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Epiphytic lichen indication of nitrogen deposition and climate in the northern rocky mountains, USA

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ABSTRACT

Lichen bioindication can provide economical and spatially extensive monitoring of climate and pollution impacts on ecological communities. We used non-metric multidimensional scaling of lichen community composition and generalized additive models to analyze regional climate and pollution gradients in the northern Rocky Mountains, U.S. Temperature extremes, relative humidity, and N-deposition were strongly related to lichen community composition. Eutrophic species (genera *Physcia*, *Xanthomendoza*, and *Xanthoria*) were associated with high N deposition, low precipitation, and temperature extremes. Estimated N deposition in our study ranged from <0.5 to 4.26 kg N ha^{-1} $year^{-1}$ with degradation to lichen communities observed at 4.0 kg N ha^{-1} $year^{-1}$, the indicated critical load. The resulting model can track changes in climate and N pollution related to lichen communities over time, identify probable sensitive or impacted habitats, and provide key information for natural resource management and conservation. The approach is broadly applicable to temperate ecosystems worldwide.

1. Introduction

Climate change and atmospheric nitrogen (N) deposition are adversely affecting forest health worldwide (Aber 1992; Vitosek et al., 1997; Fenn et al., 1998; Matson et al., 2002), including the Northern Rocky Mountains (Beem et al., 2010; Saros et al., 2010). Over the last century, average annual temperatures in the Northern Rocky Mountains have increased 0.74 °C, while annual precipitation has decreased 0.8 to 2.8 cm (EPA, 1997; NOAA, 2012). Decreased precipitation and shifts from snow- to rain-dominated precipitation reduces stored snow pack and summer stream flow levels. Northern Rockies background nitrogen (N) deposition is ≤1 kg N ha^{-1} $year^{-1}$ (Holland et al., 1999; Sverdrup et al., 2012). Current deposition in regional forests is 0.5–5 kg N ha^{-1} $year^{-1}$ (Burns, 2003; Grenon et al., 2010; McMurray et al., 2013). Assessing current conditions, monitoring changes, and predicting ecosystem responses is challenging because climate and air pollution are tightly linked (Burns 2004).

Epiphytic lichens obtain nutrients from atmospheric deposition, including canopy drip, and community composition shifts with changes in forest stand composition, climate, and nitrogen- and sulfur-containing air pollutants. Thus, lichens are often used as sentinels and indicators of forest health (Fenn et al., 2007; Geiser and Neitlich, 2007; Jovan and McCune, 2005; Rogers et al., 2009).

We aim to: (1) identify baseline climate and nitrogen deposition conditions for the northern Rocky Mountain forested ecosystem, (2) model interactions between climate, Pollution, and lichen community composition, and (3) evaluate lichen community based critical loads (CLs) for total N deposition.

2. Methods

2.1. Study area

Study sites were located within the northern U.S. Rocky Mountains and included parts of Montana, Idaho, and Wyoming (Fig. 1). Winters are cold to severe and most precipitation falls as snow, especially at higher elevations; summers are comparatively dry.

Sixty-eight 0.378 ha circular plots were established in the summers of 2008 ($n = 5$), 2010 ($n = 7$), and 2011 ($n = 56$) following the Forest Inventory and Analysis (FIA) protocol (FIA P3 Field Guide, 2011). To encompass the nitrogen deposition gradient, plots were located in mountainous conifer forests and near urban and agricultural centers. Plots were stratified by elevation (1108–3109 m), slope, aspect, precipitation (32–154 cm) and

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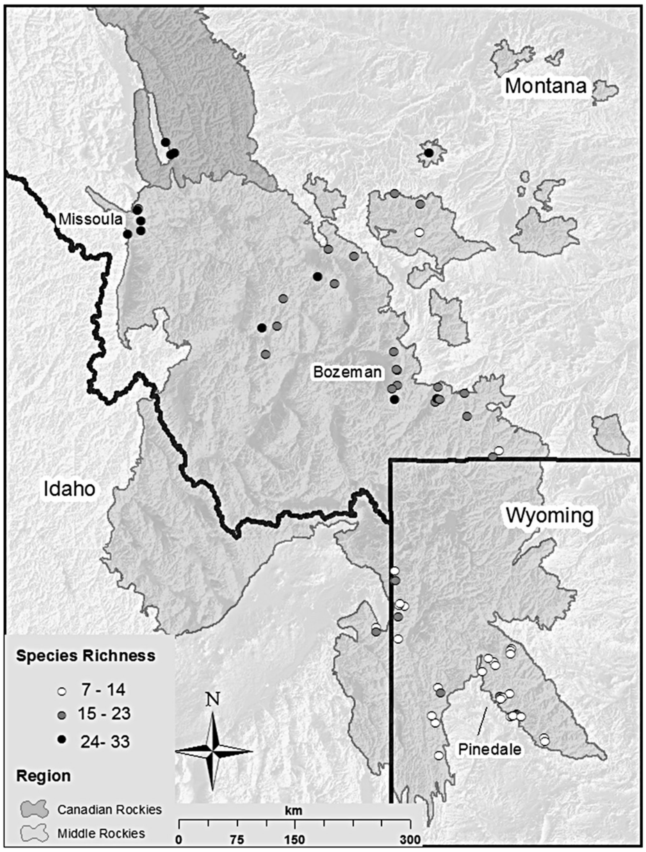

