**Supplementary Material Section 2. Details for Results**

**Lichen and environmental data**

Average coverage of frequent lichen species at a plot was 1366.3 cm2 across all plots, 10.9% of a total 12,500 cm2 examined in quadrats; for all species it was 1375.9 cm2, 11.0%. Maximum lichen coverage at plot UMo.3 was 4152 cm2 or 33.2% for frequent species and 4209 cm2 or 33.7% for all species (See Supplementary Material Section S1, Table S1.1). Minimum coverage for all species (only frequent species present) at plot Che.3 was 164 cm2 or 1.3% of total area. Qualitatively, disturbance groups 1-4 represent increasingly severe disturbance. However since the type of disturbance differed so much between groups 2 through 4, we refrained from including in analyses any quantitative variable to represent disturbance severity. Usually fewer tree species were sampled than were present (compare Table 3 with Table 1).

**Statistical tests**

Pairwise correlations between 13 variables (Tables S2.1, S2.2) supported evaluation of their usefulness. Altitude was included as a variable for both the full set of plots and for a reduced data set of plots in only montane and submontane climate zones, since some semi-evergreen climate zone plots occurred far above their usual altitude range (see main paper section Materials and Methods/Study sites and data collection). Spearman rank correlations were stronger (suggesting either nonlinear though monotonic relationships between variables or other violations of parametric assumptions) for about 60% of significant comparisons; Pearson correlations were stronger (indicating reasonably linear relationships and normal distributions) for the remainder. Altitude and years from disturbance each had mostly Pearson correlations reported, indicating their data met parametric assumptions most of the time. All variables for number or cover of lichen species were strongly correlated with each other and also with number of tree species and canopy cover, explaining most of the total variation (Table S2.1). Both lichen species number variables but only cover of frequent species (correlations with total cover were almost the same, since cover of the 50 infrequent species was so low: Table 1) were entered in further analyses. Weak correlations of average tree size with lichen diversity variables reflect that only two vegetation types had plots with large trees (>20 cm DBH): disturbed Ca with many lichen species and undisturbed USE with relatively few species. Bark pH explained none to ~14% of variation; altitude as an imperfect proxy for climate was difficult to interpret ecologically. Neither was entered in partial correlations.

All tree and environmental variables at least moderately correlated with lichen variables represented some aspect of habitat or environment that could affect lichens. Number of tree species, canopy cover, and tree lean were strongly correlated with each other (>50% of variation explained, Table S2.2). Of these three only number of tree species (strongest correlations with lichen variables) was entered into partial correlations with within-plot variables. The two large-scale quantitative disturbance variables were also strongly correlated with each other, precluding their entry into the same analysis. Years from disturbance was the stronger variable for number of lichen species while distance to undisturbed forest was the stronger for lichen cover. However, canopy cover was also strongly correlated with years from disturbance and only moderately with distance to undisturbed forest. In partial correlations evaluating effect of large-scale variables, canopy was entered to represent years from disturbance.

**Table S2.1.** Correlations (*r* or *rho*) of vegetation variables with each other and with environmental variables. Most are Spearman rank correlations; values with a P after them are Pearson correlations. Value followed by probability (p); those with p<0.0005 are in bold. N = 42 plots, except N = 30 plots for all correlations with altitude for only montane and submontane climate zones.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | No. of all lichen species | No. of frequent lichen species | Cover of all lichen species | Cover of frequent lichen species | No. of all tree species | Tree size (DBH) |
| No. of frequent lichen species | **0.969, p<0.0005** |  |  |  |  |  |
| Cover of all lichen species, cm2 | **0.910, p<0.0005** | **0.924, p<0.0005** |  |  |  |  |
| Cover of frequent lichen species, cm2 | **0.910, p<0.0005** | **0.925, p<0.0005** | **1.000000, p<0.0005** |  |  |  |
| No. of all tree species | **0.927P, p<0.0005** | **0.957P, p<0.0005** | **0.927, p<0.0005** | **0.928, p<0.0005** |  |  |
| Tree size (DBH) | **0.438, p<0.0005** | 0.427, p=0.005 | 0.458P, p=0.002 | 0.459P, p=0.005 | 0.444, p=0.003 |  |
| Altitude | **0.648P, p<0.0005** | **0.658, p<0.0005** | **0.680, p<0.0005** | **0.680, p<0.0005** | **0.656, p<0.0005** | NS |
| Altitude, montane + submontane climate zones only | **0.676P, p<0.0005** | **0.720P, p<0.0005** | **0.721P, p<0.0005** | **0.720P, p<0.0005** | **0.661P, p<0.0005** | NS |
| Distance to undisturbed forest | **-0.513, p<0.0005** | **-0.517, p<0.0005** | **-0.571, p<0.0005** | **-0.572, p<0.0005** | **-0.602, p<0.0005** | -0.409P, p=0.007 |
| Years from disturbance | -0.579P, **p<0.0005** | -0.535P, **p<0.0005** | -0.490, p=0.001 | -0.490, p=0.001 | **-0.563P, p<0.0005** | -0.459, p=0.002 |
| Bark pH | 0.371P, p=0.016 | NS | 0.375P, p=0.014 | 0.373P, p=0.015 | 0.336P, p=0.030 | NS |
| Tree lean | **0.732P, p<0.0005** | **0.733, p<0.0005** | **0.812P, p<0.0005** | **0.812P, p<0.0005** | **0.741, p<0.0005** | **0.545P, p<0.0005** |
| Canopy cover | **0.859, p<0.0005** | **0.896, p<0.0005** | **0.837, p<0.0005** | **0.839, p<0.0005** | **0.920, p<0.0005** | NS |

