Life in mid-air: Monitoring air quality in Class I Wilderness Areas within the White and Green Mountain National Forests using epiphytic lichens

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Introduction & Methods:

Lichens are valued for monitoring air quality because: a) they can concentrate air- and precipitation-borne elements within the lichen thallus and b) species have different and characteristic responses to pollutants such as sulphur (S) and nitrogen (N). Wetmore (1995a, 1995b) collected lichens in 1993 to assess the pollutant concentrations in the lichens residing in Class I Wilderness areas of White Mountain National Forest in NH (Presidential Range-Dry River Wilderness (**DR**), and Great Gulf Wilderness (**GG**)) and the Green Mountain National Forest in VT (Lye Brook (**LB**).

In 2011-2013, we re-sampled for lichen chemical concentrations (following Wetmore's locale information) and surveyed for diversity and health of epiphytic lichens at 12 stands, four stands in each of the three Class I Wilderness Areas, DR, GG and LB. The plots followed the size and time restraints of the Forest Inventory Analysis plots (McCune et al. 1997), that is a 34.7m radius plot with one-hour timed survey and collection of one specimen for each species found on the plot. Bulk samples were collected off-plot due to the amount of lichen required (several grams of dry weight).

One novel aspect of our methods was the assessment of **thallus health** from the plots. We developed a four point scale on all collections:

- **0** = thallus in very poor condition (more than one of the following symptoms: convoluted lobes, bleaching, black speckles, pink blotchy areas; or extensive other discoloration
- **1** = thallus in poor condition (one or two of the previously listed symptoms, but not as extensive on the thallus surface);
- **2** = within the normal range for the species
- **3** = robust specimen

Lichen health scores: an informative addition

Fig. 1. Differences in thallus health of the common species, *Parmelia sulcata*. The specimen on the left received a health score of 2 (normal) while the specimen on the right received a health score of 0 (poor condition). Photos were taken at 14X magnification with the decreased size of the poor specimen being actual size difference.
Photos taken by Patricia Hinds on specimens collected for this project and scored by Jim Hinds.

References

McCune, B., J. Dey, J. Peck, D. Cassell, K. Heiman, S. Will-Wolf, P. Neitlich. 1997. Repeatability of community data: species richness versus gradient scores in large-scale lichen studies. Bryologist 100:40-46.

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Pollutant change over time: lichen content and direct measures

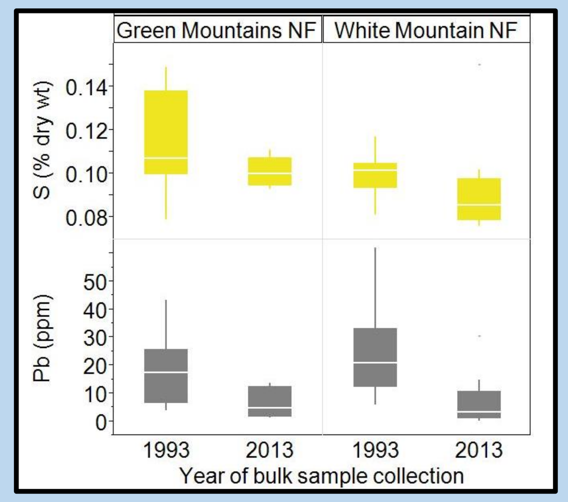

Fig.2. Change in concentrations of S (yellow) and lead (Pb; gray) in lichen thalli between 1993 and 2013. Box plots with 95% CI.

Federal regulations to improve air quality are reflected in the decrease in S and lead (Pb) content of lichen thalli (**Fig. 2**) in both the Green and White Mountain plots.

Pollutant aerosols show a significant decline over the past 12 years (**Table 1**) with some variation in the degree of reduction.

Table 1. Trends for selected aerosol species over 12 years (2001-2012) at LB from IMPROVE data.

$PM_{2.5}$ Species	Correlation vs. Date (R^2)	Slope (% / Yr)	Regression F	Significance of F
Pb	0.62	-3.8	30.8	<0.001
S	0.71	-3	47.5	<0.001
$SO_4^{=}$	0.84	-3.2	100.5	<0.001
NO_3^-	0.64	-2.5	13.2	0.002

A closer look at nitrogen: aerosol nitrate 56% higher and N deposition 33% higher at Lye Brook than Great Gulf

While the trends in pollutant deposition appear promising, many pollutants remain significantly higher at LB (**Table 2**). In particular, nitrogen pollution may need some attention (**Fig. 3**). The nitrogen content of lichen thalli was significantly higher at the LB plots and this was the main difference found between areas (**Fig. 4**).

