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Lichen elemental content bioindicators for air quality in upper Midwest, USA: A model for large-scale monitoring

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ABSTRACT

Our development of lichen elemental bioindicators for a United States of America (USA) national monitoring program is a useful model for other large-scale programs. Concentrations of 20 elements were measured, validated, and analyzed for 203 samples of five common lichen species. Collections were made by trained non-specialists near 75 permanent plots and an expert near nine air monitoring sites. *Flavoparmelia caperata* (most frequent) and *Physcia aipolia/stellaris* between them represented the full range of local forest cover and pollution load. *Evernia mesomorpha* (values saturated at intermediate pollution), *Parmelia sulcata*, and *Punctelia rudecta* (both difficult for non-specialists) were less useful. Conversion models (GLM or regression) rendered elemental data equivalent between species. Al, Cr, Cu, Fe, Hg, N, and S, plus composite indexes from them, were linked with local air pollution based on correlations with directly measured N and particulate matter as well as from PCA; elements were weakly correlated with modeled pollution estimates. Lichen Hg had no other useful surrogates. Invoking multiple causation and scale-dependence helped address several issues of interpretation, for instance conflicting bioindicator value of Al and Fe from literature.

1. Introduction

Biomonitoring response to air pollution is an important component of evaluating the health of biological systems (e.g., for lichens Fenn et al., 2003; Nimis et al., 2002). Estimation of local air quality from elemental concentrations in lichens or mosses naturally growing *in situ* (passive monitoring as opposed to active monitoring with transplants: Garty, 2002) is a classic technique (Ferry et al., 1973; Martin and Coughtrey, 1982) with wide current usage (e.g. Donovan et al., 2016; McMurray et al., 2013; Paoli et al., 2014) to complement costly instrument monitoring.

Elemental biomonitoring well represents relative local pollution loads, as compared with instrument measurements (e.g. Bargagli and Mikhailova, 2002; Root et al., 2015), although accuracy of quantitative calibration varies (e.g. Bargagli, 2016; Bari et al., 2001; Boquete et al., 2015; Cercasov et al., 2002; Vestergaard et al., 1986). Elemental bioindicator species should be relatively pollution-tolerant, widespread, and amenable to collection (e.g. Conti and Cecchetti, 2001; Puckett, 1988; Wolterbeek, 2002). Elemental accumulation rates can differ between lichen species; conversion between species (e.g. Karakas and Tuncel, 2004; Root et al., 2013; Sloof and Wolterbeek, 1993) can provide equivalent elemental data.

Our protocols were designed for large-scale studies where multiple target species are likely and simplicity plus cost-effectiveness facilitate implementation. Our general objective for the full project (located in upper Midwest, USA) was to recommend improved practices for elemental biomonitoring using in-situ mosses or lichens. Our objectives for this aspect of the full project were to: 1) evaluate elemental concentrations in multiple lichen species from non-specialist collectors; 2) develop conversion models between species; 3) calibrate lichen elemental data to measured values; and 4) evaluate lichen-indicated air quality across the study region. In two other aspects of this project, Will-Wolf et al. (2017a) assess the impact of variation in protocols and staff expertise on data quality, and Will-Wolf et al. (2017b) evaluate applications of protocols and bioindicators in eastern United States of America (E USA) for the United States Department of Agriculture Forest Service Forest Inventory and Analysis Program (FIA) program. Lichen elemental