**Table S2.2.** Correlations (*r* or *rho*) between environmental variables. Values with a P after them are Pearson correlations. Value followed by probability (p); those with p<0.0005 are in bold. N = 42 plots, except N = 30 plots for all correlations with altitude for only montane and submontane climate zones.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Altitude | Altitude for only montane + submontane climate zones | Distance to undisturbed | Years from disturbance | Bark pH | Tree lean | Canopy cover |
| Distance to undisturbed | NS | NS |  |  |  |  |  |
| Years from disturbance | -0.381P, p=0.013 | NS | **0.805, p<0.0005** |  |  |  |  |
| Bark pH | 0.478P, p=0.001 | NS | **-.539, p<0.0005** | NS |  |  |  |
| Tree lean | **0.605P, p<0.0005** | **0.656P, p<0.0005** | -0.391, p=0.011 | -0.307P, p=0.048 | **0.676, p<0.0005** |  |  |
| Canopy cover | **0.690P, p<0.0005** | **0.616P, p<0.0005** | -.492, p=0.005 | **-0.762P, p<0.0005** | **0.769, p<0.0005** | **0.720, p<0.0005** |  |

Partial correlations of lichen diversity variables with environmental variables added some insights to simple correlations. The strongest analyses for within-site and larger-scale variables are reported (Table S2.3); weaker analyses with alternate variables (not shown) had similar results. No single lichen diversity variable was the strongest for all analyses. Partial correlation of number of frequent lichen species with number of tree species controlling for tree lean and tree size was very strong (Table S2.3.A) while the reverse—partial correlations of lichen data with either of the two tree habitat variables controlling for the other plus number of tree species—were not significant. Analyses substituting canopy cover for number of tree species were weaker though consistent. This confirms conclusions from simple correlations that number of plot tree species had the strongest direct links with lichens at within-plot scale, likely integrating impacts of average tree canopy, tree lean, tree size, and bark pH on number or cover of lichen species. Partial correlations (not shown) of number of tree species with tree canopy, tree size, or tree lean controlling for the other two were each moderately significant, suggesting each factor varied somewhat independently with number of tree species. Partial correlation of number of all lichen species with canopy cover representing years from disturbance (see above discussion of simple correlations) controlling for distance to undisturbed forest (Table S2.3.B) was the strongest of large-scale variables, stronger than simple correlation with canopy. Its greater strength points to the importance of distance to undisturbed forest. Switching the primary and control-for variable gave a weaker result, supporting simple correlations that showed years from disturbance had the stronger links with number or cover of lichen species richness. Partial correlations also confirmed independent impacts on lichen diversity of both large-scale disturbance variables.

General linear modeling (GLM) for relationships of lichen variables with vegetation type, climate zone, and disturbance group evaluated the importance of large-scale factors as classes. Vegetation types are each complete subsets of climate zones (main paper Methods/Study sites and data collection); the two factors were not entered in the same GLM. All original data lichen variables had significantly heterogeneous error variances, so each was log10-transformed for analysis. Massive SPSS output has been condensed for reporting. GLM of number of frequent lichen species on vegetation type and disturbance group (Table S2.4) accounted for over 80% of variation: ~65% attributed to vegetation type and 19% to disturbance group. GLM of number of all lichen species on climate zone and disturbance groups (Table S2.5.) accounted for less of the variance – 76%. Of the total, 78% was attributed to disturbance groups and 34% to climate zone. Interaction effect of the sufficiently independent disturbance and climate was not significant.

**Table S2.3.** Partial correlations of lichen variables with (A) variables representing within-site factors and (B) variables representing large-scale factors. Significance (2-tailed) p<0.0005 unless noted, degrees of freedom 38 for all.

1. Partial correlations of lichen variables with within-plot variables

|  |  |  |  |
| --- | --- | --- | --- |
| **Control Variables** | **Primary variables** | | **Number of tree species** |
| Tree lean log10 + Tree size log10 | Number of frequent lichen species | Correlation | 0.909 |

1. Partial correlations of lichen variables with large-scale variables

|  |  |  |  |
| --- | --- | --- | --- |
| **Control Variable** | **Primary variables** | | **Canopy L10** |
| Distance to undisturbed forest L10 | Number of all lichen species L10 | Correlation | 0.865 |

**Table S2.4.** GLM of number of frequent lichen species on vegetation type and within-plot disturbance group. GLM results include **A.** Main effects, **B.** single-factor effects, and **C.** post-hoc tests for homogeneous subgroups. Disturbance groups 3 and 4 had the same sites as vegetation types 5 and 7, respectively, with no degrees of freedom remaining for test of interaction effect. See Table 2 for names and codes of vegetation types and composition of disturbance groups. Abbreviations: df = degrees of freedom; p = probability; Sig. = significance. Partial Eta Squared is the variance explained by a given predictor variable, of the variance remaining after excluding variance explained by other predictors.

