080	207.1	0.091	0.386	0.072	41.0	1.219	46.45
61	WW3081	272.7	0.104	0.209	0.065	37.2	1.200	27.95
62	WW3083	322.0		0.196	0.042	34.6		28.00
62	WW3084	525.5		0.537	0.121	81.7		77.50
63	WW3046	345.1	0.127	0.351	0.081	107.8	1.702	24.25
63	WW3047	325.2	0.121	0.400	0.059	136.8	1.897	15.70
63	WW3050	419.1	0.075	0.558	0.114	111.1	2.517	19.60
63	WW3048	356.6	0.110	0.160	0.062	77.2	1.810	19.30
63	WW3049	312.4	0.078	0.286	0.068	114.1	1.695	25.00
64	WW3061	271.8	0.126	0.374	0.066	146.4	1.646	17.15
64	WW3062	225.5	0.064	0.235	0.060	121.4	1.399	15.60
65	WW269	337.9	0.081	0.820	0.111	43.8	2.778	59.55
65	WW270	321.2	0.071	0.821	0.127	62.7	2.658	48.80
65	WW273	230.0	0.089	0.274	0.079	28.0	1.559	32.40
65	WW274	254.9	0.087	0.255	0.080	25.3	1.598	19.15
66	WW3063	882.5	0.070	0.428	0.121	58.7	1.261	20.40
66	WW3064	201.2	0.074	0.285	0.100	17.3		79.75

Table 19B—Lichen samples handled with fully rigorous protocols: data for elements Fe through Na (continued)

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
67	WW3067	598.0	0.136	0.276	0.076	62.5	1.578	33.70
67	WW3068	255.9	0.060	0.246	0.078	54.4	1.294	12.60
68	WW268	75.6		0.105	0.024	5.1		3.70
68	WW264	465.9	0.081	0.760	0.129	22.1	2.530	44.20
68	WW265	419.4	0.050	0.777	0.131	20.4	2.643	90.30
68	WW267	369.6		0.258	0.077	40.3	2.566	31.25
69	WW3051	405.9	0.159	0.364	0.093	139.8	2.075	20.00
69	WW3052	346.3	0.091	0.242	0.100	80.3	1.660	16.65
70	WW3053	438.2	0.102	0.411	0.109	38.4	1.564	19.80
70	WW3054	414.9	0.086	0.400	0.113	26.8	1.657	12.80
70	WW3055a	475.4	0.078	0.286	0.105	35.1	1.385	27.60
70	WW3055b	453.1	0.064	0.269	0.096	30.5	1.454	17.05
71	WW262	639.1	0.098	0.726	0.139	18.4	2.792	60.55
71	WW263	650.6	0.097	0.735	0.135	21.0	2.718	83.35
72	WW3045	362.8	0.084	0.301	0.069	85.8	1.280	20.75
73	WW3041	303.0	0.157	0.420	0.085	52.1	1.707	19.80
73	WW3042	251.9	0.089	0.229	0.085	128.7		23.25
74	WW260a	708.1	0.068	0.489	0.087	22.1	2.618	74.00
74	WW260b	820.6	0.084	0.475	0.088	22.8	2.705	67.80
74	WW261	632.2	0.068	0.701	0.104	16.3	3.388	98.30
75	WW256	656.1	0.082	0.822	0.135	28.6	3.013	102.95
75	WW257	624.1	0.054	0.841	0.135	28.6	2.949	117.60
75.5	WW258	high	0.162	0.811	0.155	39.0	3.104	119.10
75.5	WW259	high	0.193	0.805	0.149	40.6	3.036	127.20
76	WW3043	280.5		0.329	0.071	15.0		54.80
76	WW3044	396.7	0.093	0.569	0.105	19.2	2.282	20.00
77	WW3011	534.1	0.058	0.728	0.136	26.0	3.398	56.75
78	WW3010	483.0	0.089	0.616	0.095	60.9	3.129	20.40
78	WW3009	223.2	0.103	0.253	0.088	18.1		17.90
79	WW3006	352.6	0.054	0.820	0.160	25.3	2.610	17.60
80	WW3008	479.7	0.089	0.455	0.165	38.8		79.25
80	WW3007	211.3		0.170	0.060	9.1		bdl
81	WW3121	544.5	0.079	0.746	0.114	41.5		25.30
82	WW3119a	373.7	0.095	0.488	0.099	19.5		26.20
82	WW3119b	200.2	0.129	0.280	0.055	9.9		15.05
83	WW3120	257.9	0.071	0.371	0.061	22.1		17.95

Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium.

Table 19C—Lichen samples handled with fully rigorous protocols: data for elements Ni through Zn

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
1	WW3076	1.530	0.046	0.565	0.324	0.091	4.93	31.77
1	WW3075	0.960	0.085	2.305	0.147	0.083	27.31	81.57
2	WW3073	0.290	0.082	4.950	0.099	0.079	69.43	40.86
2	WW3074	0.300	0.048	5.150	0.113	0.069	83.18	39.69
3	WW3030a	0.565	0.064	0.895	0.254	0.145	7.52	19.80
3	WW3030b	0.620	0.065	1.005	0.233	0.139	7.38	17.97
3	WW3029	0.730	0.108	5.280	0.152	0.141	26.37	32.02
4	WW3110	4.150	0.078	0.690	0.268	0.103	9.71	25.88
4	WW3111	0.425	0.078	2.070	0.093	0.077	23.05	37.58
4	WW3112	0.670	0.122	5.370	0.153	0.097	17.17	44.59
5	WW3023	0.615	0.059	1.020	0.238	0.106	2.54	29.11
5	WW3024	0.740	0.136	2.370	0.143	0.095	12.20	26.82
6	WW3142	3.010	0.056	0.955	0.327	0.088	5.59	18.50
6	WW3140	0.540	0.079	5.825	0.205	0.123	17.63	56.99
6	WW3141a	0.710	0.123	6.360	0.184	0.112	18.89	31.20
6	WW3141b	0.715	0.125	6.395	0.213	0.106	15.97	34.92
7	WW3014	1.415	0.078	1.300	0.275	0.121	8.46	26.91
7	WW3015	1.240	0.081	1.205	0.269	0.116	7.70	26.49
7	WW3012	0.900	0.072	5.995	0.114	0.088	30.52	42.69
7	WW3013	0.505	0.056	7.105	0.094	0.071	39.90	19.74
7	WW3016	0.905	0.100	5.480	0.161	0.105	17.12	64.79
7	WW3017	0.775	0.102	7.195	0.150	0.103	17.32	63.14
8	WW3022	0.930	0.142	2.425	0.172	0.103	8.37	192.89
9	WW3025	0.535	0.094	5.905	0.144	0.147	69.74	50.89
9	WW3026	0.525	0.119	6.135	0.182	0.175	40.78	57.19
9	WW3027	0.805	0.127	2.385	0.196	0.183	10.87	28.91
9	WW3028	0.905	0.143	3.255	0.184	0.180	14.60	44.68
10	WW3019	0.940	0.107	0.875	0.165	0.086	2.87	28.89
10	WW3018	1.660	0.095	5.785	0.102	0.067	42.15	49.14
11	WW3106	1.720	0.048	1.160	0.248	0.083	1.75	28.37
11	WW3107	1.450	0.046	1.500	0.186	0.101	1.75	30.01
11	WW3108	0.920	0.085	7.680	0.159	0.089	7.08	34.44
11	WW3109	0.920	0.077	6.445	0.156	0.095	6.50	35.39
12	WW3020	0.235	0.053	5.330	0.134	0.079	55.79	17.20
12	WW3021	0.700	0.137	6.800	0.180	0.120	26.70	64.74
13	WW3102	2.195	0.142	1.020	0.212	0.090	3.60	25.09
13	WW3103	0.735	0.121	7.860	0.121	0.061	41.55	25.94

Table 19C—Lichen samples handled with fully rigorous protocols: data for elements Ni through Zn (continued)

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
14	WW3079	0.450	0.068	0.960	0.209	0.084	6.43	18.86
14	WW3078	0.830	0.090	4.545	0.113	0.070	36.92	22.49
15	WW3104	0.420	0.100	2.075	0.129	0.070	38.23	30.46
15	WW3105	0.715	0.115	3.460	0.168	0.095	22.59	60.94
16	WW3144	0.425	0.052	1.550	0.256	0.067	3.97	23.99
16	WW3143	0.195	0.061	2.720	0.082	0.050	114.60	23.77
17	WW3126	0.665	0.083	0.960	0.189	0.086	7.63	29.17
17	WW3125	0.495	0.075	5.680	0.140	0.087	20.04	50.09
18	WW3071	0.535	0.105	5.835	0.114	0.070	44.22	28.72
18	WW3072	0.585	0.110	7.545	0.117	0.086	42.93	34.02
19	WW3128a	0.365	0.042	1.180	0.216	0.094	5.43	30.55
19	WW3128b	1.045	0.040	0.970	0.169	0.089	4.66	27.62
19	WW3127	0.320	0.084	2.335	0.113	0.069	59.25	20.02
20	WW3058	0.275	0.087	2.010	0.091	0.068	85.26	22.51
20	WW3059a	0.920	0.128	2.780	0.130	0.106	13.94	86.77
20	WW3059b	0.600	0.122	2.230	0.193	0.110	14.16	70.23
21	WW143	1.650	0.069	1.705	0.211	0.151	11.40	33.24
21	WW148	1.510	0.109	0.910	0.173	0.097	10.68	29.36
21	WW149	0.575	0.070	1.250	0.226	0.144	4.00	33.12
21	WW144	0.450	0.068	22.645	0.117	0.096	110.55	18.21
21	WW145	0.365	0.049	14.555	0.123	0.092	105.95	25.86
21	WW150	0.510	0.089	7.200	0.140	0.113	67.00	32.81
21	WW151	0.445	0.107	5.275	0.100	0.083	61.15	51.07
21	WW152	0.485	0.097	4.960	0.109	0.074	68.75	29.26
21	WW153	1.380	0.103	2.175	0.152	0.110	19.27	46.17
21	WW154	0.700	0.129	5.920	0.122	0.096	30.42	75.17
21	WW146	0.990	0.194	3.355	0.178	0.147	36.92	75.97
21	WW155	1.200	0.104	6.235	0.197	0.154	38.95	87.02
21	WW208	0.685	0.163	1.150	0.367	0.220	2.59	48.09
21	WW209	0.625	0.125	0.915	0.306	0.180	2.12	36.70
21	WW163	0.500	0.133	3.905	0.114	0.089	40.98	32.99
22	WW3124	0.460	0.075	1.260	0.255	0.106	11.33	44.39
22	WW3123a	0.295	0.087	3.790	0.135	0.073	76.80	38.57
22	WW3123b	0.290	0.073	3.595	0.109	0.066	87.10	42.01
23	WW3057	0.545	0.064	1.165	0.237	0.120	9.55	40.76
23	WW3056	0.695	0.090	3.995	0.098	0.076	17.30	32.11
24	WW215	0.720	0.105	1.300	0.228	0.125	15.95	30.57

Table 19C—Lichen samples handled with fully rigorous protocols: data for elements Ni through Zn (continued)

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
24	WW216	0.375	0.094	1.080	0.252	0.111	13.25	18.22
24	WW211	0.990	0.094	5.285	0.124	0.088	46.46	20.51
24	WW212	0.820	0.091	6.135	0.137	0.093	50.85	24.20
24	WW217	0.580	0.217	2.805	0.150	0.096	29.02	40.95
24	WW218	0.645	0.217	2.835	0.150	0.098	28.29	39.47
24	WW219	0.395	0.185	0.430	0.228	0.133	3.33	73.44
24	WW220	0.395	0.190	0.455	0.237	0.146	3.44	71.04
24	WW213	0.335	0.081	2.045	0.081	0.072	66.05	18.18
24	WW214	0.335	0.068	2.375	0.094	0.064	75.00	15.52
25	WW3003	0.820	0.128	8.100	0.149	0.107	33.30	90.24
25	WW3004	0.550	0.090	8.080	0.084	0.066	70.84	33.51
26	WW3032	0.220	0.086	5.085	0.102	0.104	60.81	32.06
26	WW3033	0.780	0.143	3.570	0.152	0.144	21.17	86.38
27	WW123	0.690	0.059	1.765	0.249	0.139	5.21	31.84
27	WW124	0.605	0.057	1.685	0.214	0.133	4.90	35.53
27	WW126	0.425	0.111	1.600	0.149	0.099	19.77	38.35
27	WW127	1.065	0.123	1.725	0.164	0.109	19.83	35.17
27	WW128	1.350	0.101	1.415	0.139	0.091	18.01	35.01
27	WW136	0.755	0.103	2.465	0.191	0.113	14.25	78.67
27	WW137	0.735	0.091	2.920	0.189	0.115	16.99	72.82
28	WW3036	2.325	0.087	2.800	0.163	0.117	22.66	31.93
29	WW3038	0.645	0.170	0.725	0.360	0.201	3.30	49.13
30	WW3037	0.590	0.249	1.260	0.286	0.172	8.16	41.87
31	WW3134	0.395	0.107	29.380	0.152	0.110	48.56	31.26
32	WW3093	0.985	0.075	7.645	0.235	0.154	40.12	38.23
33	WW3095	0.620	0.103	3.100	0.185	0.143	38.20	21.02
33	WW3096	0.900	0.196	3.975	0.211	0.140	24.40	55.98
34	WW3101a	1.125	0.160	1.265	0.289	0.187	8.44	65.89
34	WW3101b	1.070	0.166	1.055	0.289	0.181	8.11	68.49
35	WW3135	0.705	0.103	16.800	0.173	0.117	34.35	41.24
36	WW3100	1.240	0.201	1.990	0.359	0.225	2.81	73.99
36	WW3099a	0.460	0.107	1.405	0.141	0.107	24.13	35.87
36	WW3099b	0.375	0.112	1.240	0.134	0.103	25.48	34.98
37	WW3089	2.170	0.113	4.155	0.134	0.083	46.98	33.02
37	WW3090	0.975	0.123	1.160	0.115	0.085	34.71	38.14
38	WW3094	0.445	0.063	5.010	0.141	0.107	56.43	43.55
39	WW3039	0.450	0.062	7.405	0.177	0.116	51.66	33.21

