

Calculating lichen-based critical loads for N deposition in temperate forests

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Introduction

Because epiphytic lichens are highly N-sensitive forest components, lichen-based CLs can help identify deposition targets that convey forest-wide protection. Lichens also play integral forest roles as nesting material, winter forage for rodents and ungulates, invertebrate habitat, and in nutrient cycling. Working with epiphyte community data for North American marine west coast forests (MWCF), Geiser et al. (3) modeled shifts from oligotroph- to eutroph-dominated (Fig. 1) communities as N deposition increases and precipitation decreases.

Here, we test the hypothesis that N deposition, precipitation, and lichen community composition relationships are consistent across temperate forests. Using the MWCF model we re-calculate CLs for dry, mesic, and wet temperate forests in CA and Scotland. If they match published CLs then other temperate forest CLs may be predictable using the MWCF model too.



Figure 1. Typical oligotrophic (left) and eutrophic (right) epiphytic lichens of marine west coast forests. Oligotrophs play important ecological roles as forage and nesting materials; eutrophs are smaller, weedy species.

Materials and methods

The MWCF model was developed for coniferous forests of Oregon & Washington using lichen community survey data from >1500 sites (Fig. 2). Survey sites were ordinated using Non-metric Multi-dimensional Scaling Analysis (NMS) and assigned airscores equivalent to their distance along a regional N gradient (2) (Fig. 3). A regression model (3) of air score response to N deposition and precipitation (Table 1) predicted CLs of 3-9 kg N/ha/y (Fig. 4) at air score 0.21, a response threshold of 41-30% oligotrophs and <34% nitrophytes (Table 2), increasing with precipitation.



Figure 2. Distribution of western Oregon and Washington lichen survey plots (left) within North America's Marine West Coast Forests (MWCF) ecoregion (shaded area, right).

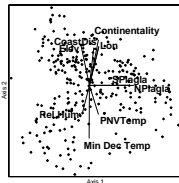


Figure 3. NMS ordination of lichen survey sites (from 3). Sites close together in space have similar community composition. Air scores are the survey site position along Axis 1, which was correlated with increasing N deposition. Climate was scored along Axis 2, the gradient from coastal to continental climates.

Table 1. The MWCF model of lichen response (air score) to nitrogen deposition (estimated by CMAQ) accounts for the influence of mean annual precipitation. Epiphytes may be more influenced by exposure concentrations than total loading; precipitation presumably has a diluting or leaching effect on lichen N accumulation.

Linear Regression Model	R ² adj.	Term	Estimate	S.E.	t Ratio	Prob > t
Air Score = $\beta_0 + \beta_1$ Precip (cm) + β_2 N deposition (kg ha ⁻¹ yr ⁻¹)	0.35	β_0	-0.0918	0.0323	-2.84	0.0046
		β_1	-0.0024	0.0001	-18.26	<.0001
		β_2	0.1493	0.0068	21.86	<.0001

Critical loads can be calculated from the MWCF model (Table 1) for any community response threshold (air score) using the formula:

$$\text{Critical load kg N/ha/yr} = (\text{threshold air score} + 0.918 + 0.0024 \text{ precip cm})/0.1493$$



Figure 4. Map of N critical loads for western Oregon and Washington, US. CLs are the amount of N deposition necessary to shift epiphytic macrolichen communities to an air score of 0.21, the point where oligotrophic species comprise 30 to 41% of the community. CLs vary over the landscape because precipitation moderates lichen response. White shading, generally associated with largest urban and agricultural areas and low elevations, indicates likely critical load exceedances from 1994-2002 (air score \geq 0.21). From (2).

Table 2. Cross walk of air scores to lichen community composition (as percentage contributions of oligotrophs and nitrophytes to total species richness). Percentages represent the mean and standard deviation (sd) for survey sites within each air score division for the MWCF study area. N = number of survey sites. Air score 0.21 was selected as the response threshold for MWCFs.

