*Supplementary Information File*

# Global relationships in tree functional traits

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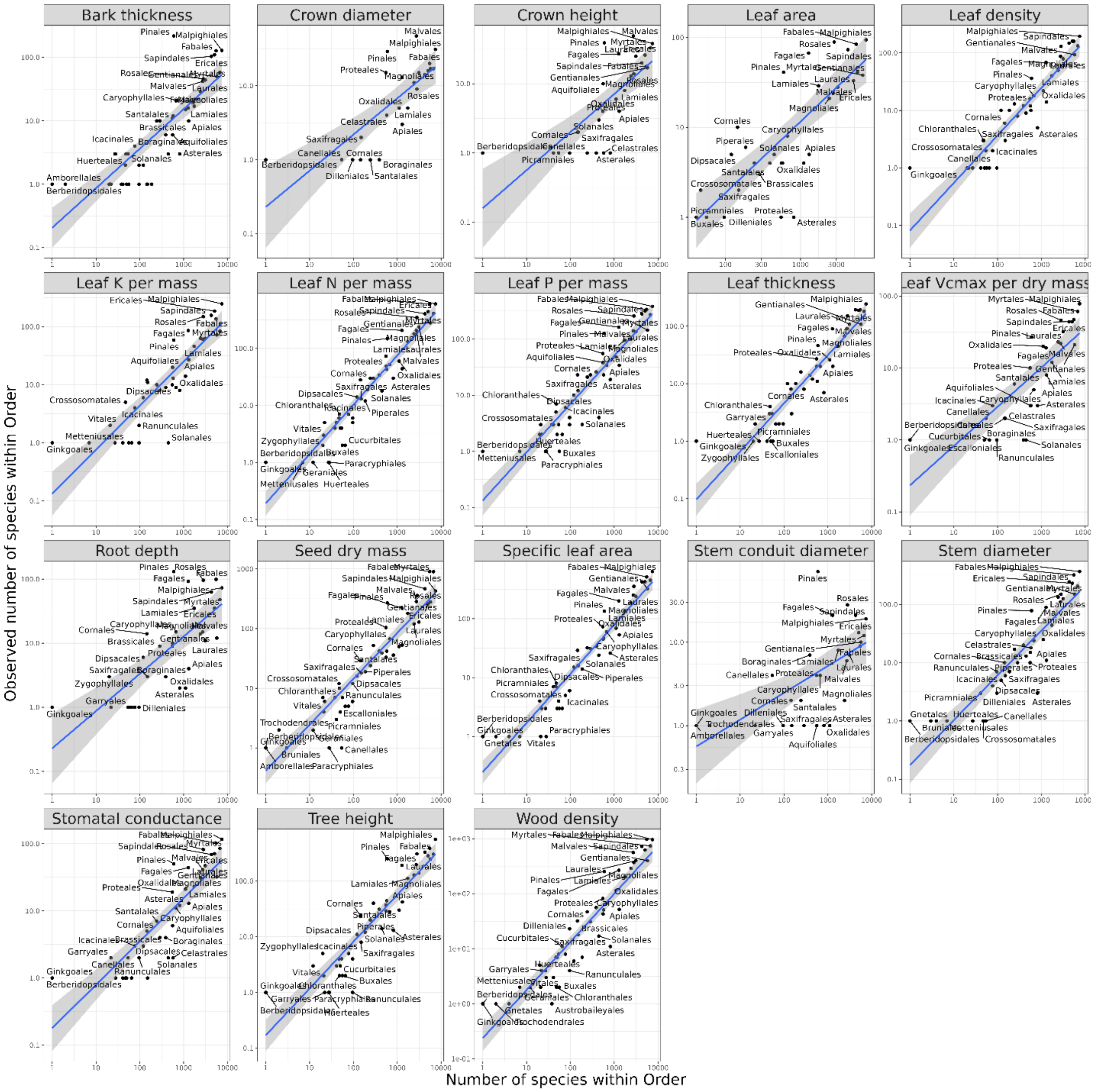
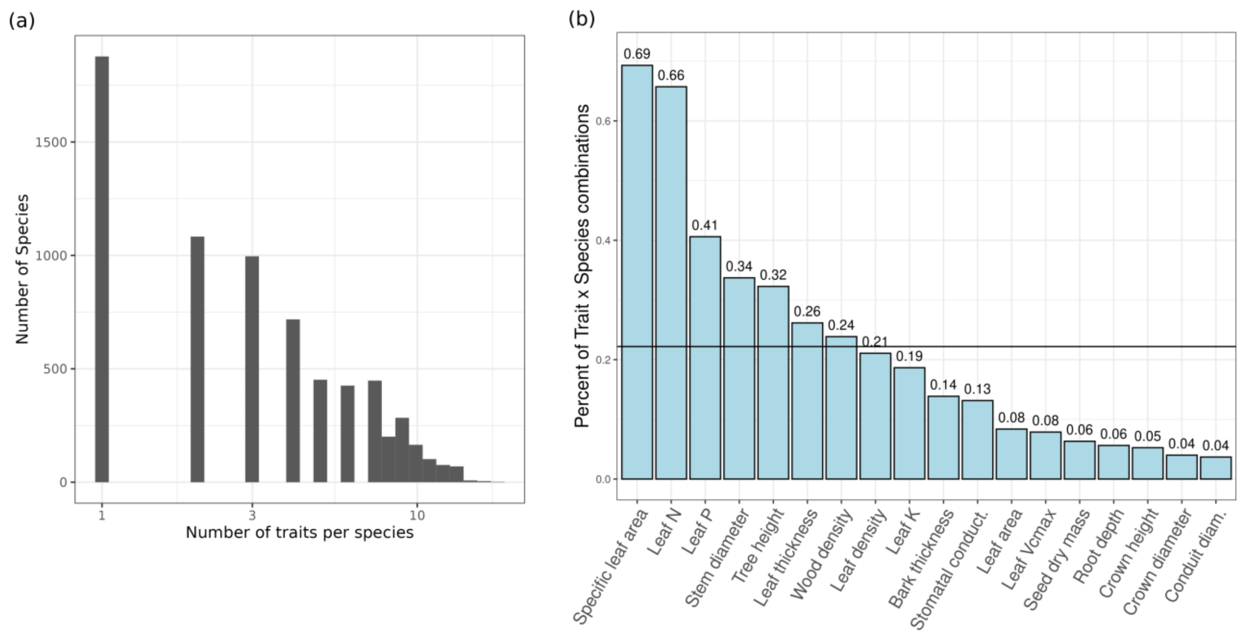
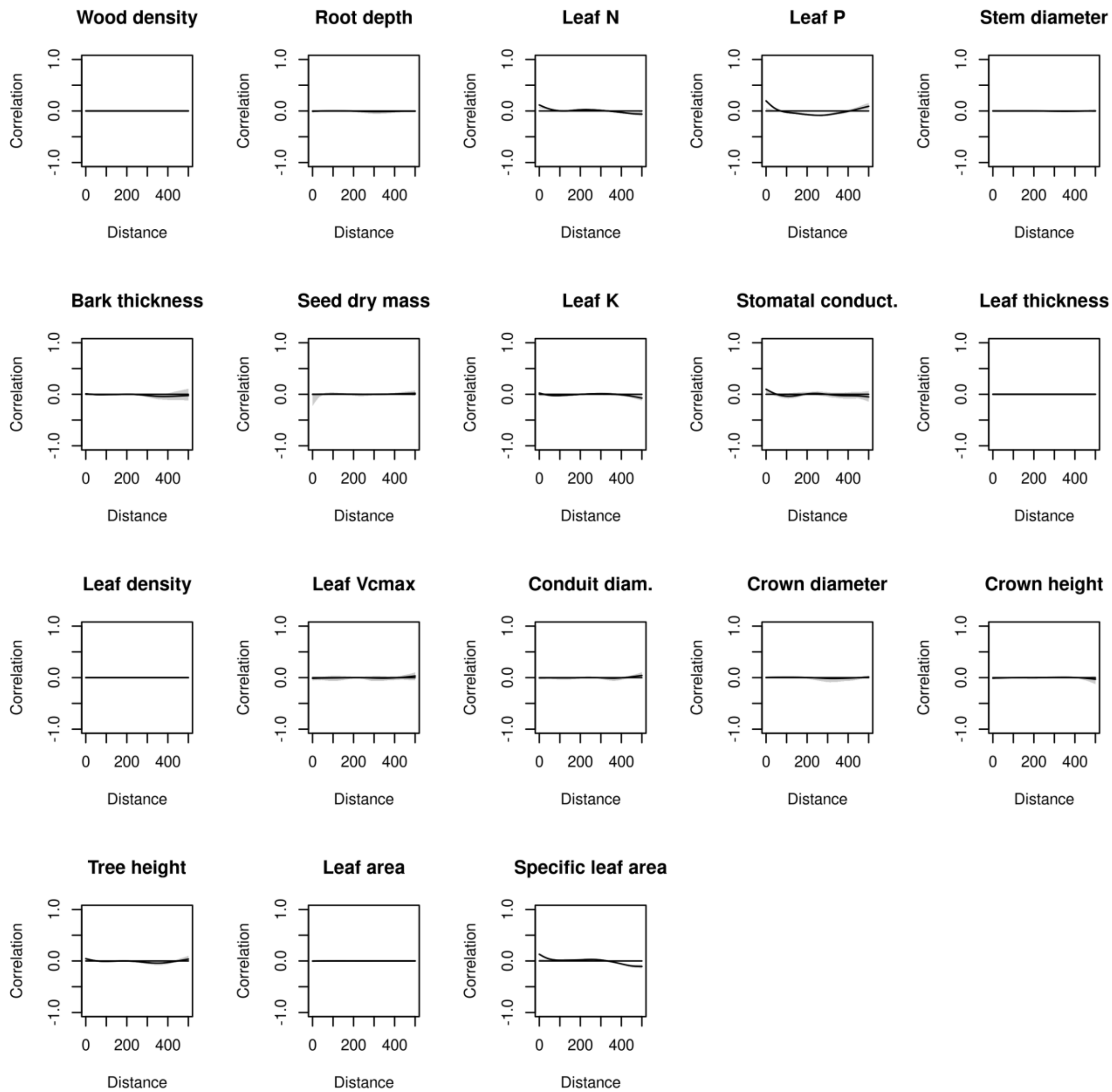


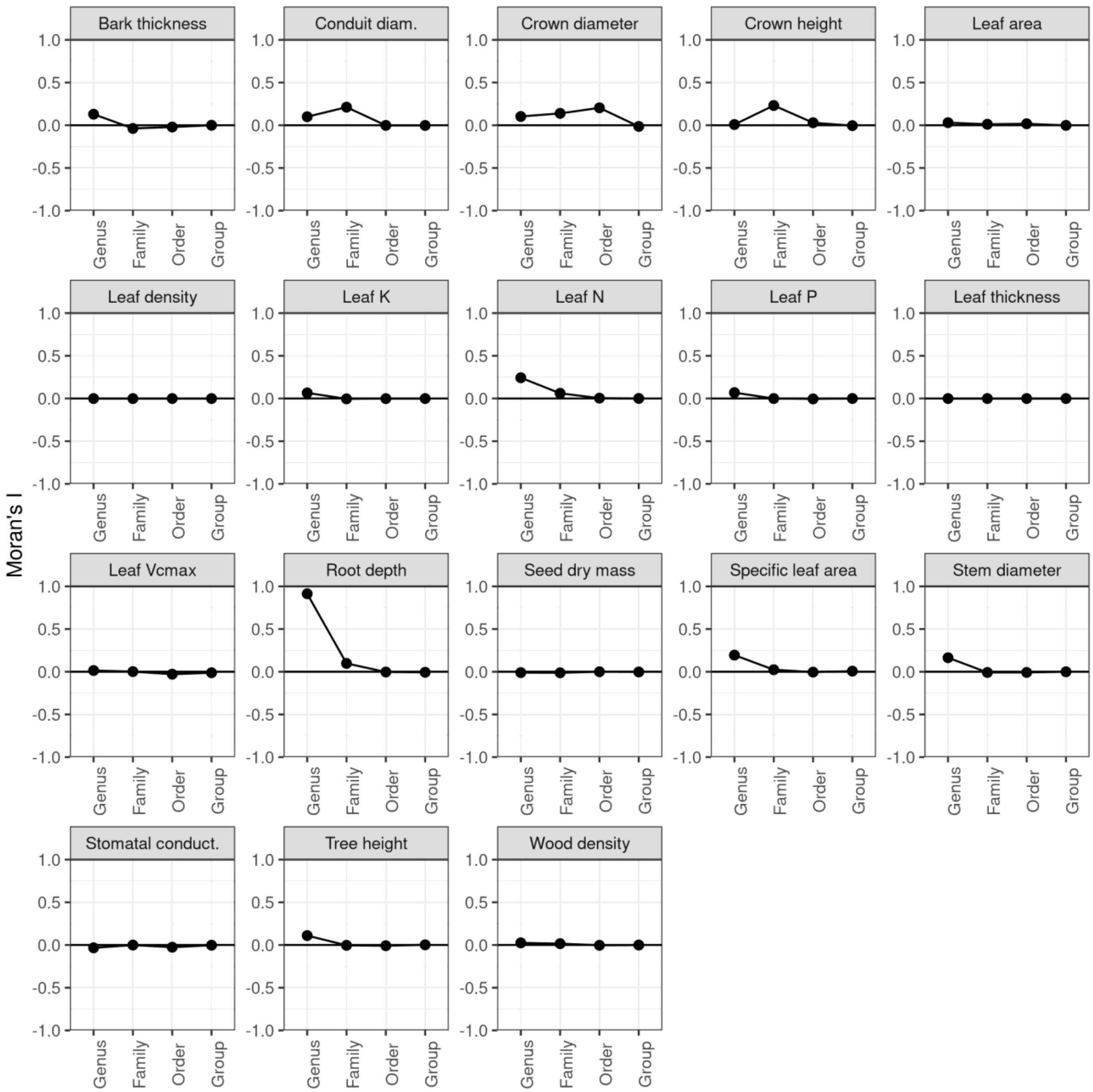