1. GLM Main effects

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tests of Between-Subjects Effects** | | | | | | |
| Dependent Variable: | Number of frequent lichen species L10 | | | | | |
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
| Corrected Model | 3.119a | 7 | 0.446 | 25.186 | p<0.0005 | 0.838 |
| Intercept | 25.361 | 1 | 25.361 | 1433.609 | p<0.0005 | 0.977 |
| Vegetation Type (7) | 0.725 | 4 | 0.181 | 10.240 | p<0.0005 | 0.546 |
| Disturbance group (4) | 0.112 | 1 | 0.112 | 6.328 | p=0.017 | 0.157 |
| Error | 0.601 | 34 | 0.018 |  |  |  |
| Total | 33.547 | 42 |  |  |  |  |
| Corrected Total | 3.720 | 41 |  |  |  |  |
| a. R Squared = .838 (Adjusted R Squared = .805) | | | | | | |
| Levene’s test for equality of variances = NS | | | | | | |

1. GLM Single-factor effects

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Univariate Test of Vegetation Type** | | | | | |  |
| Dependent Variable: | Number of frequent lichen species L10 | | | | |  |
|  | Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
| Contrast | 3.007 | 6 | 0.501 | 24.586 | <0.0005 | 0.808 |
| Error | 0.713 | 34 | 0.020 |  |  |  |
| **Univariate Test of Disturbance group** | | | | | | |
| Dependent Variable: | Number of frequent lichen species L10 | | | | | |
|  | Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
| Contrast | 2.394 | 2 | 0.798 | 22.870 | <0.0005 | 0.644 |
| Error | 1.326 | 34 | 0.035 |  |  |  |

1. GLM Post-Hoc tests

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Homogeneous subsets of vegetation type** | | **N** | **Subset** | | | |
| **1** | **2** | **3** | |
| Tukey Ba,b | 7 | 6 | 0.3597 |  |  | |
| 5 | 6 |  | 0.6429 |  | |
| 6 | 6 |  | 0.7293 |  | |
| 2 | 6 |  | 0.8374 |  | |
| 4 | 6 |  |  | 1.0868 | |
| 3 | 6 |  |  | 1.1125 | |
| 1 | 6 |  |  | 1.1303 | |
| Means for groups in homogeneous subsets (between group p<0.001) are displayed, based on observed means. The error term is Mean Square (Error) = .018. | | | | | | |
| a. Uses Harmonic Mean Sample Size = 6.000. | | | | | | |
| b. Within-group differences (LSD): 2v5 p = 0.016, 2v6 p=0.168, 5v6 p=0.268; 1v3 p = 0.818, 1v4 p=0.575, 3v4 p=0.740 | | | | | | |
| **Homogeneous subsets of disturbance group** | | **N** | **Subset** | | | |
| **1** | **2** | **3** | **4** |
| Tukey Ba,b | 4 | 6 | 0.3597 |  |  |  |
|  | 3 | 6 |  | 0.6429 |  |  |
|  | 2 | 15 |  |  | 0.8985 |  |
|  | 1 | 15 |  |  |  | 1.0600 |
| Means for groups in homogeneous subsets (between group p<0.001) are displayed, based on observed means. The error term is Mean Square (Error) = .018. | | | | | | |
| a. Uses Harmonic Mean Sample Size = 8.571. | | | | | | |
| For both factors: The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed. | | | | | | |

**Table S2.5.** GLM: number of all lichen species by climate zone and within-plot disturbance group. GLM results include **A.** Main effects, **B.** single-factor effects, and **C.** post-hoc tests for homogeneous subgroups. See Table 2 for codes and composition of habitat and disturbance groups. Abbreviations: df = degrees of freedom; p = probability; Sig. = significance. Partial Eta Squared is the variance explained by a given variable, of the variance remaining after excluding variance explained by other predictors.

1. GLM Main effects

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tests of Between-Subjects Effects** | | | | | | |
| Dependent Variable: | Number of all lichen species L10 | | | | | |
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
| Corrected Model | 3.242a | 6 | 0.540 | 22.402 | <0.0005 | 0.793 |
| Intercept | 28.529 | 1 | 28.529 | 1182.784 | <0.0005 | 0.971 |
| Disturbance group (4) | 1.351 | 3 | 0.450 | 18.666 | <0.0005 | 0.615 |
| Climate zone (3) | 0.316 | 2 | 0.158 | 6.546 | 0.004 | 0.272 |
| Disturbance \* Climate | 0.004 | 1 | 0.004 | 0.164 | 0.688 | 0.005 |
| Error | 0.844 | 35 | 0.024 |  |  |  |
| Total | 41.433 | 42 |  |  |  |  |
| Corrected Total | 4.086 | 41 |  |  |  |  |
| a. R Squared = .793 (Adjusted R Squared = .758) | | | | | | |
| Levene’s test for equality of variances = NS | | | | | | |

1. GLM Single-factor effects

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Univariate Test of Disturbance group** | | | | | | | |
| Dependent Variable: | Number of all lichen species L10 | | | | | | |
|  | Sum of Squares | df | Mean Square | F | Sig. | | Partial Eta Squared |
| Contrast | 2.915 | 3 | 0.972 | 31.508 | <0.0005 | | 0.713 |
| Error | 1.172 | 35 | 0.031 |  |  | |  |
| **Univariate Test of Climate zone** | | | | | | | |
| Dependent Variable: | Number of all lichen species L10 | | | | | | |
|  | Sum of Squares | df | Mean Square | F | | Sig. | Partial Eta Squared |
| Contrast | 1.875 | 2 | 0.937 | 16.532 | | <0.0005 | 0.459 |
| Error | 2.211 | 35 | 0.057 |  | |  |  |