Division	N	Air Score Range	Mean % Oligotrophs (sd)	Mean % Eutrophs (sd)
1	845	-1.40 to -0.11	53 (13)	9 (7)
2	215	>-0.11 to 0.02	44 (11)	20 (8)
3	212	>0.02 to 0.21	41 (14)	27 (10)
4	50	>0.21 to 0.33	30 (14)	34 (11)
5	55	>0.33 to 0.49	25 (12)	47 (10)
6A	117	>0.49 to 1.00	21 (15)	57 (17)
6B	25	>1.00 to 2.0	3 (6)	83 (12)

To test the model for more general application, we calculated CLs for:

- California's Greater Central Valley**, dry, mixed-deciduous forest. *Published CL: 5.5 (6)*. *Response threshold: 50% nitrophytes*. *Precipitation: 17-120 cm.*
- California's Sierra Nevada**, a mesic coniferous forest. *Published CLs: 3.1, 5.2, and 10.2 for lichen lichen response thresholds of 40%, 25%, and 0% oligotrophs (1)*. *Precipitation: 111 cm.*
- Scotland's Atlantic Oakwoods**, a wet deciduous forest. *Published CL: 11-18 (4)*. *Response threshold: ~0% oligotrophs (inferred from spp lists)*. *Precipitation: 150 cm.*

Results

The MWCF model replicated published values for all three comparison areas (Table 3). Low North American values support proposals for lowering European lichen-based CLs for forests.

Table 3. Application of the regression model developed for MWCFs to datasets from California and Scotland, substituting relevant precipitation ranges and lichen community thresholds, yielded CLs comparable to published CLs. Applying the more protective response threshold (air score 0.21) to the Scotland dataset yielded CLs comparable to North American studies.

Study Area	Threshold Lichen community composition	Matching OR/WA air score	Ann precip (cm)	CL using OR/WA model		N Deposition Ref measure
				(kg N ha ⁻¹ yr ⁻¹)	Published CL (kg N ha ⁻¹ yr ⁻¹)	
Marine West Coast	30-41% oligos	0.21	44	2.7		(2) CMAQ
Forests N Am	30-41% oligos	0.21	186	5		(2) CMAQ
California	30-41% oligos	0.21	451	9.2		(2) CMAQ
Sierras, US	40% oligos	0.02-0.21	111	2.5-3.8	3.1	(1) Thruffall
Central Valley	25% oligos	0.33-0.49	111	4.6-5.7	5.2	(1) Thruffall
Oakwoods, boreal	0% oligos	1.0-2.0	111	9.1-15.8	10.2	(1) Thruffall
Scotland, UK	50% nitros	0.33-0.49	17	3.1-4.2	5.5	(5) CMAQ
Sweden	50% nitros	0.33-0.49	156	5.3-6.4	5.5	(5) CMAQ
Netherlands	0% oligos	1.0-2.0	221	10.8-17.5	11-18	(5) modeled
Switzerland	30-41% oligos	0.21	221	2.1	5.6	(3)
Switzerland	diversity/cover	n.a.	n.a.		5-10	(4) N addns
Netherlands	diversity/cover	n.a.	n.a.		8-9	(6) simulated

Conclusions

- The MWCF regression model generated from CMAQ-modeled N deposition data can predict N CLs at any desired lichen community composition (response threshold) and precipitation level. Replication by this model of previously published CLs for dry to mesic forests of California and wet forests of Scotland suggests a consistent relationship between N deposition, precipitation and lichen-community composition. This relationship may be used to predict nitrogen CLs in other temperate forests.
- Lichen-based CLs for western North America range from 3-10 kg N ha⁻¹ yr⁻¹ which, together with a CLs of 5.6 predicted by our model for wet Atlantic oakwoods of Scotland using North American marine forest lichen response thresholds, supports efforts to lower the UNECE CL for European forests.

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For further information

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