**Supplementary Figure 1.** The relationships between the number of species within each taxonomic order[21], versus the observed number of species for each trait. The line shows the standard linear regression fit, with the shaded region giving the 95% confidence interval for the mean.



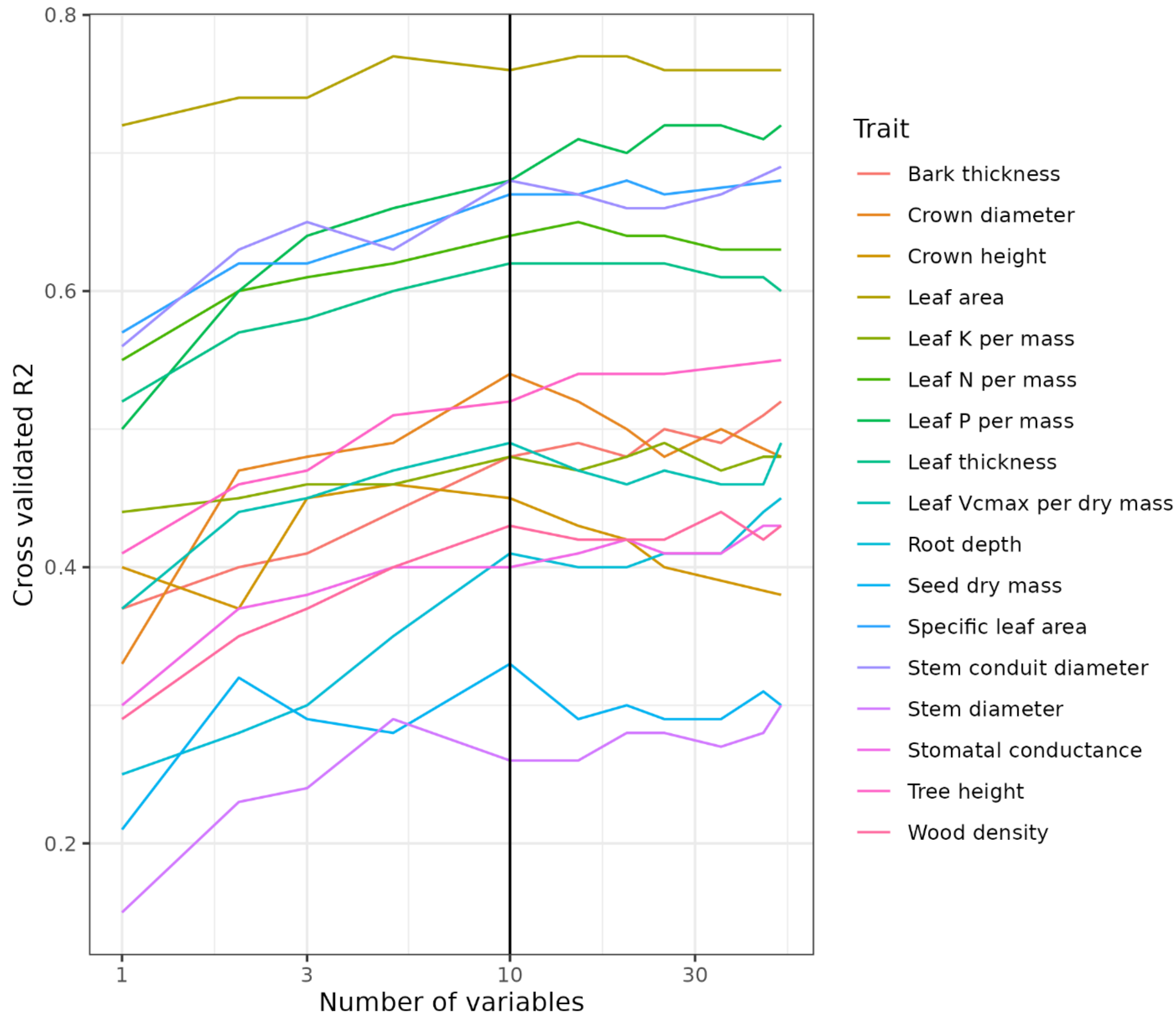

**Supplementary Figure 2**. **The degree of missingness in the data**. **(a)** The distribution of the number of traits per species. There was an average of 4 traits measured per species, with 423 species having more than 