1. GLM Post-Hoc tests

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Homogeneous subsets of disturbance groups** | | **N** | **Subset** | | | | |
| **1** | **2** | | **3** | |
| Tukey Ba,b | 4 | 6 | 0.3597 |  | |  | |
|  | 3 | 6 |  | 0.8027 | |  | |
|  | 2 | 15 |  |  | | 1.0225 | |
|  | 1 | 15 |  |  | | 1.1528 | |
| Means for groups in homogeneous subsets (between group p<0.001) are displayed. Based on observed means. The error term is Mean Square (Error) = .024. | | | | | | | |
| a. Uses Harmonic Mean Sample Size = 8.571. | | | | | | | |
| b. Within-group difference (LSD): 2v1 p = 0.028 | | | | | | | |
| **Homogeneous subsets of climate zones** | | **N** | **Subset** | | | | |
| **1** | | **2** | | **3** |
| Tukey Ba,b | 3 | 12 | 0.6262 | |  | |  |
| 2 | 12 |  | | 0.9726 | |  |
| 1 | 18 |  | |  | | 1.1344 |
| Means for groups in homogeneous subsets (between group p<0.008) are displayed.  The error term is Mean Square (Error) = .024. | | | | | | | |
| a. Uses Harmonic Mean Sample Size = 13.500. | | | | | | | |
| For both factors: The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed. | | | | | | | |

**Ordination results**

The best 3-dimensional NMS solution reported in the paper, from 250 runs of NMS autopilot (McCune & Mefford 2011) “slow and thorough,” after 99 iterations reached a final stress of 16.54654, final instability of 0.00000, probability of p = 0.004 of being no different from 250 randomized runs. More than half of original information was represented in the best solution, and axes were orthogonal (Table S2.6). The solution was thus supported as a stable and informative ordination suitable for ecological interpretation. Final ordination axis scores for each plot (Table S2.7) generated the diagram in Fig. 2. Independent (i. e. not affecting the ordination diagram) secondary correlations with ordination axes of 12 environmental and lichen diversity variables (Table S2.8) supported ecological interpretation of the NMS ordination. Number of all lichen species was distinct from other lichen diversity variables; arrows for other lichen diversity variables (not shown on Fig. 2) would overlap the Bark pH arrow but be shorter. Disturbance-related variables including canopy cover had strong to moderate correlations with ordination axes. Lichen diversity variables and several within-plot environmental variables in bold had weak correlations with ordination axes; other within-plot environmental variables had correlations too weak to be useful for ecological interpretation. Altitude was not correlated with ordination axes even for only montane and submontane climate zone plots: Altitude vs Axis 1 r = -0.208, vs Axis 2 r = 0.283, vs Axis 3 r = 0.041 (N = 30 plots, p>0.05 for all). The 20 species in bold in Table S2.9 were strong contributors to ordination pattern. Most of the species in bold were also found to be strong indicators for one or more ISA grouping factors.

NMS ordination was tried with several other data sets but solutions were notably less stable, accounted for less variation, and were harder to interpret ecologically. Data sets with more species generated less stable best NMS solutions accounting for less than 30% of variation total. Data sets of lichens by genus rather than species or the 74-species data set with species abundance data relativized by site each generated moderately stable ordinations with only one axis: displaying <30% of total variation, having little correlation with any environmental variables, and thus identifying little information of ecological interest.

**Table S2.6.** NMS ordination of 42 plots: specifications after principal coordinates rotation. **A**. Axis correlations; **B.** Axis orthogonality.

**A.** Coefficients of determination for the correlations between ordination

distances and distances in the original n-dimensional space:

|  |  |  |
| --- | --- | --- |
|  | ***r2*** | |
| **Axis** | **Increment** | **Cumulative** |
| 1 | 0.209 | 0.209 |
| 2 | 0.177 | 0.385 |
| 3 | 0.176 | 0.562 |

Increment and cumula tive ***r2*** were adjusted for any lack of orthogonality of axes.

**B.** Axis orthogonality

|  |  |  |
| --- | --- | --- |
| Axis pair | *r* | Orthogonality, % = 100 (1-r2) |
| 1 vs 2 | 0.000 | 100.0 |
| 1 vs 3 | 0.000 | 100.0 |
| 2 vs 3 | 0.000 | 100.0 |