Table 19C—Lichen samples handled with fully rigorous protocols: data for elements Ni through Zn (continued)

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
39	WW3040	0.485	0.120	0.975	0.334	0.186	3.73	101.53
40	WW3097	2.435	0.057	6.030	0.169	0.122	46.22	126.19
40	WW3098	5.790	0.094	4.095	0.209	0.129	15.07	87.94
41	WW3091a	0.540	0.083	6.765	0.145	0.131	47.85	36.88
41	WW3091b	0.520	0.085	7.770	0.155	0.121	49.64	36.43
41	WW3092	0.800	0.148	1.330	0.268	0.193	4.63	71.94
42	WW3133	0.590	0.123	1.835	0.171	0.115	54.35	19.58
43	WW3130	0.580	0.191	0.710	0.314	0.213	2.19	40.78
43	WW3129a	0.810	0.079	1.150	0.209	0.161	42.92	31.64
43	WW3129b	0.795	0.083	0.865	0.238	0.173	36.13	29.38
44	WW3034	1.460	0.100	8.445	0.188	0.175	76.86	51.63
44	WW3035	1.115	0.109	6.080	0.111	0.082	45.34	39.34
45	WW3113	0.810	0.247	1.120		0.148	19.54	44.27
45	WW3114	0.890	0.266	1.385	0.317	0.214	2.75	38.47
46	WW3136	0.510	0.097	19.880	0.182	0.129	53.10	39.06
46	WW3137	0.605	0.053	14.270	0.218	0.134	34.91	39.49
47	WW3138	0.620	0.063	4.555	0.180	0.109	29.23	31.00
47	WW3139	0.920	0.099	3.575	0.249	0.129	10.61	52.89
48	WW3001	0.490	0.071	4.915	0.158	0.101	51.59	25.17
48	WW3002	0.735	0.144	3.265	0.199	0.133	16.76	57.49
49	WW3131	0.760	0.096	3.315	0.171	0.114	17.81	26.76
49	WW3132	0.570	0.201	1.120	0.287	0.146	6.91	41.33
50	WW3115	0.750	0.162	1.075	0.276	0.149	4.80	21.80
51	WW3116	0.895	0.098	1.740	0.378	0.291	3.63	37.35
52	WW3118	0.845	0.166	2.940	0.212	0.149	20.31	32.11
53	WW225	1.505	0.088	9.530	0.165	0.137	25.55	25.69
53	WW226	1.370	0.094	4.205	0.243	0.143	25.61	35.83
53	WW229	0.670	0.191	0.875	0.411	0.201	2.49	48.79
53	WW230	0.630	0.189	0.840	0.362	0.177	2.42	33.91
53	WW227	0.580	0.062	6.340	0.268	0.127	26.74	25.07
53	WW228	0.525	0.074	1.665	0.264	0.112	23.78	25.36
54	WW3085	0.850	0.184	1.525	0.375	0.246	2.54	33.64
54	WW3086	0.920	0.116	1.530	0.405	0.262	3.07	32.04
54	WW3087	1.100	0.075	1.850	0.181	0.136	18.33	29.50
55	WW3117	0.860	0.179	1.400	0.319	0.197	2.11	29.95
56	WW116	0.450	0.126	4.725	0.249	0.179	21.18	84.60
56	WW204	0.930	0.198	2.810	0.323	0.228	2.88	106.11

Table 19C—Lichen samples handled with fully rigorous protocols: data for elements Ni through Zn (continued)

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
57	WW114	0.350	0.285	3.200	0.258	0.196	14.38	21.43
57	WW115	0.590	0.332	3.760	0.276	0.177	5.72	32.28
57	WW201	0.425	0.168	0.795	0.354	0.198	1.98	43.07
57	WW202	0.490	0.199	0.940	0.296	0.210	1.93	35.72
57	WW203	0.390	0.174	0.705	0.315	0.192	1.40	23.27
58	WW206	0.600	0.168	1.745	0.379	0.255	2.37	48.09
58	WW207	0.670	0.171	1.790	0.369	0.262	2.23	48.14
58	WW117	0.435	0.077	11.085	0.234	0.151	18.57	35.51
58	WW118	0.315	0.065	10.870	0.177	0.144	19.56	35.09
59	WW238	2.080	0.107	3.035	0.211	0.121	48.27	60.18
59	WW239	2.190	0.117	3.710	0.200	0.126	53.18	74.38
59	WW240	1.285	0.102	3.215	0.232	0.125	50.93	65.43
59	WW253	0.990	0.177	3.830	0.203	0.142	26.69	63.78
59	WW251	0.550	0.188	1.185	0.386	0.172	8.10	42.92
59	WW252	0.570	0.201	1.115	0.432	0.183	6.15	42.20
59	WW248	0.745	0.113	1.720	0.221	0.119	46.98	48.48
59	WW249	0.830	0.120	2.125	0.214	0.120	46.51	50.53
59	WW250	0.825	0.110	2.205	0.206	0.126	48.06	53.28
60	WW3069	0.645	0.143	1.165	0.133	0.085	62.83	21.20
60	WW3070	0.750	0.193	1.130	0.254	0.164	4.84	46.18
61	WW3080	2.495	0.084	1.055	0.104	0.091	24.26	18.39
61	WW3081	0.650	0.065	2.400	0.134	0.091	9.77	19.92
62	WW3083	0.830	0.051	2.770	0.232	0.086	20.80	11.48
62	WW3084	1.675	0.248	2.575		0.207	6.00	48.93
63	WW3046	0.780	0.097	2.580	0.145	0.124	10.87	25.04
63	WW3047	0.890	0.110	2.255	0.140	0.122	13.48	19.93
63	WW3050	0.945	0.141	1.295	0.336	0.221	2.52	60.03
63	WW3048	0.650	0.060	1.215	0.165	0.147	11.39	41.94
63	WW3049	0.985	0.109	1.665	0.131	0.115	25.00	21.80
64	WW3061	0.560	0.111	2.505	0.181	0.125	13.83	23.66
64	WW3062	0.450	0.099	1.160	0.127	0.099	28.18	28.35
65	WW269	0.650	0.231	1.360	0.323	0.217	1.89	49.68
65	WW270	0.635	0.230	1.440	0.416	0.211	6.03	45.18
65	WW273	0.515	0.092	2.080	0.216	0.109	22.62	30.36
65	WW274	0.475	0.090	2.010	0.225	0.108	21.69	28.61
66	WW3063	0.945	0.193	2.270	0.132	0.091	16.80	22.32
66	WW3064	0.375	0.166	bdl	0.112	0.090	30.93	23.68

Table 19C—Lichen samples handled with fully rigorous protocols: data for elements Ni through Zn (continued)

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
67	WW3067	0.790	0.086	3.155	0.162	0.124	10.73	21.99
67	WW3068	0.515	0.099	0.790	0.128	0.102	20.06	30.94
68	WW268	bdl	0.043	1.220		0.032	2.13	16.00
68	WW264	0.745	0.192	1.570	0.375	0.218	1.97	60.63
68	WW265	0.640	0.180	1.655	0.416	0.220	2.48	70.38
68	WW267	0.525	0.135	4.125	0.203	0.181	17.63	40.23
69	WW3051	0.655	0.108	2.450	0.188	0.159	13.15	46.18
69	WW3052	0.705	0.096	1.860	0.173	0.125	13.60	34.47
70	WW3053	0.370	0.194	1.610	0.141	0.115	16.03	22.31
70	WW3054	0.375	0.155	2.025	0.163	0.125	18.72	19.64
70	WW3055a	0.380	0.156	0.720	0.128	0.099	14.73	33.77
70	WW3055b	0.440	0.160	1.095	0.131	0.101	15.88	26.95
71	WW262	1.085	0.152	3.180	0.370	0.271	1.77	80.68
71	WW263	1.120	0.158	3.360	0.391	0.260	2.45	85.03
72	WW3045	0.925	0.094	1.630	0.099	0.088	25.38	17.60
73	WW3041	0.620	0.112	3.230	0.184	0.120	10.52	24.40
73	WW3042	0.525	0.117	1.830	0.230	0.140	40.80	25.28
74	WW260a	1.440	0.170	27.950	0.438	0.225	21.29	79.93
74	WW260b	1.505	0.166	27.370	0.432	0.236	22.07	83.68
74	WW261	1.070	0.196	7.460	0.333	0.325	5.78	135.56
75	WW256	1.420	0.243	7.825	0.157	0.278	3.75	92.38
75	WW257	1.440	0.243	6.995	0.298	0.269	3.45	86.28
75.5	WW258	6.010	0.211	41.415	0.296	0.286	3.63	High
75.5	WW259	5.760	0.207	45.120	0.339	0.283	3.77	High
76	WW3043	0.130	0.102	1.680	0.167	0.126	12.86	25.22
76	WW3044	0.550	0.139	0.550	0.310	0.207	2.11	36.00
77	WW3011	0.725	0.259	1.360	0.402	0.274	2.21	28.87
78	WW3010	0.790	0.130	1.320	0.427	0.297	2.49	42.37
78	WW3009	0.325	0.143	0.735	0.152	0.119	15.13	19.13
79	WW3006	0.535	0.235	1.205	0.323	0.217	1.77	31.27
80	WW3008	0.855	0.215	1.855	0.287	0.220	9.62	24.21
80	WW3007	0.500	0.057	1.150	0.117	0.075	19.55	35.55
81	WW3121	0.670	0.244	1.680	0.374	0.253	6.43	53.36
82	WW3119a	0.360	0.156	0.940	0.383	0.216	2.58	22.22
82	WW3119b	0.210	0.080	0.515	0.381	0.116	1.69	11.84
83	WW3120	0.310	0.116	0.575	0.393	0.106	1.57	19.73

Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; Sr = strontium; Zn = zinc.

Appendix 10: Original Data for Validated Elements in Lichen Samples From Protocol Variations, Other Species, and Reference Material

See text for details of field collection and sample handling protocols; See appendix 8 for information about each lichen plot. Tables 20A through D have information and data for lichen samples handled with variations of less rigorous field and handling protocols. None of these samples had any field data quality issues. Data were analyzed in Will-Wolf et al. (2017b). Tables 21A through D have sample information and data for measured non-focus lichen species. These data were not included in most analyses. Tables 22A through D have information and data for samples of the certified external standard and internal Flacap reference (fully rigorous protocols) measured for validation analyses conducted by Will-Wolf et al. (2017a) and reported in appendix 5. None of these samples had any field data quality issues.

These notes refer to all tables:

- The lichen analysis site code orders sites by latitude north (1) to south (83).
- Sample laboratory codes are the project internal codes for each sample measured for elemental content.
- Sample laboratory codes, with a or b following, designate lab splits of a single sample after grinding and before measurement. Sample data for analysis were the average of the two splits.

These notes refer to tables 20A, 21A, and 22A:

- Lichen species abbreviations: Evemes = *Evernia mesomorpha*; Flacap = *Flavoparmelia caperata*; Parsul = *Parmelia sulcata*; Phyaip = *Physcia aipolia* and *P. stellaris* combined;
- Punrud = *Punctelia rudecta*.
- Abbreviations: full = full removal of substrate during preparation; part = partial removal of substrate during preparation; small = sample <1 mg after preparation; subs = substrates
- Number on map, fig. 1, is either the number for the site itself or the number of the instrument monitor site near that lichen site.
- Field collection codes: 1 = fully rigorous field and handling protocols; 2 = least relaxed protocol, hands wiped with alcohol substituting for wearing nitrile gloves in field, all other rigorous protocols followed; 3 = moderately relaxed protocol, no field or handling cleanliness protocols followed; 4 = most relaxed and least rigorous protocol, no cleanliness protocols, no chemically clean sample containers, no separation of species until prepared for measurement (Will-Wolf et al. 2017b)

These notes refer to tables 20B through D, 21B through D, and 22B through D:

- Data for validated elements aluminum (Al), carbon (C), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), magnesium (Mg), manganese (Mn), nitrogen (N), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), strontium (Sr), and zinc (Zn) are listed in alphabetical order of their official acronyms.
- Element acronyms preceded by "Total" were measured by combustion analysis; all other elements were measured by ICP-OES. Sulfur (S) was measured by both methods.
- Cells with "high" had extremely high outliers that were excluded before validation.
- Cells with "bdl" had values below detection level.
- Blank cells indicate that element was not measured for that sample.