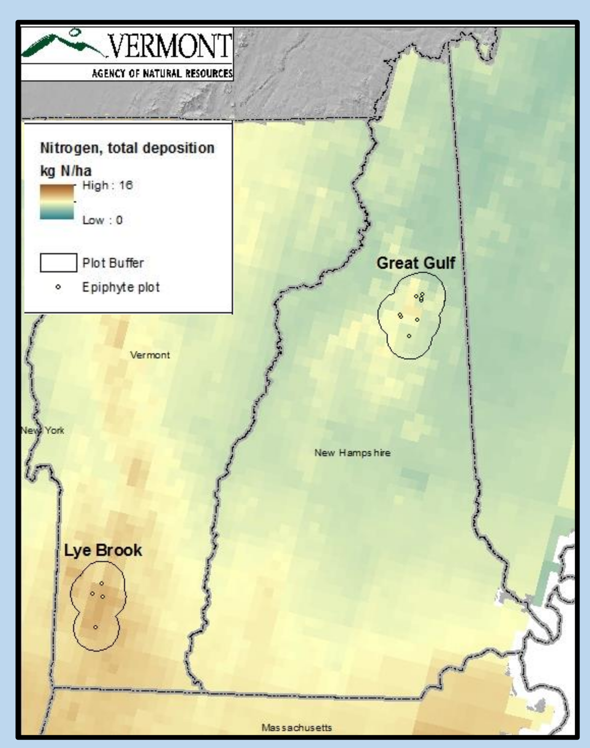

Fig. 3. Mean Annual Total Nitrogen Deposition in VT and NH, 2001-2012 (based on Schwede and Lear, 2014). Figure by Bennet Leon, VT Air Quality and Climate Division.

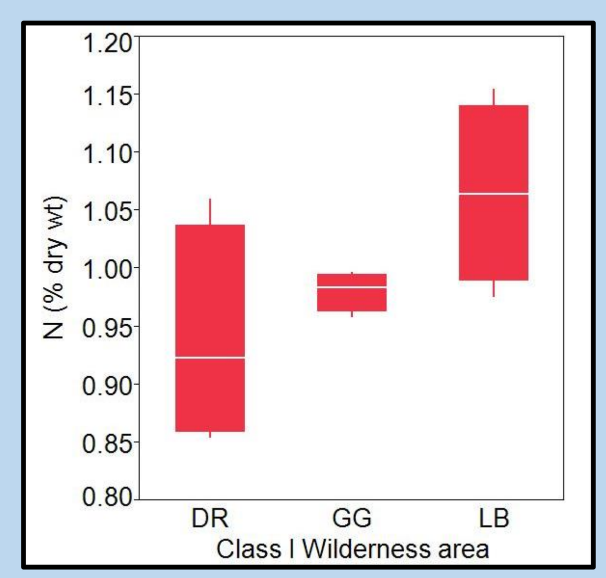

Fig. 4. Comparison of N concentrations in lichen thalli collected from the three Wilderness Areas. Box plots are shown with the box representing the 95% CI.

Table 2. Comparison of concentrations for selected aerosol species over 12 years at LB and GG from IMPROVE data.

	LB 2001-2012 Mean concentration (μg/m³) ± 95% CI	GG 2001-2012 Mean concentration (μg/m³) ± 95% CI	% difference in 12-year means (1-GG/LB)*100
Pb	0.00130 ± 3.68e-05	0.00112 ± 2.96e-05	14%
S	0.64151 ± 0.03429	0.54885 ± 0.02608	14%
$SO_4^{=}$	1.79018 ± 0.10123	1.54045 ± 0.07817	14%
NO_3^-	0.35000 ± 0.01925	0.15392 ± 0.00842	56%

Lichen responses: decreased species richness and health

Despite improvements in air quality, the lichens are still hampered by pollution effects at LB. At LB, the lichens had a significantly lower number of species per plot (**Fig. 5**) and poorer thallus health on average (**Fig. 6**) when compared to plots in the White Mountain Wilderness Areas (GG and DR). Overall, there is a strong relationship between lichen species richness and health scores (**Fig. 7**) suggesting that the differences in species richness are linked to damaging of lichens by pollution.