**Table S2.7.** NMS ordination of 42 plots: final rotation axis scores for the study plots as displayed in Fig. 2

|  |  |  |  |
| --- | --- | --- | --- |
| Plot number within vegetation type | Axis 1 | Axis 2 | Axis 3 |
| 1. UMo.1 | -0.1673 | -0.4635 | 0.796 |
| 1. UMo.2 | -0.303 | -0.4346 | 0.6693 |
| 1. UMo.3 | -0.4329 | -0.5352 | 0.3023 |
| 1. UMo.4 | -0.819 | -0.5693 | 0.2993 |
| 1. UMo.5 | -0.7857 | -0.5037 | 0.4016 |
| 1. UMo.6 | -0.8179 | -0.4653 | 0.4036 |
| 2. DMo. 1 | 0.7364 | -0.2934 | 0.6022 |
| 2. DMo. 2 | 0.3675 | 0.2027 | 0.683 |
| 2. DMo. 3 | 0.6501 | -0.1812 | 0.8204 |
| 2. DMo. 4 | 0.6689 | -0.0889 | -0.6666 |
| 2. DMo. 5 | 0.7656 | -0.013 | -0.594 |
| 2. DMo. 6 | 0.9847 | 0.0191 | -0.377 |
| 3. Ca.1 | 0.2205 | 0.2815 | -0.9543 |
| 3. Ca.2 | 0.3165 | 0.4547 | -0.9362 |
| 3. Ca.3 | 0.3406 | 0.3109 | -0.981 |
| 3. Ca.4 | 0.6907 | 0.1886 | 0.1274 |
| 3. Ca.5 | 0.7256 | 0.2748 | 0.1328 |
| 3. Ca.6 | 0.7107 | 0.1263 | 0.1704 |
| 4. USM.1 | -0.971 | 0.0362 | 0.4242 |
| 4. USM.2 | -0.9605 | 0.0823 | -0.33 |
| 4. USM.3 | -0.968 | 0.0435 | 0.1801 |
| 4. USM.4 | -1.0119 | 0.0918 | -0.0769 |
| 4. USM.5 | -0.8972 | -0.1818 | -0.3271 |
| 4. USM.6 | -0.9679 | -0.2309 | -0.1671 |
| 5. MFP.1 | 0.7674 | -0.4666 | 0.1933 |
| 5. MFP.2 | 0.6631 | -0.6596 | 0.1643 |
| 5. MFP.3 | 0.6627 | -0.5276 | 0.1189 |
| 5. MFP.4 | 0.7304 | -0.6897 | -0.1227 |
| 5. MFP.5 | 0.7156 | -0.7029 | -0.3192 |
| 5. MFP.6 | 0.5421 | -0.9859 | -0.1636 |
| 6. USE.1 | -0.062 | -0.028 | 0.3602 |
| 6. USE.2 | -0.361 | 0.5199 | 0.4515 |
| 6. USE.31 | -0.2212 | -0.7957 | -0.2137 |
| 6. USE.41 | -0.7496 | -0.0494 | -0.9347 |
| 6. USE.5 | -0.6022 | -0.2834 | -0.6951 |
| 6. USE.61 | -0.4602 | -0.0561 | -1.0213 |
| 7. Che.1 | -0.1619 | 1.2947 | -0.042 |
| 7. Che.2 | -0.1182 | 1.2725 | -0.3297 |
| 7. Che.3 | -0.1074 | 0.9565 | 0.6811 |
| 7. Che.4 | 0.2054 | 1.0629 | 0.3132 |
| 7. Che.5 | 0.1597 | 1.0749 | 0.3203 |
| 7. Che.6 | 0.3216 | 0.9119 | 0.6366 |

1USE plot with adjacent village

**Table S2.8.** NMS ordination of 42 plots: Pearson (***r***) and Kendall (*tau*) correlations of ecological and environmental factors with three ordination axes. For variables with correlation *r*2 ≥ 0.10 for at least one axis, their strongest axis correlation is in bold. Only correlations with *r*2 ≥ 0.10 for Axis 1 or 2 are represented by arrows in Fig. 2.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Axis 1** | | | **Axis 2** | | | **Axis 3** | | |
| **Variable** | ***r*** | ***r2*** | ***tau*** | ***r*** | ***r2*** | ***tau*** | ***r*** | ***r2*** | ***tau*** |
| **Altitude** | -0.011 | 0.000 | 0.006 | -0.190 | 0.036 | 0.010 | 0.067 | 0.005 | 0.069 |
| **Average canopy cover** | -0.162 | 0.026 | -0.127 | **-0.585** | **0.342** | **-0.182** | -0.102 | 0.010 | -0.018 |
| **Average tree DBH** | -0.144 | 0.021 | -0.124 | -0.037 | 0.001 | -0.046 | **-0.380** | **0.144** | **-0.274** |
| **Average trunk lean** | -0.054 | 0.003 | -0.038 | -0.102 | 0.010 | -0.125 | -0.203 | 0.041 | -0.072 |
| **Average bark pH** | **-0.396** | **0.156** | **-0.222** | -0.260 | 0.067 | -0.184 | 0.204 | 0.041 | 0.112 |
| **Distance to undisturbed** | **0.786** | **0.618** | **0.579** | 0.235 | 0.055 | 0.148 | 0.035 | 0.001 | -0.051 |
| **Years from disturbance** | 0.250 | 0.063 | 0.439 | **0.791** | **0.625** | **0.396** | 0.200 | 0.040 | 0.024 |
| **No. all lichen species** | -0.305 | 0.093 | -0.172 | **-0.369** | **0.136** | **-0.146** | -0.043 | 0.002 | -0.042 |
| **No. frequent lichen species** | **-0.367** | **0.135** | **-0.179** | -0.257 | 0.066 | -0.071 | -0.066 | 0.004 | -0.033 |
| **Cover all lichen species** | **-0.388** | **0.150** | **-0.215** | -0.204 | 0.042 | -0.078 | 0.038 | 0.001 | 0.031 |
| **Cover frequent lichen species** | **-0.389** | **0.151** | **-0.214** | -0.201 | 0.040 | -0.077 | 0.037 | 0.002 | 0.030 |
| **No. tree species** | **-0.418** | **0.175** | **-0.227** | -0.302 | 0.091 | -0.111 | -0.116 | 0.014 | -0.068 |