Table 20A—Lichen samples handled with variants of less rigorous field and handling protocols: sample information

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field collection code	Laboratory preparation code
						Grams		
21	WW157	NRS Rhinelander	1	Evemes	1	2.0	4	Full
21	WW158	NRS Rhinelander	1	Evemes	2	3.47	4	Full
21	WW159	NRS Rhinelander	1	Flacap	1	4.48	4	Full
21	WW160	NRS Rhinelander	1	Flacap	2	3.4	4	Full
21	WW161	NRS Rhinelander	1	Parsul	1	2.15	4	Full
21	WW162	NRS Rhinelander	1	Parsul	2	1.41	4	Full
24	WW221	Wabikon Lake	2	Flacap	1	1.33	4	Full
24	WW222	Wabikon Lake	2	Flacap	2	1.7	4	Full
24	WW223	Wabikon Lake	2	Punrud	1	1.92	4	Full
24	WW224	Wabikon Lake	2	Punrud	2	1.92	4	Full
27	WW120	Jerry Lake	3	Evemes	1	1.76	3	Full
27	WW121	Jerry Lake	3	Evemes	2	2.01	3	Full
27	WW122	Jerry Lake	3	Evemes	3	2.09	3	Full
27	WW129	Jerry Lake	3	Flacap	1	2.26	3	Full
27	WW132	Jerry Lake	3	Flacap	1	5.57	4	Full
27	WW130	Jerry Lake	3	Flacap	2	2.49	3	Full
27	WW133	Jerry Lake	3	Flacap	2	5.67	4	Full
27	WW131	Jerry Lake	3	Flacap	3	2.59	3	Full
27	WW134	Jerry Lake	3	Flacap	3	5.04	4	Full
27	WW138	Jerry Lake	3	Parsul	1	0.94	3	Part

Table 20A—Lichen samples handled with variants of less rigorous field and handling protocols: sample information (continued)

Lichen analysis site code	Sample laboratory code	Location	Number on map	Lichen species code	Replicate number	Oven-dry weight	Field collection code	Laboratory preparation code
						Grams		
27	WW140	Jerry Lake	3	Parsul	1	0.8	3	Full
27	WW139	Jerry Lake	3	Parsul	2	0.93	3	Part
27	WW141	Jerry Lake	3	Parsul	2	0.84	3	Full
48.5	WW101	Gilbert Lake	13	Flacap	1	5.15	3	Part
48.5	WW104	Gilbert Lake	13	Flacap	1	4.94	3	Full
48.5	WW102	Gilbert Lake	13	Flacap	2	5.45	3	Part
48.5	WW105	Gilbert Lake	13	Flacap	2	3.84	3	Full
48.5	WW103	Gilbert Lake	13	Flacap	3	4.94	3	Part
48.5	WW106	Gilbert Lake	13	Flacap	3	4.47	3	Full
48.5	WW108	Gilbert Lake	13	Punrud	1	5.34	3	Part
48.5	WW111	Gilbert Lake	13	Punrud	1	4.45	3	Full
48.5	WW109	Gilbert Lake	13	Punrud	2	4.74	3	Part
48.5	WW112	Gilbert Lake	13	Punrud	2	4.03	3	Full
48.5	WW110	Gilbert Lake	13	Punrud	3	4.54	3	Part
48.5	WW113	Gilbert Lake	13	Punrud	3	4.26	3	Full
59	WW232	Baxter’s Hollow	6	Flacap	1	0.88	4	Full
59	WW235	Baxter’s Hollow	6	Flacap	1	1.11	2	Full
59	WW233	Baxter’s Hollow	6	Flacap	2	0.88	4	Full
59	WW236	Baxter’s Hollow	6	Flacap	2	1.17	2	Full
59	WW234	Baxter’s Hollow	6	Flacap	3	0.87	4	Full
59	WW237	Baxter’s Hollow	6	Flacap	3	1.38	2	Full
59	WW242	Baxter’s Hollow	6	Punrud	1	1.68	4	Full
59	WW245	Baxter’s Hollow	6	Punrud	1	1.99	2	Full
59	WW243	Baxter’s Hollow	6	Punrud	2	1.61	4	Full
59	WW246	Baxter’s Hollow	6	Punrud	2	1.27	2	Full
59	WW244	Baxter’s Hollow	6	Punrud	3	1.43	4	Full
59	WW247	Baxter’s Hollow	6	Punrud	3	1.3	2	Full
65	WW271	Madison Sandburg Park	7	Phyaip	1	2.23	1	Part
65	WW272	Madison Sandburg Park	7	Phyaip	2	1.78	1	Part
68	WW266a	Madison Hiestad Park	7	Phyaip	2	1.1	1	Part
68	WW266b	Madison Hiestad Park	7	Phyaip	2	1.1	1	Part

Full = sample with >99 percent of substrate removed; part = sample with ~95 percent of substrate removed.

Table 20B—Lichen samples handled with variants of less rigorous field and handling protocols: sample data are for elements Al through Cu

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
21	WW157	243.4	49.38	0.313	0.155	0.145	0.410	2.090
21	WW158	271.6	46.12	0.336	0.150	0.135	0.450	2.405
21	WW159	217.8	42.31	4.731	0.760	0.130	0.385	2.415
21	WW160	154.6	41.55	5.588	0.670	0.110	0.325	2.055
21	WW161	367.2	46.20	0.529	0.340	0.215	0.605	4.265
21	WW162	333.5	42.34	0.563	0.200	0.200	0.525	4.760
24	WW221	195.7	43.90	3.202	0.520	0.150	0.435	2.345
24	WW222	204.7	44.76	2.895	0.515	0.125	0.440	1.880
24	WW223	128.0	35.50	6.909	0.530	0.095	0.280	0.710
24	WW224	149.0	35.60	6.124	0.430	0.105	0.340	0.940
27	WW120	326.2	46.42	0.232	0.070	0.180	0.555	2.520
27	WW121	355.7	46.77	0.244	0.050	0.155	0.590	2.510
27	WW122	564.8	46.23	0.282	0.055	0.330	0.935	3.060
27	WW129	389.6	45.75	1.710	0.545	0.235	0.595	25.730
27	WW132	244.3	79.68	2.895	0.130	0.165	0.480	2.835
27	WW130	384.8	45.57	1.533	0.865	0.235	0.650	5.010
27	WW133	221.0	44.62	2.994	0.135	0.140	0.425	2.305
27	WW131	370.2	45.07	2.173	0.605	0.240	0.630	3.700
27	WW134	230.5	43.95	3.193	0.135	0.145	0.450	2.335
27	WW138	517.1	45.51	0.873	0.270	0.330	0.850	5.165
27	WW140	459.4	44.07	0.875	0.255	0.295	0.760	6.700
27	WW139	570.1	44.57	0.895	0.270	0.365	0.965	7.270
27	WW141	431.0	44.83	0.762	0.225	0.405	0.700	5.535
48.5	WW101	412.5	39.48	5.085	0.505	0.195	0.830	4.130
48.5	WW104	282.3	38.99	6.130	0.265	0.130	0.680	2.980
48.5	WW102	363.7	39.11	5.395	0.250	0.175	0.760	3.920
48.5	WW105	263.3	38.00	6.615	0.315	0.120	0.595	2.970
48.5	WW103	379.1	40.45	4.768	0.235	0.205	0.795	3.675
48.5	WW106	298.4	37.77	6.425	0.290	0.160	0.690	3.285
48.5	WW108	363.8	37.88	7.085	0.290	0.170	0.785	2.745
48.5	WW111	232.5	37.93	6.840	0.270	0.110	0.580	2.210
48.5	WW109	352.4	38.59	6.610	0.275	0.155	0.785	2.945
48.5	WW112	219.2	37.83	6.705	0.265	0.115	0.495	2.230
48.5	WW110	365.4	37.96	7.025	0.285	0.185	0.795	3.080
48.5	WW113	236.7	36.81	7.315	0.280	0.095	0.515	2.270
59	WW232	220.7	46.76	2.375	1.065	0.160	0.490	3.035

Table 20B—Lichen samples handled with variants of less rigorous field and handling protocols: sample data are for elements Al through Cu (continued)

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
59	WW235	265.1	45.71	2.496	1.150	0.195	0.535	3.305
59	WW233	214.3	45.75	2.650	1.180	0.165	0.485	2.845
59	WW236	295.7	42.22	2.187	1.315	0.255	0.560	3.375
59	WW234	218.1	45.58	2.579	1.335	0.195	0.470	2.795
59	WW237	298.7	40.57	2.615	1.185	0.240	0.595	3.385
59	WW242	291.0	43.10	2.500	1.495	0.180	0.600	2.485
59	WW245	302.9	43.77	2.579	1.135	0.185	0.640	2.800
59	WW243	314.5	40.87	3.297	1.870	0.190	0.700	2.620
59	WW246	258.9	42.60	2.689	1.170	0.200	0.580	2.645
59	WW244	250.5	43.18	2.822	1.725	0.185	0.570	2.365
59	WW247	290.0	44.15	3.408	1.695	0.200	0.655	2.505
65	WW271	351.0	48.03	0.571	0.175	0.240	1.065	4.910
65	WW272	359.3	51.37	0.807	0.155	0.265	1.085	5.155
68	WW266a	418.0	46.83	0.856	0.090	0.245	1.060	28.045
68	WW266b	511.9	47.98	0.613	0.135	0.315	1.270	33.350

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper.

Table 20C—Lichen samples handled with variants of less rigorous field and handling protocols: sample data are for elements Fe through Na

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
21	WW157	293.0	0.131	0.239	0.036	74.46	1.24	26.10
21	WW158	333.5	0.152	0.229	0.036	42.50	1.26	25.95
21	WW159	233.8	0.147	0.314	0.040	184.31	0.78	18.65
21	WW160	170.7	0.143	0.324	0.041	158.01	0.76	25.50
21	WW161	413.1	0.103	0.309	0.056	170.36	1.07	20.20
21	WW162	371.3	0.059	0.297	0.052	155.01	1.08	18.70
24	WW221	205.4	0.101	0.429	0.089	153.16	0.83	40.40
24	WW222	208.0	0.099	0.425	0.083	149.96	0.88	36.70
24	WW223	123.1	0.073	0.262	0.063	65.41	0.70	35.20
24	WW224	152.9	0.063	0.284	0.071	31.37	0.72	46.50
27	WW120	446.9	0.172	0.218	0.038	29.01	1.71	27.50
27	WW121	480.4	0.221	0.216	0.038	31.20	1.69	32.00
27	WW122	804.9	0.266	0.221	0.052	48.55	1.89	32.50
27	WW129	481.8	0.166	0.340	0.071	132.47	1.53	34.55
27	WW132	300.8	0.223	0.288	0.061	180.66	1.98	18.35
27	WW130	472.5	0.172	0.396	0.081	169.07	1.61	22.70
27	WW133	271.2	0.223	0.293	0.060	173.16	1.08	19.15
27	WW131	461.8	0.172	0.355	0.074	130.61	1.35	23.40
27	WW134	282.8	0.187	0.286	0.058	170.66	1.07	20.40
27	WW138	684.1	0.088	0.435	0.162	48.83	1.56	16.85
27	WW140	607.1	0.080	0.441	0.155	49.42	1.55	16.25
27	WW139	771.1	0.082	0.407	0.169	56.91	1.54	18.25
27	WW141	571.6	0.072	0.440	0.160	47.61	1.52	13.90
48.5	WW101	477.7	0.200	0.358	0.066	89.17	1.33	25.50
48.5	WW104	308.7	0.112	0.381	0.055	51.42	1.23	24.55
48.5	WW102	406.9	0.136	0.372	0.064	63.57	1.32	23.05
48.5	WW105	286.0	0.114	0.382	0.055	54.97	1.22	21.10
48.5	WW103	453.7	0.132	0.336	0.086	72.32	1.25	27.05
48.5	WW106	327.3	0.207	0.385	0.062	56.67	1.22	21.50
48.5	WW108	407.3	0.099	0.239	0.053	65.07	1.09	26.10
48.5	WW111	268.2	0.073	0.232	0.049	47.15	1.09	25.10
48.5	WW109	409.0	0.087	0.224	0.053	71.47	1.12	27.60
48.5	WW112	247.5	0.075	0.243	0.050	48.34	1.10	26.85
48.5	WW110	426.6	0.088	0.224	0.054	78.47	1.16	26.15
48.5	WW113	267.6	0.090	0.248	0.049	51.37	1.05	26.60
59	WW232	208.2	0.137	0.411	0.072	46.44	1.81	11.40

Table 20C—Lichen samples handled with variants of less rigorous field and handling protocols: sample data are for elements Fe through Na (continued)

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
59	WW235	238.4	0.160	0.479	0.075	54.65	1.56	19.05
59	WW233	194.8	0.122	0.366	0.064	46.09	1.63	16.00
59	WW236	266.6	0.166	0.443	0.078	42.90	1.68	14.50
59	WW234	196.1	0.106	0.402	0.066	39.04	1.56	12.00
59	WW237	264.8	0.142	0.407	0.071	44.95	1.62	15.70
59	WW242	266.5	0.090	0.310	0.075	37.54	1.41	13.30
59	WW245	285.1	0.104	0.265	0.073	54.95	1.46	8.80
59	WW243	295.5	0.097	0.310	0.083	39.14	1.44	10.60
59	WW246	246.2	0.089	0.310	0.082	48.85	1.61	9.45
59	WW244	235.9	0.108	0.282	0.075	37.01	1.42	8.00
59	WW247	276.9	0.097	0.281	0.076	42.42	1.60	9.90
65	WW271	459.5	0.107	0.720	0.132	111.65	2.46	60.70
65	WW272	460.4	0.126	0.610	0.131	153.10	2.30	55.30
68	WW266a	485.1	0.106	0.554	0.125	21.19	1.90	34.85
68	WW266b	610.6	0.123	0.600	0.130	30.01	2.41	43.70

Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium.