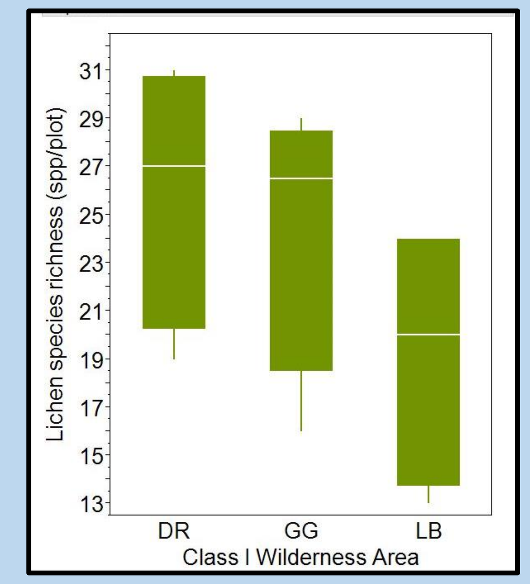

Fig. 5. Box plot comparison of lichen species collected during 1-hour timed surveys on four plots per Wilderness area. Plot size was 0.379 ha following the FIA protocol.

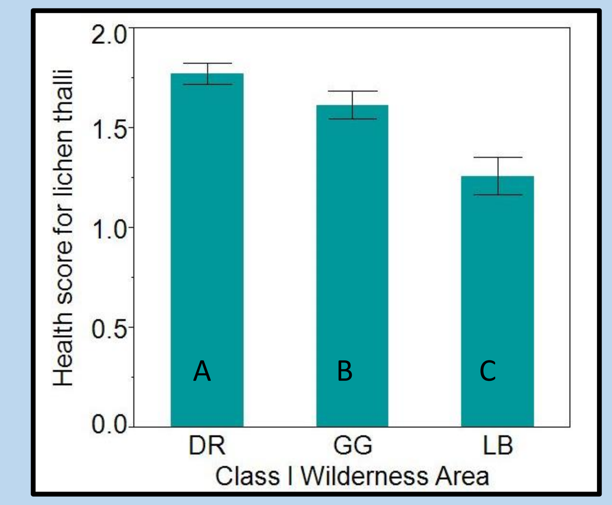

Fig. 6. Mean (SE) of thallus health scores for lichen collections. Health scores were based on a scale 0-3 with 3 being a robust specimen and 0 being a specimen with severe damage to the thallus (refer to methods for details).

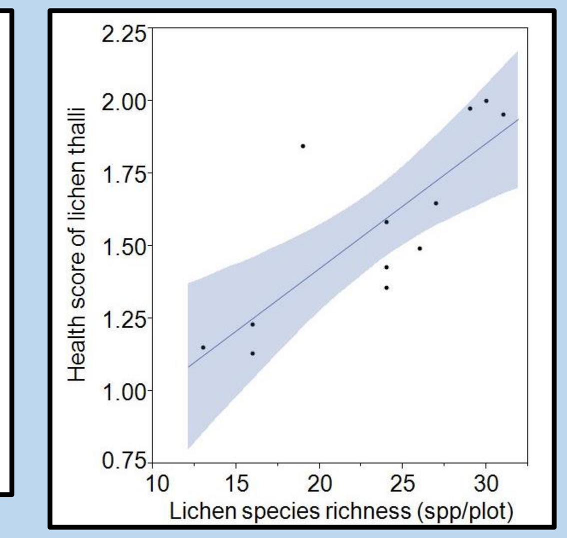

Fig. 7. Relationship between lichen species richness and average lichen thallus health on a plot (N=12; r^2 = 0.64; p = 0.0018).

Main findings:

Change over time: The concentrations of regulated emissions, sulphur and lead, have decreased in lichen thalli in agreement with IMPROVE (Interagency Monitoring of Protected Visual Environments) aerosol data. Comparison to Wetmore's data from 1993 was complicated by the lack of archived material, which could have been run in conjunction with present day samples. We recommend archiving of samples, if chemical comparisons of lichen thalli are to be made over a long time period.

Lye Brook in comparison to the other sites: In general, LB plots were higher in elements known to be harmful to lichens such as S and N. The lower air quality at LB was witnessed by lower lichen species richness and poorer health of the lichens that were still there.

Monitoring recommendations: The health scores of lichen thalli from the plots correlated well to the lichen richness of the plots and patterns in pollution. In addition, the scores demonstrate that even at sites with better air quality, average thallus health is below normal (score of 2)(**Fig. 6**). We recommend the addition of health scores to monitoring protocols using lichens to assess air quality.

Given the logistical difficulties and expense of comparing lichen chemistry over long time periods, we recommend that a subset of lichen monitoring plots be located in close proximity to already existing air quality monitoring stations, such as sites in the IMPROVE, CASTNet (Clean Air Status and Trends Network) and NADP (National Atmospheric Deposition Program) networks.