**Table S2.9.** NMS ordination of 42 plots: Pearson (***r***) and Kendall (*tau*) correlations of 74 lichen species with three ordination axes; see Supplementary Material Section S1, Table S1.2 for full species names. Values in bold have *r*2 ≥ 0.20 for that species with that axis. Numbers after a species name note an indicator from ISA: 1 = indicator for a vegetation type; 2 = indicator for a within-site disturbance group; 3 = indicator for a climate zone. See Tables 4 and 5 for the particular group(s) indicated by each species.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Axis 1** | | | **Axis 2** | | | **Axis 3** | | |
| **Lichen species Code** | ***r*** | ***r2*** | ***tau*** | ***r*** | ***r2*** | ***tau*** | ***r*** | ***r2*** | ***tau*** |
| Ba medi, 2 | **-0.624** | **0.389** | **-0.594** | -0.193 | 0.037 | -0.218 | -0.057 | 0.003 | -0.073 |
| Ch indi | **0.593** | **0.351** | **0.523** | -0.100 | 0.010 | -0.036 | -0.066 | 0.004 | -0.118 |
| Ch pate, 1 | -0.347 | 0.12 | -0.342 | 0.02 | 0 | 0.081 | 0.079 | 0.006 | 0.031 |
| Ch lepr, 1 | -0.116 | 0.014 | -0.124 | -0.173 | 0.03 | -0.212 | 0.136 | 0.019 | 0.261 |
| Cl maur, 1 | -0.431 | 0.186 | -0.374 | -0.072 | 0.005 | -0.022 | -0.048 | 0.002 | -0.011 |
| Cl subm, 1 | -0.33 | 0.109 | -0.249 | -0.229 | 0.052 | -0.230 | 0.191 | 0.036 | 0.180 |
| Co eryt, 1 | -0.428 | 0.184 | -0.401 | -0.005 | 0 | 0.022 | -0.043 | 0.002 | -0.081 |
| Co stel, 1 | **-0.460** | **0.212** | **-0.396** | -0.012 | 0 | 0.016 | -0.024 | 0.001 | -0.076 |
| Cg link, 1, 2 | **-0.522** | **0.273** | **-0.596** | -0.084 | 0.007 | -0.164 | 0.162 | 0.026 | 0.192 |
| Ct obsc, 1, 2, 3 | **0.504** | **0.254** | **0.416** | 0.092 | 0.008 | 0.200 | -0.295 | 0.087 | -0.323 |
| Ds plat, 1 | -0.356 | 0.126 | -0.277 | -0.282 | 0.08 | -0.293 | 0.201 | 0.040 | 0.179 |
| Eu bail | -0.224 | 0.050 | -0.238 | -0.004 | 0 | 0.097 | -0.164 | 0.027 | -0.116 |
| Gr rhiz, 1, 2 | 0.282 | 0.079 | 0.255 | -0.235 | 0.055 | -0.255 | 0.082 | 0.007 | 0.037 |
| Gr sril, 1 | -0.371 | 0.138 | -0.324 | -0.032 | 0.001 | -0.025 | -0.02 | 0 | -0.075 |
| Gr vitt, 1 | -0.330 | 0.109 | -0.285 | -0.307 | 0.094 | -0.343 | 0.24 | 0.057 | 0.294 |
| Gr rust, 1 | -0.290 | 0.084 | -0.222 | -0.296 | 0.088 | -0.293 | 0.259 | 0.067 | 0.217 |
| Gr pros, 1 | 0.127 | 0.016 | 0.068 | 0.171 | 0.029 | 0.236 | **-0.508** | **0.258** | **-0.336** |
| Gr subm, 1 | 0.225 | 0.051 | 0.199 | -0.021 | 0 | -0.006 | 0.336 | 0.113 | 0.330 |
| Gr sten | -0.051 | 0.003 | -0.076 | 0.049 | 0.002 | 0.065 | 0.167 | 0.028 | 0.179 |
| Hp aphn, 1 | **0.604** | **0.365** | **0.568** | -0.122 | 0.015 | -0.021 | -0.183 | 0.033 | -0.261 |
| He como | -0.251 | 0.063 | -0.187 | -0.052 | 0.003 | -0.081 | 0.163 | 0.027 | 0.243 |
| He dact | 0.399 | 0.159 | 0.320 | 0.014 | 0 | 0.081 | 0.270 | 0.073 | 0.188 |
| He diad, 1, 2 | 0.117 | 0.014 | 0.248 | -0.257 | 0.066 | -0.472 | 0.060 | 0.004 | -0.051 |
| He japo, 1 | 0.126 | 0.016 | 0.068 | 0.174 | 0.03 | 0.236 | **-0.497** | **0.247** | **-0.336** |
| He leuc | -0.254 | 0.065 | -0.211 | -0.147 | 0.022 | -0.157 | 0.181 | 0.033 | 0.244 |
| He spec, 1 | 0.101 | 0.010 | 0.062 | 0.143 | 0.021 | 0.23 | -0.443 | 0.196 | -0.342 |
| Lc mari, 1, 2 | -0.029 | 0.001 | -0.031 | **0.505** | **0.255** | **0.355** | 0.080 | 0.006 | 0.137 |
| Lc styl, 1 | 0.108 | 0.012 | 0.068 | 0.134 | 0.018 | 0.224 | **-0.452** | **0.204** | **-0.348** |
| Lp coch, 2 | **-0.489** | **0.239** | **-0.425** | -0.272 | 0.074 | -0.226 | 0.17 | 0.029 | 0.158 |
| Lp dent, 1 | 0.128 | 0.016 | 0.075 | 0.173 | 0.03 | 0.243 | **-0.489** | **0.239** | **-0.342** |
| Lp mill, 1 | 0.241 | 0.058 | 0.199 | -0.043 | 0.002 | -0.006 | 0.366 | 0.134 | 0.342 |
| Ly bisp, 1 | -0.309 | 0.095 | -0.266 | -0.273 | 0.074 | -0.304 | 0.180 | 0.032 | 0.168 |