Table 20D—Lichen samples handled with variants of less rigorous field and handling protocols: sample data for elements Ni through Zn

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
21	WW157	1.715	0.064	1.270	0.187	0.105	7.08	27.57
21	WW158	1.560	0.066	1.220	0.154	0.112	6.34	29.22
21	WW159	0.520	0.120	4.880	0.106	0.082	62.35	37.17
21	WW160	0.965	0.118	7.700	0.119	0.083	76.05	30.24
21	WW161	0.760	0.133	3.435	0.144	0.099	25.68	85.22
21	WW162	0.675	0.130	2.810	0.152	0.096	28.92	69.42
24	WW221	0.890	0.085	4.370	0.155	0.081	47.47	23.31
24	WW222	0.870	0.078	4.625	0.111	0.080	40.47	21.98
24	WW223	0.265	0.062	2.405	0.090	0.054	57.35	14.41
24	WW224	0.450	0.075	2.020	0.073	0.057	46.25	13.70
27	WW120	0.515	0.066	1.860	0.203	0.118	3.28	25.54
27	WW121	0.475	0.064	1.975	0.208	0.118	3.37	24.02
27	WW122	0.875	0.070	2.140	0.220	0.134	5.50	28.45
27	WW129	0.640	0.121	4.615	0.153	0.113	31.56	79.56
27	WW132	0.460	0.090	1.880	0.133	0.085	20.03	41.02
27	WW130	0.620	0.142	2.620	0.170	0.114	30.17	85.11
27	WW133	0.405	0.089	1.470	0.131	0.083	20.11	45.57
27	WW131	0.600	0.125	2.985	0.126	0.097	36.86	68.07
27	WW134	0.465	0.085	1.560	0.148	0.087	21.08	42.56
27	WW138	0.910	0.215	6.435	0.194	0.114	36.92	76.77
27	WW140	0.815	0.214	6.645	0.169	0.116	36.07	79.22
27	WW139	0.965	0.209	6.825	0.182	0.115	37.85	75.07
27	WW141	1.060	0.228	5.860	0.175	0.113	32.61	68.37
48.5	WW101	5.025	0.160	6.885	0.174	0.125	18.73	19.94
48.5	WW104	0.520	0.167	6.340	0.147	0.108	19.95	18.78
48.5	WW102	0.465	0.162	7.070	0.179	0.119	19.69	19.11
48.5	WW105	0.650	0.167	6.900	0.121	0.109	21.10	18.81
48.5	WW103	0.640	0.148	5.940	0.143	0.113	18.55	18.99
48.5	WW106	0.700	0.165	6.225	0.144	0.112	20.24	20.17
48.5	WW108	0.515	0.124	6.395	0.114	0.098	19.21	20.07
48.5	WW111	0.330	0.124	4.215	0.141	0.088	19.60	18.77
48.5	WW109	0.575	0.122	5.510	0.127	0.102	19.01	18.76
48.5	WW112	0.350	0.131	3.840	0.143	0.091	18.66	19.40
48.5	WW110	0.485	0.120	5.770	0.146	0.104	19.30	19.23
48.5	WW113	0.385	0.123	4.485	0.129	0.087	19.45	18.22
59	WW232	0.775	0.105	2.850	0.237	0.131	41.31	54.68

Table 20D—Lichen samples handled with variants of less rigorous field and handling protocols: sample data for elements Ni through Zn (continued)

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
59	WW235	1.280	0.121	3.875	0.242	0.125	44.14	68.88
59	WW233	1.555	0.090	3.300	0.201	0.124	42.95	54.23
59	WW236	1.845	0.124	3.660	0.199	0.129	35.70	68.43
59	WW234	1.480	0.099	3.135	0.231	0.127	44.28	54.08
59	WW237	0.915	0.103	3.495	0.192	0.124	40.12	67.08
59	WW242	0.815	0.110	2.530	0.184	0.105	43.69	61.33
59	WW245	0.760	0.105	2.880	0.160	0.106	43.68	50.33
59	WW243	0.925	0.123	2.940	0.174	0.107	53.63	67.38
59	WW246	2.675	0.128	3.155	0.217	0.116	41.61	59.28
59	WW244	0.870	0.109	2.500	0.190	0.104	46.05	57.93
59	WW247	0.785	0.123	3.290	0.186	0.109	49.28	59.48
65	WW271	1.010	0.202	2.850	0.439	0.197	9.14	46.83
65	WW272	1.665	0.193	2.500	0.415	0.187	17.09	41.65
68	WW266a	0.665	0.149	2.470	0.425	0.170	14.18	51.33
68	WW266b	0.875	0.154	3.085	0.393	0.199	10.17	61.63

Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; Sr = strontium; Zn = zinc.

Table 21A—Non-target lichen species: sample information

Lichen analysis site code	Sample laboratory code	Location	Number on map	Species	Replicate number	Oven-dry weight	Field issue	Field collection code	Laboratory preparation code
						Grams			
66	WW3065	FIA plot		Punmis	1	0.8	Small, <6 subs	1	Full
79	WW3005	FIA plot		Punmis	1	1.07		1	Full
61	WW3082	FIA plot		Ramame	1	0.24	Small, <6 subs	1	Full
66	WW3066	FIA plot		Ramame	1	0.6	Small, <6 subs	1	Full
1	WW3077	FIA plot		Ramame	1	1.41		1	Full
59	WW254	Baxter's Hollow	6	Ramame	1	0.28	Small, 1 subs	1	Full
27	WW142	Jerry Lake	3	Ramame	1	0.99		1	Full

Field collection code 1 = fully rigorous; subs = substrates.

Table 21B—Nontarget lichen species: sample data for elements Al through Cu

Lichen analysis site code	Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
66	WW3065	533		3.669	0.135	0.350	1.015	2.35
79	WW3005	270	39.3	6.549	0.110	0.140	0.520	2.57
61	WW3082	130		0.323	bdl	bdl	0.475	1.70
66	WW3066	126		0.666	bdl	0.110	0.540	1.82
1	WW3077	94	47.3	0.257	0.135	0.085	0.320	1.65
59	WW254	66	44.3	0.262	bdl	bdl	0.450	bdl
27	WW142	233	43.1	0.250	0.055	0.215	0.525	2.71

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper.

Table 21C—Nontarget lichen species: sample data for elements Fe through Na

Lichen analysis site code	Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*Percent*	*Percent*	*mg/kg*
66	WW3065	809	0.035	0.329	0.106	52.2		11.5
79	WW3005	278	0.079	0.285	0.112	38.0	1.54	20.6
61	WW3082	177		0.106	0.024	12.4		bdl
66	WW3066	178	0.038	0.221	0.063	15.6		18.7
1	WW3077	123	0.037	0.109	0.022	24.1	0.84	28.9
59	WW254	72		0.245	0.060	10.8	1.56	71.0
27	WW142	329	0.052	0.198	0.042	18.7	1.59	38.6

Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium.

Table 21D—Nontarget lichen species: sample data for elements Ni through Zn

Lichen analysis site code	Sample laboratory code	Ni	P	Pb	Total S	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
66	WW3065	0.880	0.192	1.695	0.134	0.092	14.65	23.1
79	WW3005	0.405	0.140	1.285	0.147	0.118	13.41	24.7
61	WW3082	1.225	0.038	1.075	0.153	0.096	2.23	15.0
66	WW3066	0.430	0.113	0.640	0.138	0.090	3.49	14.0
1	WW3077	0.790	0.034	0.270	0.120	0.061	4.38	14.5
59	WW254	bdl	0.100	bdl	0.184	0.081	3.58	10.2
27	WW142	0.675	0.081	0.940	0.189	0.108	4.80	15.0

Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; Sr = strontium; Zn = zinc.

Table 22A—Lichen reference material for validation analyses: sample information

Sample laboratory code	Location	Number on map	Lichen species	Replicate code	Oven-dry weight	Field collection code	Laboratory preparation code
					Grams		
Flacap internal reference sample:							
Pre-run test	Mead Wildlife Area	12	Flacap	1	1.0	1	Full
WW119	Mead Wildlife Area	12	Flacap	1	1.0	1	Full
WW135	Mead Wildlife Area	12	Flacap	2	1.0	1	Full
WW147	Mead Wildlife Area	12	Flacap	3	1.0	1	Full
WW210	Mead Wildlife Area	12	Flacap	1	1.0	1	Full
WW241	Mead Wildlife Area	12	Flacap	2	1.0	1	Full
WW3060	Mead Wildlife Area	12	Flacap	1	1.0	1	Full
WW3122	Mead Wildlife Area	12	Flacap	2	1.0	1	Full
IAEA-336 certified standard:							
Pre-run test	rural Portugal		Evepru	1	1.0		
WW107	rural Portugal		Evepru	1	1.0		
WW125	rural Portugal		Evepru	2	1.0		
WW156	rural Portugal		Evepru	3	1.0		
WW231	rural Portugal		Evepru	1	1.0		
WW255	rural Portugal		Evepru	2	1.0		
WW3031	rural Portugal		Evepru	1	1.0		
WW3088	rural Portugal		Evepru	2	1.0		

Field collection code 1 = fully rigorous.

Table 22B—Lichen reference material for validation analyses: sample data for elements Al through Cu

Sample laboratory code	Al	Total C	Ca	Cd	Co	Cr	Cu
	mg/kg	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
Flacap internal reference sample (12 on fig. 1):							
Pre-run test	427	42.81	3.690	0.35	0.26	0.66	3.8
WW119	352	43.06	3.685	0.34	0.24	0.61	3.7
WW135	349	42.25	3.760	0.48	0.23	0.57	121.2
WW147	345	43.12	3.712	0.39	0.22	0.53	3.8
WW210	309	42.10	3.440	0.38	0.25	0.54	2.9
WW241	337	41.51	3.606	0.40	0.26	0.62	3.0
WW3060	374	46.57	3.769	0.39	0.27	0.67	4.1
WW3122	383	43.91	3.697	0.41	0.27	0.58	4.2
IAEA-336 certified standard:							
Pre-run test	234	44.30	0.230	0.08	0.23	0.52	2.5
WW107	240	43.79	0.238	0.07	0.24	0.52	2.3
WW125	206	44.30	0.214	0.07	0.19	0.44	2.2
WW156	217	44.81	0.226	0.07	0.20	0.41	2.3
WW231	206	41.68	0.219	0.10	0.23	0.48	2.1
WW255	222	46.32	0.227	0.10	0.21	0.50	2.0
WW3031	209	45.98	0.210	0.09	0.25	0.39	2.3
WW3088	206	42.69	0.215	0.09	0.26	0.48	2.3

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper.

Table 22C—Lichen reference material for validation analyses: sample data for elements Fe through Na

Sample laboratory code	Fe	Total Hg	K	Mg	Mn	Total N	Na
	mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
Flacap internal reference sample (12 on fig. 1):							
Pre-run test	465	0.1414	0.338	0.082	51	1.190	27
WW119	478	0.1491	0.338	0.085	49	1.205	23
WW135	482	0.1538	0.334	0.087	50	1.190	24
WW147	469	0.1212	0.324	0.084	49	1.175	20
WW210	382	0.1265	0.329	0.081	44	1.198	26
WW241	375	0.1382	0.342	0.086	45	1.249	19
WW3060	528	0.1176	0.332	0.087	53	1.223	29
WW3122	500	0.1358	0.358	0.092	54	1.171	32
IAEA-336 certified standard:							
Pre-run test	279	0.1795	0.144	0.050	56	0.624	257
WW107	298	bdl	0.146	0.053	57	0.649	265
WW125	269	0.1637	0.146	0.050	53	0.621	257
WW156	284	0.1952	0.145	0.052	55	0.601	266
WW231	229	0.2091	0.147	0.051	51	0.692	264
WW255	254	0.1944	0.154	0.053	54	0.685	276
WW3031	314	0.1756	0.140	0.049	54	0.626	259
WW3088	290	0.2240	0.121	0.047	55	0.671	236

Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium.

Table 22D—Lichen reference material for validation analyses: sample data for elements Ni through Zn

Sample laboratory code	Ni	P	Pb	Total S	S	St	Zn
	mg/kg	*Percent*	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*mg/kg*
Flacap internal reference sample (12 on fig. 1):							
Pre-run test	0.8	0.114	6.6	0.144	0.098	66.8	43.6
WW119	0.7	0.113	6.6	0.150	0.098	67.8	44.5
WW135	2.0	0.119	7.9	0.157	0.101	69.3	46.3
WW147	1.0	0.118	6.9	0.126	0.099	67.8	44.5
WW210	0.8	0.108	6.4	0.143	0.093	64.1	40.9
WW241	0.8	0.114	7.2	0.166	0.101	67.4	42.5
WW3060	0.8	0.119	7.0	0.135	0.106	72.3	49.2
WW3122	0.7	0.127	7.1	0.151	0.104	71.7	47.3
IAEA-336 certified standard:							
Pre-run test	0.7	0.051	4.2	0.119	0.058	6.5	26.9
WW107	0.7	0.053	4.4	0.106	0.062	6.7	29.1
WW125	0.6	0.049	4.1	0.112	0.058	6.1	27.2
WW156	0.7	0.053	4.6	0.137	0.061	6.5	28.5
WW231	0.7	0.050	4.4	0.134	0.061	6.4	26.9
WW255	0.7	0.052	4.7	0.133	0.063	6.6	28.3
WW3031	0.7	0.047	4.2	0.125	0.085	6.3	29.7
WW3088	0.8	0.051	4.8	0.125	0.058	6.3	28.4

Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; St = strontium; Zn = zinc.

Appendix 11: Conversion Formulas Between Lichen Species

Each formula converts elemental values of another species to equivalence with those of *Flavoparmelia caperata*. Modified from Will-Wolf et al. (2017a).

These notes apply to each of the four tables that follows (tables 23 through 26):

- Em, Evemes = *Evernia mesomorpha*
- Fc, Flacap = *Flavoparmelia caperata*
- Ps, Parsul = *Parmelia sulcata*
- Pa, Phyaip = *Physcia aipolia/stellaris*
- Pr, Punrud = *Punctelia rudecta*

All estimated marginal means, coefficients, and constants in formulas and equations are truncated to eight significant digits.