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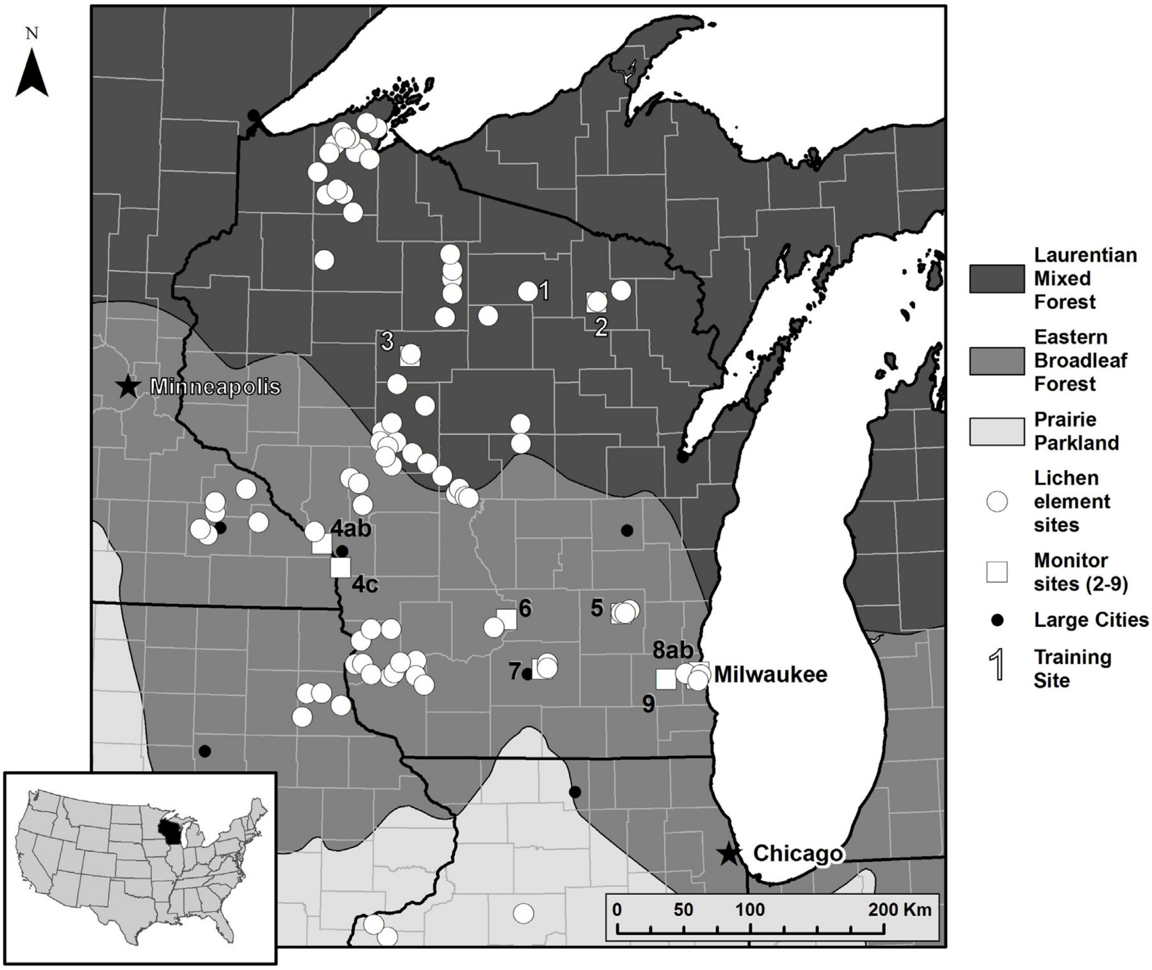

Fig. 1. Locations of lichen sites and instrument monitor sites. Wisconsin, marked in the USA inset, is in the center with Minnesota west, Iowa southwest, and Illinois south.

bioindicators for two other E USA projects (Will-Wolf et al., 2014, 2015b) used similar protocols, but only expert staff.

2. Methods

2.1. Study region and environmental variables

The 241,800 km^2 project area includes USA states Wisconsin and parts of adjacent Illinois, Iowa, and Minnesota (Fig. 1). It mostly extends across two Bailey ecoregions (Bailey et al., 1994; Cleland et al., 2007): Laurentian Mixed Forest (province 212) and Eastern Broadleaf

Forest (province 222); three southern (Illinois) plots are in Prairie Parkland (province 251). Laurentian Mixed Forest has high cover of mixed deciduous broadleaf-conifer forests; Eastern Broadleaf Forest has more fragmented deciduous broadleaf forests interspersed with agricultural land; Prairie Parkland now has sparse deciduous broadleaf forests in an agricultural landscape. Environmental variables represent location, climate, land cover, and modeled pollution deposition (Table 1; Supplementary Document 1). Lichen elemental concentrations and species distributions were correlated with land cover in a subset of the project area (Will-Wolf et al. 2011, 2015b); similar links were investigated at this larger spatial scale. Measured pollutants for 2008–2013 were from 11 instrument monitoring stations at eight monitor sites (2–9 on Fig. 1) linked with national networks (Supplementary Document 2).

2.2. Target species, field data collection, and measurement

Five macrolichen species common in eastern North America (E NA: Brodo et al., 2001) were collected: *Evernia mesomorpha* Nyl. (acronym Evemes; small/medium size fruticose growth form), *Flavoparmelia caperata* (L.) Hale (acronym Flacap: large foliose), *Parmelia sulcata* Taylor (acronym Parsul; medium foliose), *Physcia aipolia* (Ehrh. ex Humb.) Fürnr. var . *aipolia* and *P. stellaris* (L.) Nyl. combined (acronym Phyaip; small foliose, tightly appressed), and *Punctelia rudecta* (Ach.) Krog (acronym Punrud: large foliose). Flacap and Punrud were used in two recent E USA studies (Will-Wolf et al., 2014, 2015b) and all but Phyaip have been used in other studies in the region (Will-Wolf et al., 2017a).

Lichens were collected by FIA field staff with no prior experience with lichens, who survey permanent plots on a preset 10-year rotation (USDA FS, 2015), and by professional lichenologist Susan Will-Wolf (the expert). Field staff were trained (at site 1, Fig. 1) for one day by the expert (details in Will-Wolf et al., 2017b). Field staff collected lichens September-November 2013; the expert collected in Summer-Fall 2013 from temporary sites near monitor sites 2–9 on Fig. 1 (Supplementary Document 2).

Collection areas were forest openings or edges with 20–50% canopy near permanent FIA plots (no destructive sampling on plots: USDA FS, 2015) or at temporary sites with similar characteristics. The moderately narrow range of relatively open canopy reduced habitat variability (e.g. Gandois et al., 2014), allowed penetration of air pollution, and still represented forest conditions. Areas affected by local chemical contamination (e.g. adjacent to active agricultural