| Ly com2, 1 | -0.425 | 0.180 | -0.38 | -0.064 | 0.004 | 0 | -0.104 | 0.011 | -0.103 |
| Ly comp, 1 | -0.262 | 0.069 | -0.199 | -0.071 | 0.005 | -0.056 | -0.435 | 0.189 | -0.317 |
| Ma ceyl, 1 | 0.306 | 0.093 | 0.261 | 0.094 | 0.009 | 0.162 | 0.076 | 0.006 | 0.025 |
| Ma gran, 1, 2 | 0.282 | 0.079 | 0.243 | -0.376 | 0.141 | -0.348 | -0.095 | 0.009 | -0.106 |
| Ma hypo, 1, 2 | 0.100 | 0.010 | 0.044 | **0.494** | **0.244** | **0.317** | 0.224 | 0.05 | 0.193 |
| Mg sulp, 1 | 0.410 | 0.168 | 0.383 | 0.028 | 0.001 | 0.110 | -0.188 | 0.036 | -0.119 |
| Mg tube, 1, 3 | **-0.526** | **0.277** | **-0.505** | -0.001 | 0 | 0.043 | 0.069 | 0.005 | -0.034 |
| Me micr, 1 | -0.409 | 0.167 | -0.342 | 0.023 | 0.001 | 0.081 | 0.083 | 0.007 | 0.031 |
| Me subc | 0.237 | 0.056 | 0.342 | -0.079 | 0.006 | -0.031 | 0.117 | 0.014 | -0.068 |
| Oc dipl | -0.351 | 0.123 | -0.343 | -0.182 | 0.033 | -0.141 | -0.170 | 0.029 | -0.231 |
| Oc eumo, 1 | -0.263 | 0.069 | -0.253 | -0.297 | 0.088 | -0.303 | 0.38 | 0.145 | 0.334 |
| Oc maru, 1 | -0.379 | 0.143 | -0.33 | -0.071 | 0.005 | -0.031 | -0.095 | 0.009 | -0.124 |
| Oc mono, 1 | 0.297 | 0.088 | 0.299 | -0.077 | 0.006 | -0.056 | -0.005 | 0 | -0.075 |
| Oc perf, 1 | -0.318 | 0.101 | -0.267 | -0.292 | 0.085 | -0.307 | 0.32 | 0.102 | 0.321 |
| Pl nigr, 1 | 0.126 | 0.016 | 0.066 | 0.171 | 0.029 | 0.234 | **-0.505** | **0.255** | **-0.341** |
| Pw wall | -0.357 | 0.128 | -0.342 | -0.013 | 0 | 0.043 | 0.086 | 0.007 | 0.033 |
| Pa cris, 1 | 0.115 | 0.013 | 0.075 | 0.167 | 0.028 | 0.243 | -0.441 | 0.194 | -0.342 |
| Pa ravu, 1 | 0.291 | 0.085 | 0.286 | -0.091 | 0.008 | -0.062 | 0.229 | 0.052 | 0.143 |
| Pa tinc, 1 | -0.027 | 0.001 | -0.081 | -0.008 | 0 | -0.025 | 0.116 | 0.014 | 0.100 |
| Pa uber, 1 | 0.129 | 0.017 | 0.078 | 0.172 | 0.030 | 0.241 | **-0.501** | **0.251** | **-0.347** |
| Pe subr, 1 | -0.350 | 0.123 | -0.276 | -0.297 | 0.088 | -0.325 | 0.220 | 0.048 | 0.242 |
| Pe subs, 1 | 0.192 | 0.037 | 0.137 | 0.11 | 0.012 | 0.187 | -0.267 | 0.072 | -0.212 |
| Pe trun, 1 | -0.399 | 0.159 | -0.342 | -0.033 | 0.001 | -0.019 | -0.077 | 0.006 | -0.112 |
| Ph bras, 1, 2 | -0.002 | 0 | -0.016 | **0.59** | **0.348** | **0.407** | -0.023 | 0.001 | 0.011 |
| Pb hypo | 0.087 | 0.008 | 0.157 | 0.209 | 0.044 | 0.400 | 0.286 | 0.082 | 0.332 |
| Po afri, 1 | -0.330 | 0.109 | -0.249 | -0.288 | 0.083 | -0.287 | 0.207 | 0.043 | 0.184 |
| Po inte, 1, 3 | **-0.563** | **0.317** | **-0.469** | -0.034 | 0.001 | 0.034 | -0.083 | 0.007 | -0.087 |
| Po tetr, 1 | -0.232 | 0.054 | -0.171 | -0.045 | 0.002 | 0.030 | -0.250 | 0.063 | -0.057 |
| Su argy | -0.331 | 0.110 | -0.292 | -0.180 | 0.032 | -0.168 | 0.034 | 0.001 | -0.056 |
| Py circ, 1 | 0.163 | 0.027 | 0.173 | 0.179 | 0.032 | 0.281 | -0.445 | 0.198 | -0.271 |
| Py mami, 1 | 0.354 | 0.125 | 0.324 | -0.010 | 0 | 0.019 | -0.276 | 0.076 | -0.243 |
| Px cora | -0.344 | 0.118 | -0.319 | -0.173 | 0.030 | -0.134 | 0.303 | 0.092 | 0.311 |
| Px subc, 1 | -0.333 | 0.111 | -0.249 | -0.284 | 0.081 | -0.287 | 0.210 | 0.044 | 0.184 |
| Sa intr, 2 | 0.382 | 0.146 | 0.492 | -0.245 | 0.060 | -0.213 | 0.111 | 0.012 | 0.020 |
| St cyph, 1 | -0.38 | 0.145 | -0.355 | 0.015 | 0 | 0.037 | 0.019 | 0 | -0.031 |
| Th quas | 0.255 | 0.065 | 0.278 | -0.226 | 0.051 | -0.188 | **0.530** | **0.281** | **0.414** |
| Tl berk, 1 | 0.117 | 0.014 | 0.068 | 0.169 | 0.029 | 0.236 | **-0.476** | **0.226** | **-0.336** |
| Tl pori, 1 | 0.248 | 0.062 | 0.218 | 0.112 | 0.013 | 0.193 | -0.031 | 0.001 | -0.112 |
| Tl rhod | 0.087 | 0.008 | 0.011 | -0.027 | 0.001 | -0.027 | -0.185 | 0.034 | -0.155 |
| Us corn | -0.050 | 0.002 | -0.070 | 0.012 | 0 | 0.009 | **-0.585** | **0.342** | **-0.420** |
| Us stein, 1 | -0.347 | 0.120 | -0.255 | -0.246 | 0.061 | -0.236 | 0.191 | 0.036 | 0.174 |
| Wt desq, 1 | 0.273 | 0.074 | 0.206 | 0.184 | 0.034 | 0.259 | -0.322 | 0.104 | -0.269 |