All sites with both species were included unless listed.

Original data were used unless a transformation is listed.

Abbreviations:

coeff = coefficient, for regression equation

EMM = estimated marginal mean, from GLM

GLM = general linear model

m or mp = model probability value

regress = regression model

spp = species probability value

wk = weak model; model $0.01 < p < 0.05$

Data: If a conversion model indicates that logarithm base 10-transformed (log10) data should be used, all data are log10-transformed and the conversion formula is applied, then the converted data are back-transformed to original units. For data to be averaged in log10 form, data for that species and converted data for Flacap are all log10 transformed and log10 data are averaged, then the average is back-transformed to original units.

Regression model formulas—examples:

Conversion Formula example:	Original model regression equation example:
Fc equivalent value = (Em – constant) / coefficient for Fc	Equation: Em = constant + coefficient × Fc

GLM models: The EMM for the other species was subtracted from the EMM for Fc. The result was used as additive conversion factor for the other species.

Excluded sites: A site was excluded from calibration between two species for a particular element if all samples for one of the species had moderate (2 to 5 times the average for all samples) outlier values or locally "odd" values (1.5 to 2 times higher or more than 25 percent lower as compared with several other samples at that or nearby sites**).** All values excluded for conversion between species were also excluded from subsequent analyses.

All formulas to convert new data from these other species to equivalence with Flacap are in the column with header "Conversion formula: use to convert new data" of each table.

Table 23—Flacap vs. Evemes conversion formulas

Element	Exclude sites	Transform	Model	p values	Calculations: EMMs (GLM) or Fc coefficient and constant (regression)						
									EMM Fc—EMM Em	Conversion formula: USE TO CONVERT NEW DATA	Original regression equation
Al	3, 6, 11		GLM	mp 0.0058, spp 0.0001	EMM Fc	219.8021978	EMM Em	322.32051	–102.51832	Fc equiv = Em – 102.51832	
C	3, 6		GLM, wk	mp 0.016, spp 0.0002	EMM Fc	43.29460884	EMM Em	46.881071	–3.5864626	Fc equiv = Em – 3.5864626	
Ca	3, 6		GLM	mp 0.0008, spp<0.0000	EMM Fc	4.595722789	EMM Em	0.36269048	4.2330323	Fc equiv = Em + 4.2330323	
Cd	3, 6	L10 Data	GLM	mp 0.0003, spp<0.0000	EMM L10 Fc	–0.23040436	EMM L10 Em	–0.85969069	0.62928633	Log10 Fc equiv = Log10 Em + 0.62928633	
Co	3, 6, 11		regress	mp 0.0017, spp 0.0019	Fc coef-ficient:	1.493590602	constant:	–0.03656837		Fc equiv value = (Em + 0.03656837) / 1.4935906	Em = – 0.03656837 + 1.4935906 × Fc
Cr	3, 6		GLM	mp 0.0069, spp 0.0001	EMM Fc	0.441989796	EMM Em	0.59071429	–0.14872449	Fc equiv = Em – 0.14872449	
Cu	3, 6, 11, 17	L10 Data	GLM, wk	mp 0.015, spp 0.123	NO CONVERSION NEEDED if first convert to L10 data before averaging with Fc.						
Fe	3, 6		GLM	mp 0.0002, spp<0.0000	EMM Fc	253.03912	EMM Em	412.35714	–159.31803	Fc equiv = Em – 159.31803	
Hg	3, 6		GLM	mp<0.0000, spp<0.0000	EMM Fc	0.12836548	EMM Em	0.169153571	–0.04078810	Fc equiv = Em – 0.04078810	
K	3, 6		GLM	mp 0.0002, spp 0.026	EMM Fc	0.28540136	EMM Em	0.25555952	0.02984184	Fc equiv = Em + 0.02984184	
Mg			regress, wk	m, spp 0.009	Fc coef-ficient:	0.34875688	constant:	0.02677991		Fc equiv (Em – 0.02677992) / 0.34875688	Em = 0.02677992 + 0.34875688 ×* Fc
Mn			regress	m, spp 0.0001	Fc coef-ficient:	0.41695043	constant:	8.0709211		Fc equiv = (Em – 8.0709211) / 0.41695043	Em = 8.0709211 + 0.41695043 × Fc
N	3, 6		GLM	mp 0.0001, spp<0.0000	EMM Fc	0.86377381	EMM Em	1.310131	–0.44635714	Fc equiv = Em – 0.44635714	
Na	3, 6	L10 Data	GLM, wk	mp 0.031, spp 0.025	EMM L10 Fc	1.2965518	EMM L10 Em	1.3725524	–0.07600058	Log10 Fc equiv = Log10 Em—0.07600058	
Ni	3, 6	L10 Data	GLM, wk	mp 0.019, spp 0.013	EMM Fc	–0.22869085	EMM Em	–0.05558766	–0.17310319	Log10 Fc equiv = Log10 Em—0.17310319	

Table 23—Flacap vs. Evemes conversion formulas (continued)

Element	Exclude sites	Transform	Model	p values	Calculations: EMMs (GLM) or Fc coefficient and constant (regression)				EMM Fc—EMM Em	Conversion formula: USE TO CONVERT NEW DATA	Original regression equation
P	3, 6	L10 Data	GLM, wk	mp 0.050, spp 0.053	EMM Fc	–1.0702364	EMM Em	–1.1374773	0.06724089	Log10 Fc equiv = Log10 Em + 0.06724089	
Pb	3, 6	L10 Data	GLM	mp 0.0008, spp<0.0000	EMM L10 Fc	0.62965352	EMM L10 Em	0.05474457	0.57490895	Log10 Fc equiv = Log10 Em + 0.57490895	
S	3, 6		regress	m, spp 0.003	Fc coef-ficient:	1.0436658	constant:	0.02114465		Fc equiv = (Em – 0.02114465) / 1.0436658	Em =0.02114465 + 1.0436658 × Fc
Sr	3, 6		GLM, wk	mp 0.012, spp 0.0001	EMM Fc	43.777551	EMM Em	7.0214286	36.756122	Fc equiv = Em + 36.756122	
Zn	6, 10, 17		regress, wk	m, spp 0.049	Fc coef-ficient:	0.59621721	constant:	10.393344		Fc equiv = (Em – 10.393344) / 0.59621721	Em = 10.393344 + 0.59621721 × Fc

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; St = strontium; Zn = zinc.

Table 24—Flacap vs. Parsul conversion formulas; no sites excluded

Element	Transform	Model	p values	Calculations: EMMs (GLM) or Fc coefficient and constant (regression)						
								EMM Fc—EMM Ps	Conversion formula: use to convert new data	Original regression equation
Al	L10 Data	GLM	mp 0.0003, spp <0.0000	EMM L10 Fc	2.3712436	EMM L10 Ps	2.5715942	–0.20035059	L10 Fc equiv = L10 Ps – 0.20035059	
C		GLM, wk	mp 0.013, spp <0.0000	EMM Fc	42.675968	EMM Ps	46.844	–4.1680318	Fc equiv = Ps—4.1680318	
Ca		GLM	mp 0.0023, spp <0.0000	EMM Fc	4.6183079	EMM Ps	0.61236667	4.0059413	Fc equiv = Ps + 4.0059413	
Cd	L10 Data	regress, wk	m, spp 0.010	L10 Fc coefficient:	0.90806679	constant:	–0.36425250		L10Fc equiv = (L10Ps + 0.36425252) / 0.90806679	L10Ps = -0.36425252 + 0.90806679 * L10Fc
Co	L10 Data	GLM	mp 0.0003, spp <0.0000	EMM L10 Fc	–0.77564528	EMM L10 Ps	-0.58213775	–0.19350753	L10 Fc equiv = L10 Ps – 0.19350753	
Cr	L10 Data	GLM	mp 0.0004, spp <0.0000	EMM L10 Fc	–0.33116017	EMM L10 Ps	–0.18473018	–0.14642999	L10 Fc equiv = L10 Ps – 0.14642999	
Cu	L10 Data	GLM	mp 0.0002, spp <0.0000	EMM L10 Fc	0.43988878	EMM L10 Ps	0.65800000	–0.21811122	L10 Fc equiv = L10 Ps – 0.21811122	
Fe		GLM	mp <0.0000, spp <0.0000	EMM Fc	295.03651	EMM Ps	466.83333	–171.79683	Fc equiv = Ps—171.79683	
Hg		GLM	mp 0.0001, spp <0.0000	EMM Fc	0.12802	EMM Ps	0.087	0.04102	Fc equiv = Ps + 0.04102	
K	L10 Dat	GLM	mp 0.0007, spp <0.0000	EMM L10 Fc	–0.48784674	EMM L10 Ps	-0.38524952	–0.10259722	L10 Fc equiv = L10 Ps – 0.10259722	
Mg		regress, wk	m, spp 0.013	Fc coefficient:	0.94870224	constant:	0.03961008		Fc equiv = (Ps—0.03961008) / 0.94870224	Ps = 0.03961008 + 0.94870224 * Fc
Mn		regress	m, spp 0.002	Fc coefficient:	1.2620819	constant:	29.445438		Fc equiv = (Ps—29.445438) / 1.2620819	Ps =29.445438 + 1.2620819 × Fc
N		regress, wk	m, spp 0.042	Fc coefficient:	0.51384254	constant:	0.7594555		Fc equiv value = (Ps – 0.75945550) / 0.51384254	Ps = 0.75945550 + 0.51384254 × Fc
Na		regress	m, spp 0.005	Fc coefficient:	0.70195721	constant:	7.3834422		Fc equiv value= (Ps – 7.3834422) / 0.70195721	Ps = 7.3834422 + 0.70195721 × Fc
Ni	L10 Data	GLM, wk	mp 0.052, spp 0.0031	EMM L10 Fc	–0.28932732	EMM L10 Ps	–0.10335114	–0.18597618	L10 Fc equiv = L10 Ps – 0.18597618	
P	L10 Data	GLM	mp 0.0038, spp <0.0000	EMM L10 Fc	–1.0752623	EMM L10 Ps	–0.86215042	–0.21311189	L10 Fc equiv = L10 Ps – 0.21311188	
Pb		GLM	mp 0.0082, spp 0.641	Conversion not needed						
S		GLM	mp <0.0000, spp <0.0000	EMM Fc	0.10156825	EMM Ps	0.12403333	–0.02246508	Fc equiv = Ps – 0.02246508	
Sr	L10 Data	GLM	mp 0.0094, spp <0.0000	EMM L10 Fc	1.60754982	EMM L10 Ps	1.2898066	0.3177432	L10 Fc equiv = L10 Ps + 0.31774320	
Zn	L10 Data	GLM, wk	mp 0.028, spp <0.0000	EMM L10 Fc	1.5070217	EMM L10 Ps	1.7571755	–0.25015378	L10 Fc equiv = L10 Ps – 0.25015378	

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; St = strontium; Zn = zinc.

Table 25—Flacap vs. Phyaip conversion formulas

Element	Exclude sites	Transform	Model	p values	Calculations: EMMs (GLM) or Fc coefficient and constant (regression)				EMM Fc—EMM Pa	Conversion formula: use to convert new data	Original regression equation
Al	56		regress, wk	m, spp 0.030	Fc coefficient:	0.77144681	constant:	-105.75415		Fc equiv = (Pa – 105.75415) / 0.77144681	Pa = 105.75414 + 0.77144681 × Fc
C			GLM	mp 0.004, spp 0.011	EMM Fc:	43.321	EMM Pa:	45.257	–1.936	Fc equiv = Pa—1.936	
Ca			GLM	mp 0.002, spp <.0005	EMM Fc:	4.3028571	EMM Pa:	0.22179167	4.0810655	Fc equiv = Pa + 4.0810655	
Cd		L10 Data	GLM	mp <.0005, spp <.0005	EMM L10 Fc:	–0.32968221	EMM L10 Pa:	–0.75474394	0.42506174	L10 Fc equiv = L10 Pa + 0.42506174	
Co			GLM	mp 0.003, spp 0.106				Conversion not needed			
Cr		L10 Data	GLM	mp 0.002, spp 0.008	EMM L10 Fc:	–0.24091968	EMM L10 Pa:	–0.14710381	–0.09381587	L10 Fc equiv = L10 Pa – 0.09381587	
Cu			regress	m, spp 0.001	Fc coefficient:	1.0532472	constant:	–0.48336063		Fc equiv = (Pa – 0.48336063) / 1.0532472	Pa = –0.48336063 + 1.0532472 × Fc
Fe	56		regress	m, spp 0.003	Fc coefficient:	0.84794642	constant:	112.27581		Fc equiv = (Pa – 112.27581)/ 0.84794642	Pa = 112.27581 + 0.84794642 × Fc
Hg			GLM	mp 0.002, spp <.0005	EMM Fc:	0.127	EMM Pa:	0.069	0.058	Fc equiv = Pa + 0.058	
K	56	L10 Data	GLM	mp <.0005, spp <.0005	EMM L10 Fc:	–0.44520775	EMM L10 Pa:	–0.21773094	–0.22747681	L10 Fc equiv = L10 Pa – 0.22747681	Pa = 0.08427551 + 1.4566716 × Fc
Mg		L10 Data	GLM	mp <.0005, spp <.0005	EMM Fc:	–1.1545968	EMM Pa:	–0.94476902	–0.20982779	L10 Fc equiv = L10 Pa – 0.20982779	
Mn	56		regress, wk	m, spp 0.033	Fc coefficient:	0.39934496	constant:	10.735662		Fc equiv = (Pa – 10.735662) / 0.39934496	Pa = 10.735662 + 0.39934496 × Fc
N	21	L10 Data	regress, wk	m, spp 0.014	Fc coefficient:	0.59466406	constant:	0.28		L10 Fc equiv = (L10 Pa—0.280)/ 0.59466406	L10 Pa = 0.280 + 0.59466406 × L10 Fc
Na			GLM	mp 0.008, spp 0.113				Conversion not needed			
Ni	56		GLM, wk	mp 0.011, spp 0.205				Conversion not needed			
P			GLM	mp <.0005, spp <.0005	EMM Fc:	0.11228175	EMM Pa:	0.176875	–0.06459325	Fc equiv = Pa – 0.06459325	
Pb		L10 Data	GLM	mp 0.001, spp <.0005	EMM L10 Fc:	0.54739331	EMM L10 Pa:	0.01986589	0.52752742	L10 Fc equiv = L10 Pa + 0.52752742	
S			GLM	mp <.0005, spp <.0005	EMM Fc:	0.12219643	EMM Pa:	0.18879167	–0.06659524	Fc equiv = Pa – 0.06659524	
Sr		L10 Data	GLM	mp <.0005, spp <.0005	EMM L10 Fc:	1.4847088	EMM L10 Pa:	0.53937963	0.94532917	L10 Fc equiv = L10 Pa+ 0.94532917	
Zn		L10 Data	GLM, wk	mp 0.015, spp 0.001	EMM Fc:	1.5311418	EMM Pa:	1.7324437	–0.20130191	L10 Fc equiv = L10 Pa – 0.20130191	

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; St = strontium; Zn = zinc.