Fig. 1. Study site locations and lichen species richness.

estimated N deposition (0.5–4.0 kg ha^{-1} $year^{-1}$). Dominant tree species included *Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson, *Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.) Franco, *Picea engelmannii* Parry ex Engelm., and *Abies lasiocarpa* (Hook.) Nutt. An additional 65 FIA plots within a 50 km buffer of the study area were used to test the prediction accuracy of the final model.

2.2. Lichen elemental analysis

Lichens *Letharia vulpina* L. (Hue) and *Usnea lapponica* Vainio thalli were collected for analysis of dry weight N concentrations (Geiser, 2004). To represent the population at each plot, a 10 g sample of each species consisting of multiple thalli from ≥6 substrates was collected. If only one species was present, 1–2 additional field replicates were collected. Samples were hand-cleaned of debris and mailed to the University of Minnesota Research Analytical Laboratory, St Paul, MN for total ash and N analyses. At the laboratory, each sample (n = 201) was dried (65 °C) and ground (stainless steel grinder with 20-mesh sieve). Total nitrogen content was measured from 0.5 g subsamples with a LECO Nitrogen Analyzer, Model No. FP-528. Laboratory accuracy and precision was assessed every 10th sample with National Institute of Standards and Technology (NIST) reference material – apple 1515. Reagent blanks and Orchard 1029 leaves were used to calibrate equipment.

We predicted %N values for *U. lapponica* or *L. vulpina* at plots where one of the species was missing using regression of plots where both species were collected (n = 45, r^2= 0.72, p = <0.001).

$$\%\text{N } U.\ lapponica = 0.408 + 0.826\,(\%\text{N } L.\ vulpina)\%\text{N } L.\ vulpina = 0.88(\%\text{N } U.\ lapponica) - 0.042 \quad (1)$$

2.3. Lichen community

Epiphytic macrolichens on woody substrates above 0.5 m height were surveyed over the whole plot for 45 min to 2 h (FIA P3 Field Guide, 2011). A sample of each species detected was sent to a certified lichenologist for identification. Taxonomic identification followed McCune and Geiser (2009) and McCune and Goward (1995) (Table A1). An abundance rating for each species was recorded where: 1 = ≤3 thalli, 2 = 4–10 thalli, 3 = >10 thalli on less than half of the available substrates, and 4 = species occurred on more than half of the available substrates.

Sensitivity to and nutritional requirements for N differ among lichen species. The abundance and diversity of eutrophs typically increases in N-enriched environments, mesotrophs show little change, and oligotrophs typically decline or disappear. Lichen species were classified as eutrophic or oligotrophic based on published analyses (McCune and Geiser, 2009; Jovan, 2008; Jovan et al., 2012; McCune et al., 2010; Neitlich et al., 1999), and plots were assigned a eutrophic index based on species composition.

2.4. Site data

Ten site variables were recorded, including latitude, longitude, elevation, slope, aspect, stand age (from tree cores), tree size class, percent gap disturbance, and percent shrub cover. Percent basal area of live trees was calculated from tree counts at plot center and four subplots using a 20-BAF factor prism.

2.5. Climate

The climate dataset was constructed from 800 m resolution gridded data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly and Taylor, 2000). Six derived variables were included in the analyses: mean annual (1971–2000) precipitation, maximum temperature (Tmax), minimum temperature (Tmin), and (1999–2009) dew point, and relative humidity from mean annual maximum (RHmax) and minimum temperatures (RHmin). Heat load and direct incident radiation were calculated following McCune and Keon (2002).

2.6. Nitrogen deposition data

Nitrogen deposition (kg ha^{-1} $year^{-1}$) was extracted from the Community Multiscale Air Quality model (CMAQ) output for 2002 (12 km grid; Byun and Schere, 2006. Dry weight concentrations of N (%) in *L. vulpina* thalli were used to estimate annual canopy throughfall (TF) N deposition using the regression equation in McMurray et al. (2013):

$$\text{TF N kgha}^{-1}\text{year}^{-1} = 4.26\,(\%\text{N } L.\ vulpina) - 3.77 \quad (2)$$

where TF = dissolved inorganic N measurements from ammonium and nitrate in canopy throughfall. Adjusted r^2 = 0.78.

2.7. Statistical procedures

All statistical analyses were completed with R.2.9.2 (R Development Core Team, 2010). Calculations of species richness per plot (α-diversity), heterogeneity between plots (β-diversity)