**ISA results**

ISA results are reported for seven vegetation types, three climate zones, and only the version of four disturbance groups with three USE plots near villages assigned to moderately disturbed group 2 (rather than undisturbed group 1). Since 63 species (Tables 4 and 5) were independently identified as strong indicators with p<0.05, about three of those would likely have been identified as significant just by chance. Alternatively, to achieve a similar likelihood (1 in 20 chances) of rejecting a “true” null hypothesis of random indication, the critical p value should be 0.016 (0.05 \* 20/63). Three species indicating a vegetation type with p = 0.0410- 0.0464 were excluded as likely appearing significant just by chance. All other strong species indicators (for a vegetation type or disturbance group) had p ≤ 0.015. Strong significant indicators from ISA are noted in Table S2.9 above, for comparison with ordination results. Differences between species important for ISA and ordination reflect that for ISA each species is evaluated alone, while for ordination all species in the data set contribute to the single best solution.

Visually distinctive genera (listed in text) or multi-genus groups evaluated for use by parataxonomists included both frequent and infrequent species in the same genus. Recently segregated genera that look similarare for this study considered a single genus group (for instance *Phaeographis/Sarcographa*). *Ocellularia* included one species distributed counter to the major trend. *Coccocarpia* included infrequent *Coccocarpia pellita* (Ach.) Müll. Arg.; *Graphis* (with one species distributed counter to the trend) included infrequent *Graphis arbusculiformis* (Vain.) Lücking; *Sticta/Dendriscosticta* (recently segregated) included infrequent *Sticta limbata* (Sm.) Ach. and *Sticta weigelii* (Ach.) Vain.; *Usnea/Eumitria* (recently segregated), part of one multi-genus group, included infrequent *Eumitria baileyi* Stirt. The visually distinctive species *Parmelinella wallichiana* was not a statistically significant indicator, while visually distinctgenera *Heterodermia/Polyblastidium*, *Myriotrema*, *Parmotrema*, *Pyrenula,* and *Thelotrema* had two or more sampled species that indicated very different vegetation types, disturbance groups, and/or climate zones. These outcomes preluded their use by parataxonomists as indicators.

**Suggestions for future analyses**

Plot altitude might be more useful for studies of lichen species composition at only montane or submontane sites, since correlation of altitude with lichen diversity variables was stronger when semi-evergreen climate zone plots were excluded. All the tree-level variables as well as number of tree species per plot should be re-investigated in tree-level analyses of lichens.