Table 26—Flacap vs. Punrud conversion formulas

					Calculations: EMMs (GLM) or Fc coefficient and constant (regression)						
Element	Exclude sites	Transform	Model	p values					EMM Fc— EMM Pr	Conversion formula: use to convert new data	Original regression equation
Al	67, 69		regress	m, spp 0.0007	Fc coefficient:	0.95232326	constant:	37.72489		Fc equiv = (Pr – 37.724890) / 0.95232326	Pr = 37.724890 + 0.95232326 * Fc
C	67, 69		GLM	mp 0.0031, spp 0.114	Conversion not needed						
Ca	44, 67, 69	L10 Data	GLM, wk	mp 0.0258, spp 0.0102	EMM Fc:	0.52398583	EMM Pr:	0.67253716	–0.14855133	Fc equiv = Pr – 0.14855133	
Cd	67, 69		GLM	mp 0.0001, spp 0.327	Conversion not needed						
Co	67, 69		GLM	mp 0.0001, spp 0.486	Conversion not needed						
Cr	67, 69		regress	m, spp <0.0000	Fc coefficient:	1.3870626	constant:	–0.12309827		Fc equiv = (Pr + 0.12309827) / 1.3870626	Pr = – 0.12309827 + 1.3870626 * Fc
Cu	67, 69		GLM	mp 0.0013, spp 0.0095	EMM Fc:	2.9819444	EMM Pr:	2.5972222	0.38472222	Fc equiv = Pr + 0.38472222	
Fe	44, 67, 69		regress	m, spp 0.0011	Fc coefficient:	1.6521495	constant:	–160.91740		Fc equiv = (Pr + 160.91740) / 1.6521495	Pr =—160.91740 + 1.6521495 * Fc
Hg	67, 69	L10 Data	GLM	mp 0.0025, spp 0.0003	EMM L10 Fc:	–0.91595647	EMM L10 Pr:	–1.0157018	0.09974529	Log10 Fc equiv = Log10 Pr + 0.09974529	
K	67, 69		GLM	mp 0.0005, spp<0.0000	EMM Fc:	0.38263492	EMM Pr:	0.246875	0.13575992	Fc equiv = Pr + 0.13575992	
Mg	67, 69		regress	m, spp 0.0011	Fc coefficient:	0.53505411	constant:	0.03132873		Fc equiv = (Pr— 0.03132873) / 0.53505411	Pr = 0.03132873 + 0.53505411 * Fc
Mn	67, 69	L10 Data	regress, wk	m, spp 0.0488	Fc coefficient:	0.44726185	constant:	1.0020072		L10 Fc equiv = (L10 Pr— 1.0020072) / 0.59466406	L10 Pr =—1.0020072 + 0.44726185 * L10 Fc
N	67, 69		regress	m, spp 0.0012	Fc coefficient:	0.79129706	constant:	0.14454006		Fc equiv = (Pr – 0.14454006) / 0.79129706	Pr = 0.14454006 + 0.79129706 * Fc
Na			DO NOT CONVERT		Significant site x sp interaction from GLMs, regressions not significant.						
Ni	67, 69	L10 Data	GLM	mp 0.0003, spp 0.0003	EMM L10 Fc:	–0.01411064	EMM L10 Pr:	–0.21786648	0.20375584	Log10 Fc equiv = Log10 Pr + 0.20375584	
P	44, 67, 69		GLM	mp 0.0092, spp 0.275	Conversion not needed						
Pb	67, 69		regress	m, spp <0.0000	Fc coefficient:	0.69214237	constant:	–0.49465875		Fc equiv = (Pr + 0.49465875) / 0.69214237	Pr =—0.49465875 +0.69214237 * Fc
S	44, 67, 69		GLM	mp 0.0002, spp 0.166	Conversion not needed						
Sr	67, 69	L10 Data	GLM	mp 0.0041, spp 0.967	Conversion not needed						
Zn	67, 69		regress	m, spp 0.0004	Fc coefficient:	0.55619804	constant:	13.321805		Fc equiv = (Pr – 13.321805) / 0.55619804	Pr = 13.321805 + 0.55619804 * Fc

Al = aluminum; Ca = calcium; C = carbon; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; St = strontium; Zn = zinc.

Appendix 12: Site Average Elemental Values After Species Conversion

All elements were averaged by site after species data conversion following formulas in appendix 11. All data excluded for species conversion were excluded from averages as well. Validated elements aluminum (Al), carbon (C), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), magnesium (Mg), manganese (Mn), nitrogen (N), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), strontium (Sr), and zinc (Zn) are listed in alphabetical order of their official acronyms. All Punrud data for Na were excluded because they could not be converted for equivalence with Flacap data. Table 27A has values for Al through Cu; table 27B has values for Fe through Na; table 27C has values for Ni through Zn. These data were used for correlations with monitor site variables (app. 13, monitor site information) and environmental variables (app. 8, site information), as well as with each other (Will-Wolf et al. 2017a).

Table 27A—Site average values for Al through Cu

Lichen analysis site code	Number of species	Al	C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
1	2	152.53	45.742	4.6067	1.1465	0.1531	0.3473	2.6328
2	1	135.89	39.883	7.8090	0.9700	0.1150	0.3975	2.3525
3	2	396.04	45.366	2.6925	0.6450	0.2800	0.6650	2.7300
4	3	175.26	42.669	4.7249	0.8955	0.1548	0.3561	2.2978
5	1	222.43	42.963	4.4821	0.6465	0.1526	0.4148	2.2836
6	3	274.40	45.490	3.5885	0.5501	0.2041	0.5022	2.7508
7	3	217.38	42.129	4.6365	0.9441	0.1612	0.4344	2.4943
8	1	249.62	42.560	4.3190	1.4349	0.2114	0.4925	2.9079
9	2	275.01	42.879	5.0483	0.8026	0.1841	0.5523	3.3917
10	2	179.58	43.513	4.3132	0.8456	0.1917	0.3906	2.0194
11	2	422.26	44.786	3.4885	0.6859	0.1925	0.4769	3.6450
12	2	163.17	39.753	6.9542	1.0776	0.1156	0.3506	2.5955
13	2	314.45	42.301	4.1410	0.7573	0.2403	0.6481	3.7473
14	2	123.70	43.513	4.0145	0.4992	0.1249	0.3631	2.4789
15	2	187.18	43.327	3.9888	0.6592	0.1446	0.3809	3.0998
16	2	150.03	42.337	6.6430	0.3541	0.1183	0.3256	1.4976
17	2	376.76	45.692	3.8063	0.4987	0.2503	0.5806	3.0550
18	1	222.64	46.223	3.5615	0.3950	0.1675	0.4975	2.9950
19	2	194.18	42.826	5.2635	0.3088	0.1517	0.3856	1.8793
20	1	194.51	43.770	4.8160	0.6876	0.1780	0.4230	2.1810

Table 27A—Site average values for Al through Cu (continued)

Lichen analysis site code	Number of species	Al	C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
21	5	242.70	41.101	5.1418	0.6378	0.1466	0.4942	2.6404
22	2	183.19	41.580	6.4184	0.8150	0.1367	0.3769	2.1481
23	1	244.29	45.945	3.5773	0.9070	0.1917	0.4081	3.3267
24	5	150.14	43.438	4.9607	0.4101	0.1189	0.3784	1.7070
25	1	327.79	46.184	0.7495	0.4600	0.2250	0.5100	5.7300
26	2	180.07	42.114	5.7651	0.7767	0.1374	0.3399	2.2134
27	3	289.38	43.086	3.6301	0.2295	0.1664	0.5468	2.6724
28	1	314.83	49.460	2.4559	0.4250	0.2000	0.6250	3.8650
29	1	358.12	44.265	4.2201	0.5056	0.2350	0.5882	2.4844
30	1	388.62		4.3078	0.3726	0.2700	0.5721	2.1995
31	1	303.04	45.749	3.5674	0.3400	0.2250	0.4200	3.3650
32	1	671.31	41.102	4.2181	0.6550	0.3250	1.3250	4.8000
33	1	385.32	43.414	4.4687	0.6088	0.2616	0.7059	3.5219
34	1	662.14		4.3176	0.8382	0.4125	1.1743	5.1475
35	1	587.39	41.935	5.2894	0.7350	0.2900	0.7150	3.5900
36	1	576.81	46.171	0.1346	0.3100	0.3050	1.1100	4.7850
37	1	433.82	38.778	5.4997	0.4425	0.2725	0.9536	3.4149
38	1	272.41	41.779	5.7691	0.5900	0.1750	0.5700	3.7500
39	1	260.20	44.865	4.3254	0.5976	0.1950	0.4653	2.7086
40	1		43.589	3.4776				
41	1	325.97	42.717	4.6812	0.4525	0.2750	0.6958	2.9906
42	1	260.14	45.837	3.5214	0.2700	0.1900	0.5200	3.4200
43	2	501.82	45.354	5.4713	0.4203	0.2688	0.7819	3.1886
44	1	692.93	40.381	6.9894	0.9100	0.3275	1.0211	3.0624
45	2	505.94	41.520	4.1090	0.5028	0.4050	0.9261	3.3120
46	2	393.28	42.548	5.0746	0.6375	0.2025	0.6945	3.9300
47	1	402.50	44.732	3.8590	0.5321	0.1944	0.6677	3.0200
48	2	232.17	41.037	4.7700	0.6172	0.1374	0.4388	2.7826
49	2	246.60	45.696	3.6492	0.2780	0.1725	0.5675	2.4329
50	1	354.80	42.725	4.2931	0.3060	0.2300	0.6003	2.3087
51	1	484.29		4.8477	0.2395	0.3400	0.8943	3.2866
52	1	441.86	45.564	2.3921	0.3800	0.2800	0.7150	3.8350
53	3	255.86	37.372	4.9692	0.6980	0.1850	0.5766	2.6981
54	1	409.16	42.276	4.4055	0.2994	0.2925	0.7030	2.9923
55	1	370.43		4.3121	0.6121	0.3600	0.5721	2.4749
56	2	320.35	40.619	5.0308	2.2514	0.3017	1.0125	4.3557
57	1	149.91	40.516	4.2866	0.2617	0.1500	0.4727	2.8230

Table 27A—Site average values for Al through Cu (continued)

Lichen analysis site code	Number of species	Al	C	Ca	Cd	Co	Cr	Cu
		mg/kg	*Percent*	*Percent*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
58	2	281.88	39.049	6.0301	0.3921	0.1700	0.5974	4.1236
59	4	250.72	43.780	3.4492	0.8195	0.1976	0.5138	2.6527
60	2	198.92	46.622	3.6963	0.2330	0.1475	0.6369	3.2900
61	2	177.74	41.989	3.5812	0.1950	0.1775	0.4054	2.4699
62	1	260.94		3.1060	0.2350	0.1700	0.5050	1.5150
63	3	265.73	43.345	3.7282	0.3511	0.1980	0.4627	3.1348
64	1	183.34	46.851	3.5575	0.3950	0.1475	0.5087	2.8249
65	2	184.02	45.150	3.6646	0.2754	0.1800	0.5639	2.7228
66	1	590.44	45.548	3.1875	0.1100	0.3950	1.2100	4.2250
67	2	448.39	44.938	2.8915	0.1650	0.2750	0.9150	3.3250
68	1	332.40	43.863	4.2618	0.3459	0.2450	0.8480	4.6752
69	2	346.83	44.735	2.5494	0.2700	0.2050	0.5850	4.0350
70	2	329.45	43.696	3.6402	0.1017	0.1983	0.5999	3.2174
71	1	349.09	44.909	4.2955	0.4524	0.2800	1.4020	7.4025
72	1	322.93	46.630	2.7864	0.3050	0.2250	0.5650	2.4100
73	2	227.88	47.904	2.8661	0.1675	0.1725	0.4151	2.9299
74	2	286.67	42.191	4.4625	0.5947	0.2247	2.1996	5.5706
75	1	313.76	44.025	4.3324	0.4723	0.2275	1.7887	5.5392
76	2	225.04	46.829	5.4691	0.1483	0.1650	0.4507	2.3243
77	1	426.84	40.519	4.3459	0.2927	0.2400	0.6687	2.8024
78	2	270.98	42.898	5.4508	0.1938	0.1300	0.5110	3.1427
79	1	246.01	42.221	4.3540	0.4125	0.1650	0.4995	2.9638
80	1	400.26		4.5070	0.3859	0.2350	0.6083	2.6932
81	1	405.64		4.2583	0.5056	0.2300	0.6929	3.8705
82	1	143.76		4.2442	0.1597	0.1550	0.3787	1.3498
83	1	130.00		4.1759	0.1730	0.1400	0.2820	1.2216
Count		82	74	83	82	82	82	82

Al = aluminum; C = carbon; Ca = calcium; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper.

Table 27B—Site average values for iron through sodium

Lichen analysis site code	Number of species	Fe	Hg	K	Mg	Mn	N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
1	2	154.16	0.1167	0.2193	0.0454	124.59	0.4722	22.239
2	1	164.00	0.1245	0.2367	0.0367	117.38	0.7203	11.675
3	2	602.12	0.1343	0.3334	0.0440	206.32	1.2370	23.350
4	3	231.41	0.1539	0.3058	0.0565	318.01	0.7716	18.934
5	1	237.81	0.1177	0.3176	0.0521	285.77	0.6113	13.748
6	3	376.72	0.1765	0.2726	0.0367	243.79	1.1151	18.833
7	3	243.16	0.1416	0.3172	0.0431	484.77	0.9102	16.918
8	1	262.87	0.1323	0.3474	0.0190	270.43	1.2176	13.913
9	2	396.44	0.1176	0.3964	0.0547	283.07	1.1161	93.334
10	2	201.76	0.0949	0.3719	0.0449	235.55	0.7519	20.477
11	2	332.10	0.2119	0.2256	0.0256	61.65	0.8980	19.914
12	2	182.82	0.1486	0.3300	0.0404	179.85	0.8791	14.294
13	2	362.46	0.1086	0.3228	0.0644	315.76	0.7414	33.804
14	2	137.76	0.0831	0.3068	0.0435	193.07	0.7824	15.978
15	2	215.30	0.1108	0.3200	0.0583	227.83	0.8009	17.510
16	2	154.59	0.0911	0.2225	0.0283	230.98	0.4881	18.251
17	2	384.14	0.1268	0.2466	0.0434	95.52	0.7821	21.338
18	1	259.10	0.1343	0.3283	0.0504	236.18	0.9744	18.000
19	2	227.05	0.0903	0.1791	0.0210	72.44	0.7749	19.077
20	1	239.71	0.0977	0.2566	0.0420	283.04	0.7871	18.888
21	5	278.84	0.1291	0.3297	0.0441	167.46	1.0077	20.635
22	2	191.86	0.1214	0.2305	0.0429	98.67	0.7230	15.021
23	1	275.32	0.1402	0.2645	0.0433	212.33	0.8963	19.526
24	5	149.11	0.1197	0.4249	0.0968	74.75	0.8766	25.416
25	1	365.82	0.0997	0.4462	0.1029	144.25	1.0134	22.900
26	2	226.11	0.1055	0.3191	0.0389	199.01	0.6235	21.380
27	3	381.07	0.1727	0.2776	0.0541	139.25	1.2324	21.946
28	1	382.56	0.1263	0.3121	0.0514	163.62	1.3376	30.100
29	1	523.48	0.1020	0.3437	0.0691	196.91	1.2865	19.400
30	1	473.66	0.1512	0.4027	0.0748	90.61		29.700
31	1	584.17	0.1310	0.3439	0.0485	237.40	1.2088	19.550
32	1	805.80	0.1532	0.2891	0.0608	263.58	1.7848	38.900
33	1	462.11	0.1264	0.3718	0.0548	301.68	1.5821	32.950
34	1	878.62		0.3169	0.0750	148.79		23.725
35	1	949.17	0.1218	0.3105	0.0640	309.75	1.2831	17.200
36	1	726.80	0.0690	0.6629	0.1197	104.03	2.5326	39.500
37	1	452.71	0.1008	0.3563	0.0557	164.70	1.1526	5.300
38	1	310.90	0.1170	0.2323	0.0551	283.23	1.2709	28.700
39	1	308.99	0.1302	0.2934	0.0466	157.51	1.1128	23.225
40	1		0.1710	0.2429	0.1242	50.43	1.3442	43.750
41	1	388.69	0.1087	0.3083	0.0551	414.31	1.3179	22.275
42	1	298.27	0.1265	0.3483	0.0577	133.65	1.7341	18.100

Table 27B—Site average values for iron through sodium (continued)

Lichen analysis site code	Number of species	Fe	Hg	K	Mg	Mn	N	Na
		mg/kg	*mg/kg*	*Percent*	*Percent*	*mg/kg*	*Percent*	*mg/kg*
43	2	517.64	0.1121	0.3275	0.0835	155.54	2.2367	22.700
44	1	788.16	0.1019	0.4012	0.0643	162.57	1.0552	21.350
45	2	737.32	0.1196	0.4154	0.0977	106.01	1.7339	48.575
46	2	393.32	0.1660	0.3431	0.0553	216.82	1.5037	40.350
47	1	499.27	0.1306	0.2671	0.0431	114.17	1.2709	30.553
48	2	231.12	0.1009	0.3354	0.0560	130.75	1.4943	27.194
49	2	294.21	0.1299	0.3282	0.0696	48.70	1.4315	24.000
50	1	473.52	0.1070	0.3129	0.0656	27.83	1.0872	41.550
51	1	757.74		0.2031	0.0586	127.07		27.300
52	1	527.80	0.1460	0.4448	0.1095	123.23	1.9828	40.300
53	3	306.81	0.1537	0.3578	0.0669	122.60	1.7445	25.763
54	1	628.15	0.1263	0.2846	0.0559	47.61	2.1527	22.075
55	1	523.16		0.3215	0.0702	154.94		69.900
56	2	490.23	0.1502	0.3167	0.1114	135.55	1.5670	60.533
57	1	180.96	0.1229	0.3268	0.0756	2.96	1.2926	41.300
58	2	341.29	0.1453	0.3221	0.0589	38.22	2.0178	28.500
59	4	242.85	0.1362	0.4270	0.0722	86.77	1.6389	22.536
60	2	241.34	0.0820	0.4096	0.0884	93.75	1.1660	10.000
61	2	234.77	0.1108	0.3653	0.0670	61.00	1.2762	46.450
62	1	322.00		0.1956	0.0416	34.59		28.000
63	3	326.36	0.1232	0.3598	0.0672	183.82	1.8519	19.850
64	1	252.84	0.1032	0.3725	0.0599	207.77	1.6157	17.000
65	2	250.19	0.1226	0.4432	0.0816	81.87	1.8147	54.175
66	1	882.55	0.0695	0.4284	0.1211	58.70	1.2609	20.400
67	2	598.05	0.1362	0.2762	0.0757	62.50	1.5778	33.700
68	1	389.63	0.1233	0.4551	0.0799	26.24	1.6723	67.250
69	2	405.86	0.1585	0.3642	0.0928	139.82	2.0745	20.000
70	2	410.47	0.0922	0.4080	0.1170	45.44	1.6106	16.300
71	1	628.09	0.1554	0.4326	0.0845	22.55	1.8591	71.950
72	1	362.81	0.0835	0.3008	0.0689	85.82	1.2795	20.750
73	2	276.40	0.1345	0.3925	0.0922	168.81	1.7074	19.800
74	2	602.88	0.1214	0.3979	0.0571	7.53	2.6323	94.392
75	1	622.49	0.1255	0.4924	0.0833	44.79	2.1224	110.275
76	2	307.97	0.1509	0.3328	0.0681	18.07	1.3537	37.400
77	1	497.48	0.1156	0.4315	0.0837	38.21	2.6451	56.750
78	2	334.85	0.1385	0.3770	0.0818	81.86	2.3023	20.400
79	1	283.44	0.1124	0.4857	0.0984	36.46	1.6968	17.600
80	1	433.33	0.1472	0.2696	0.1016	70.35		79.250
81	1	509.78	0.1371	0.4419	0.0701	77.14		25.300
82	1	206.03	0.1702	0.2275	0.0474	10.03		20.625
83	1	171.70	0.1289	0.2198	0.0376	28.57		17.950
Count		82	79	83	83	83	74	83

Fe = iron; Hg = mercury; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium.

Table 27C—Site average values for N through Zn

Lichen analysis site code	Number of species	Ni	P	Pb	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*mg/kg*	*mg/kg*
1	2	0.8263	0.0528	2.2140	0.0638	49.219	49.551
2	1	0.2950	0.0647	5.0500	0.0740	76.300	40.273
3	2	0.7300	0.1075	5.2800	0.1410	26.370	31.830
4	3	1.2158	0.0811	3.3442	0.0769	35.064	35.337
5	1	0.4475	0.0760	3.1014	0.0769	32.324	31.933
6	3	0.5022	0.0776	6.1013	0.1049	26.921	37.787
7	3	0.7137	0.0729	5.8646	0.0847	38.612	37.304
8	1	0.6060	0.0869	2.4250	0.0806	17.386	108.432
9	2	0.5436	0.0945	4.4200	0.1599	40.860	37.361
10	2	1.1455	0.1100	4.5364	0.0643	40.886	49.140
11	2	0.9920	0.0679	6.0300	0.0797	22.647	41.917
12	2	0.3456	0.0685	6.0650	0.0881	55.640	26.797
13	2	1.1042	0.1434	5.8464	0.0638	40.951	33.993
14	2	0.5660	0.0849	4.0761	0.0652	40.051	27.039
15	2	0.4430	0.0850	2.7675	0.0713	42.591	32.358
16	2	0.2401	0.0609	4.2721	0.0470	77.658	31.979
17	2	0.4707	0.0859	4.6436	0.0744	32.211	50.090
18	1	0.5600	0.1074	6.6900	0.0779	43.573	31.365
19	2	0.3966	0.0657	3.1872	0.0683	50.522	34.379
20	1	0.3851	0.0819	2.2575	0.0767	57.226	33.317
21	5	0.6855	0.0959	4.7268	0.1043	46.782	40.740
22	2	0.3006	0.0839	4.2135	0.0752	65.013	57.352
23	1	0.5304	0.0825	4.1863	0.0855	31.803	50.217
24	5	0.5204	0.1079	3.6800	0.0796	49.980	27.521
25	1	0.8200	0.1279	8.1000	0.1072	33.295	90.240
26	2	0.3641	0.0868	4.3275	0.1125	52.403	40.306
27	3	0.6686	0.0844	3.2984	0.1002	29.449	43.799
28	1	2.3250	0.0872	2.8000	0.1167	22.660	31.930
29	1	0.6450	0.1052	2.4427	0.1344	29.053	30.906
30	1	0.5900	0.1844	4.2452	0.1051	71.948	26.339
31	1	0.3950	0.1067		0.1104	48.555	31.260
32	1	0.9850	0.0753	7.6450	0.1538	40.115	38.225
33	1	0.6032	0.1116	3.5375	0.1301	44.455	26.240
34	1	1.0975	0.0985	3.9083	0.1173	72.940	42.267
35	1	0.7050	0.1034		0.1169	34.345	41.235
36	1	1.2400	0.2012	1.9900	0.2249	2.810	73.990
37	1	1.8643	0.1184	3.2728	0.0837	40.379	38.816
38	1	0.4450	0.0629	5.0100	0.1072	56.425	43.545
39	1	0.4675	0.0588	5.3450	0.1179	42.272	48.537
40	1		0.0569		0.1224	46.215	
41	1	0.6650	0.0836	5.8743	0.1261	44.783	40.953
42	1	0.5900	0.1226	1.8350	0.1151	54.345	19.580

Table 27C—Site average values for N through Zn (continued)

Lichen analysis site code	Number of species	Ni	P	Pb	S	Sr	Zn
		mg/kg	*Percent*	*mg/kg*	*Percent*	*mg/kg*	*mg/kg*
43	2	0.9315	0.1034	2.2812	0.1569	27.626	28.274
44	1	1.6213	0.0997	8.9720	0.1749	59.027	49.200
45	2	0.8500	0.2246	2.8932	0.1479	21.872	34.234
46	2	0.7386	0.0753		0.1316	43.050	43.050
47	1	0.6098	0.0621	4.0650	0.1076	25.641	30.366
48	2	0.4845	0.0796	4.0900	0.1056	43.210	28.744
49	2	0.6650	0.1164	3.5443	0.0968	39.366	26.380
50	1	0.7500	0.0973	3.6219	0.0824	42.322	13.711
51	1	0.8950	0.0333	5.8624	0.2240	31.962	23.493
52	1	0.8450	0.1656	2.9400	0.1490	20.305	32.105
53	3	0.9903	0.0949	5.4180	0.1271	24.071	26.048
54	1	0.8850	0.0851	5.1465	0.1875	24.732	20.657
55	1	0.8600	0.1147	4.7169	0.1302	18.604	18.841
56	2	0.7700	0.1313	7.8866	0.1676	23.987	72.700
57	1	0.4350	0.1159	2.7403	0.1331	15.592	21.398
58	2	0.6172	0.0880	5.9551	0.1696	19.643	34.885
59	4	1.2397	0.1151	3.6027	0.1200	52.333	54.593
60	2	0.6975	0.1360	2.4861	0.0912	52.750	25.125
61	2	1.7671	0.0746	2.6186	0.0907	15.394	15.127
62	1	0.8300	0.0509	2.7700	0.0856	20.795	11.480
63	3	1.0458	0.0903	2.9577	0.1324	15.607	29.881
64	1	0.6397	0.1048	2.4478	0.1119	19.742	25.337
65	2	0.7169	0.1285	4.1931	0.1280	25.655	29.448
66	1	0.9450	0.1932	2.2700	0.0912	16.800	22.315
67	2	0.7900	0.0864	3.1550	0.1240	10.725	21.990
68	1	0.6925	0.1215	5.4328	0.1520	19.618	41.207
69	2	0.6550	0.1080	2.4500	0.1592	13.150	46.180
70	2	0.4668	0.1690	1.8869	0.1132	16.621	24.191
71	1	1.1025	0.0904	11.0173	0.1992	18.560	52.121
72	1	0.9250	0.0936	1.6300	0.0883	25.380	17.600
73	2	0.7296	0.1141	3.2943	0.1299	23.513	22.943
74	2	1.0148	0.1168	25.1343	0.2333	48.007	65.631
75	1	1.4300	0.1786	24.9658	0.2072	31.720	56.195
76	2	0.3400	0.0883	1.7665	0.1331	15.732	23.933
77	1	0.7250	0.1941	4.5821	0.2072	19.486	18.158
78	2	0.6548	0.1043	3.1120	0.1742	18.207	18.547
79	1	0.5350	0.1707	4.0599	0.1505	15.606	19.671
80	1	0.8550	0.1506	6.2499	0.1529	84.777	15.230
81	1	0.6700	0.1794	5.6603	0.1860	56.694	33.567
82	1	0.2850	0.0535	2.4511	0.0993	18.803	10.711
83	1	0.3100	0.0513	1.9373	0.0392	13.799	12.408
Count		82	83	79	83	83	82

Ni = nickel; P = phosphorus; Pb = lead; S = sulfur; Sr = strontium; Zn = zinc.

Appendix 13: Monitor Site Information—General Information, Environmental Variables, and Variables From Instrument-Measured Data

Table 28 includes general information about monitor sites and stations; tables 29 and 30 have environmental variables for monitor site locations; table 31 includes values for monitor site variables from measured data. Monitor station information for table 28 and source annual average measured data for table 31 were extracted from https://www.epa.gov/air-data (current Web address). Data were downloaded August 2015, before an October 2016 substantial website redesign. Information in table 28 was adapted from Will-Wolf et al. (2017a). Monitor site values in tables 29 and 30 for environmental variables were extracted with those for lichen sites; see appendix 8 for sources.

Information for all tables:

- Site numbers (number in fig. 1) with letters after them have more than one monitoring station for the years used; stations 4a and 4b were co-located; station 4c was somewhat distant; stations 8a and 8b were within 0.3 mi.
- Data from multiple stations for a site were averaged to compare with lichen elemental data.

Information for table 31:

Tables 31A through D have monitor site variables developed from instrument-measured pollutant data. Data for 25 different types of instrument measurements (listed in Will-Wolf et al. 2017a) for particulate matter (PM) and the elements aluminum (Al), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), nickel (Ni), nitrogen (N), strontium (Sr), sulfur (S), and zinc (Zn) also measured in lichens were available from one to eight monitor sites. For most individual measurement types, sample size was too small to compare directly with lichen elemental data; only measurement types with data from four or more monitor sites were included for analyses. Data were first averaged within station for all years used (table 28). Next, data for the same measurement type at multiple stations in a single site were averaged, then ranks (1 low to 15 high) for that measurement type were assigned to all monitor sites. A monitor site variable for comparison with lichen elemental data was the average of ranks for different measurement types for the same element or compound, or the rank or annual averaged data for the single type measured at the most sites. Composite variables for measured PM, Cr, Fe, Mn, N, nitrogen oxides (NO_x), reduced nitrogen (NH_x), Ni, Pb, and sulfur oxides (SO_x) (averages of measurement ranks) were most useful to compare with lichen elemental data. Monitor station 4c had data only for PM. Monitor stations 4a and 4b had data for other compounds and elements, but not PM. A number at the end of a variable name indicates the number of measurement types averaged.

Table 28—Monitor site/station location and information

Local site name	Network	Data years used	Monitor site number	Latitude	Longitude	Elevation	State	FIPS state code	FIPS county code	Ecoregion
						Feet				
Crandon East Tribal	AQS	2008–2011	2	45.563	-88.8088	559	Wisconsin	55	41	1
Perkinstown	NADP/NTN	2008–2012	3	45.2066	-90.5972	472	Wisconsin	55	119	1
Winona, Minnesota	IMPROVE	2008–2012	4ab	43.937299	-91.405348	370	Minnesota	27	169	2
LaCrosse DOT building	SLAMS/AQS	2008–2012	4c	43.7775	-91.2269	667	Wisconsin	55	63	2
Horicon SE DNR	NCore	2010–2012	5	43.466111	-88.621111	286.5	Wisconsin	55	27	2
Devil's Lake State Park	AQS	2008–2012	6	43.4351	-89.6797	392	Wisconsin	55	111	2
Madison East	SLAMS/AQS	2010–2013	7	43.100838	-89.357298	260	Wisconsin	55	25	2
Milwaukee West Allis Health Center	NATTS	2009–2012	8a	43.016667	-87.933333	200	Wisconsin	55	79	2
Milwaukee West Allis DNR	SLAMS/AQS	2008–2012	8b	43.060975	-87.913504	208	Wisconsin	55	79	2
Milwaukee Waukesha	Supplemental Speciation	2008–2012	9	43.020075	-88.21507	261	Wisconsin	55	79	2

Abbreviations: AQS = Air Quality System; DNR = Department of Natural Resources; DOT = Department of Transportation; FIPS = Federal Information Processing Standards; IMPROVE = Interagency Monitoring of Protected Visual Environments; NADP/NTN = National Atmospheric Deposition Network National Trends Network; Ncore = National Core; SE = southeast; SLAMS = State or Local Air Monitoring Stations.

Table 29—Monitor site climate and modeled air quality

Monitor site number	Minimum temperature, PRISM	Maximum temperature, PRISM	Mean temperature, PRISM	Precipitation, PRISM	N deposition 2013, NADP	NH_4 deposition 2013, NADP	NO_3 deposition 2013, NADP	SO_4 deposition 2013, NADP	Hg deposition 2013, NADP	S total deposition 2013, CMAQ	N total deposition 2013, CMAQ	Lichen Pollution Index, N + S	Lichen Pollution Index, 5 metals
	- - - - - - - - - - °C	- - - - - - - - - - - -		*Millimeters*									
2	-0.96	10.24	4.64	794.8	5.91	4.96	9.11	6.60	10.23	4.13	9.00	0.89	0.69
3	-0.86	10.93	5.04	819.1	7.95	7.16	10.64	8.74	9.88	4.45	16.30	1.18	1.19
4ab	2.26	12.46	7.36	875.8	6.67	5.91	9.25	7.41	10.90	6.30	15.00	1.59	1.15
4c	3.20	13.84	8.52	870.0	6.42	5.69	8.91	7.23	10.82	4.61	12.76	1.59	1.15
5	2.60	13.22	7.91	843.1	5.70	4.83	8.64	7.58	10.73	4.96	16.89	1.70	1.33
6	3.24	12.82	8.03	899.1	6.41	5.58	9.22	7.77	12.37	4.76	13.82	1.50	1.08
7	2.60	13.57	8.09	893.8	6.48	5.53	9.71	8.60	12.48	9.63	19.85	1.67	1.34
8ab	4.48	13.60	9.04	856.8	5.80	4.83	9.09	8.31	11.02	5.84	7.76	2.44	2.30
9	3.32	13.50	8.41	878.8	6.41	5.34	10.08	9.15	12.39	6.22	14.46	2.06	2.33

PRISM = parameter-elevation relationships on independent slopes model; NADP = National Atmospheric Deposition Program.
Data from the multiple stations were averaged to compare with lichen element data, except that only 4ab environmental data were compared with lichen data. Monitor station 4c had only particulate matter measured and was farther from the lichen site.

Table 30—Monitor site land cover

Monitor site number	Forest land cover, 100 m buffer	Forest land cover, 500 m buffer	Forest land cover, 1000 m buffer	Open semi-natural cover, 100 m buffer	Open semi-natural cover, 500 m buffer	Open semi-natural cover, 1000 m buffer	Agricultural cover, 100 m buffer	Agricultural cover, 500 m buffer	Agricultural cover, 1000 m buffer	Developed land cover, 100 m buffer	Developed land cover, 500 m buffer	Developed land cover, 1000 m buffer
							Percent					
2	100.0	86.9	81.0	0	0	0	0	0	0	0	13.1	12.1
3	33.3	88.2	95.6	0	0	0	0	0	0	0	3.2	1.8
4ab	58.0	53.6	52.5	0	1.7	1.9	0	1.7	5.6	17.0	6.7	4.5
4c												
5	40.0	11.6	9.5	22.9	63.4	70.9	17.1	9.0	7.4	20.0	9.4	6.6
6	88.6	90.8	81.8	4.3	3.1	2.3	0	2.5	13.6	7.1	3.6	2.4
7	82.4	14.9	5.5	13.6	7.2	3.7	0	7.8	14.0	4.1	70.1	76.8
8ab	1.0	1.0	1.0	0	0	0	0	0	0	99.0	99.0	99.0
9	40.0	30.2	17.5	5.7	12.2	5.5	31.4	11.8	12.9	22.9	45.8	64.1

Data from the multiple stations were averaged to compare with lichen element data, except that only 4ab environmental data were compared with lichen data. Monitor station 4c had only particulate matter measured and was farther from the lichen site; land cover variables were not extracted for this location.

Table 31A—Monitor site variables for PM and N compounds

Monitor site number	PMa rank3	PMb rank3	PMc rank4	PM25 rank1	PM25 wm1	Average N rankA3	Average N rankW3	NO_x rank2	tNO_3 rank1	tNO_3 am1	NH_4 rank1	NH_4 am1
	1	1	1	1	6.16	1	1	1				
3	6.5	6.5	6.5	6	8.25	5.5	5.7	6	6	1.45	5	0.79
4ab(c)	8.25	8	8	9	9.80	10	9.3	8	8.5	1.66	12	1.18
5	8	8.25	8.25	7.5	9.06	8.5	8.7	9	10.5	1.84	8	0.92
6	8.1	7.7	6.9	8	9.46							
7	9.7	10.1	9.5	7	8.65							
8ab	12.8	12.8	13.1	12.5	11.0	13	13.7	15	13	2.11	11	1.16
9	15	15	15	15	11.9	11.5	12	13	14	2.19	10	1.12

PM = particulate matter; N = nitrogen; NO_x = nitrogen oxides; NO_3 = nitrate; NH_4 = ammonium; A or am = arithmetic mean; t = total; W or wm = weighted mean.
PMa, PMb, and PMc are different variants averaging across PM2.5 and PM10 measurements, explained in Will-Wolf et al. 2017a.

Table 31B—Monitor site variables for S compounds, Al, Cd, Co, and Cr

Monitor site number	S rank3	SO_x PM rank1	SO_x PM am1	Al rank1	Al PM am1	Cd rank2	Cd PM25 rank1	Cd PM25 am1	Co rank1	Co PM am1	Cr rank2	Cr PM2.5 lc rank1	Cr PM2.5 am1
2	12					6					8		
3	6	1	1.5	7	0.020	13	13	0.002	7	0.000698	5	5	0.00066
4ab(c)	8.5	8.3	1.9	13	0.025						1	1	0.00001
5	7.3	3.5	1.6	11	0.023	11.5	15	0.002	8	0.000726	10	10	0.00165
6													
7	12.75												
8ab	14	9.5	1.86	14	0.025	11.5	10	0.002	8.5	0.000742	12.5	13	0.00223
9	8	10	1.88	15	0.026	8	5.5	0.001	15	0.00083	15	15	0.00262

S = sulfur; SO_x = sulfur oxides; Al = aluminum; Cd = cadmium; Co = cobalt; Cr = chromium, PM = particulate matter; am = arithmetic mean; lc = local conditions.

Table 31C—Monitor site variables for Cu, Fe, Hg, Mg, and Mn

Monitor site number	Cu rank1	Cu PM am1	Fe rank1	Fe PM am1	Hg rank2	Mg rank1	Mg PM am1	Mn rank2	Mn PMrank1	Mn PMam1
2					1			1		
3	8	0.0010	6	0.02	5	6	0.007868	5	6	0.000458
4ab(c)	6	0.0005	7	0.03		12	0.013248	7	9	0.001034
5	11	0.0052	9	0.03		7	0.00838	8.25	9.5	0.00119
6										
7										
8ab	9.5	0.0030	12	0.07	14.5	8	0.00907	10.5	10	0.00318
9	15	0.0127	15	0.11	10	12	0.03415	15	15	0.009684

Cu = copper; Fe = iron; Hg = mercury; Mg = magnesium; Mn = manganese; PM = particulate matter; am = arithmetic mean.

Table 31D—Monitor site variables for Ni, Pb, Sr, and Zn

Monitor site number	Ni rank2	Ni PM rank1	Ni PM am1	Pb rank2	Pb PM rank1	Pb PM am1	Sr rank1	Sr PM am1	Zn rank1	Zn PM am1
2	7			1						
3	6	6	0.00024	3	6	0.0009	11	0.0014	15	0.293
4ab(c)	1	1	0.00001	10	9.5	0.0017	6	0.0004	6	0.005
5	7	8	0.00043	6	7	0.0015			6.5	0.006
6										
7										
8ab	13.5	13	0.00092	12.5	11	0.0023	12	0.0015	8	0.010
9	15	15	0.00112	15	15	0.0054	13.5	0.0016	9	0.053

Ni = nickel; Pb = lead; Sr = strontium; Zn = zinc; PM = particulate matter; am = arithmetic mean.

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