10 unique traits measures, and two species (*Picea abies* and *Pinus sylvestris*) having all traits measured. **(b)** The proportion of unique species with at least one measurement for each trait. The dataset captured 22% of all trait-by-species combinations (horizontal black line), slightly better than other large-scale trait analyses across the entire plant kingdom[30,31].



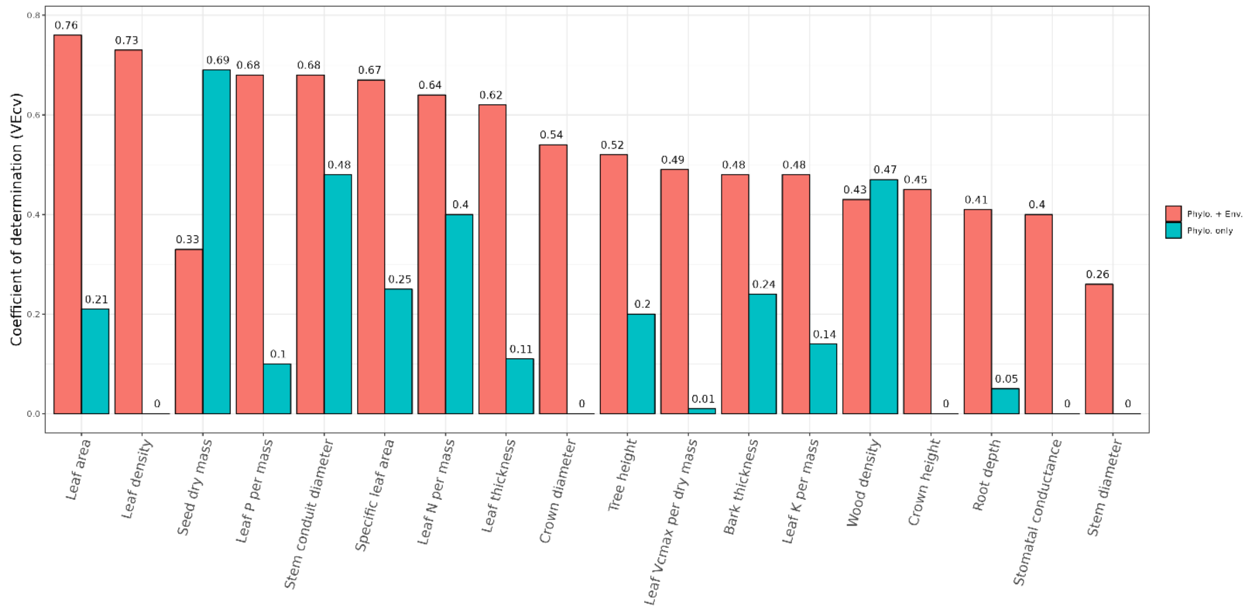

**Supplementary Figure 3.** Residual spatial autocorrelation (Moran's I) for all 18 traits, assessed using standard linear regression models.



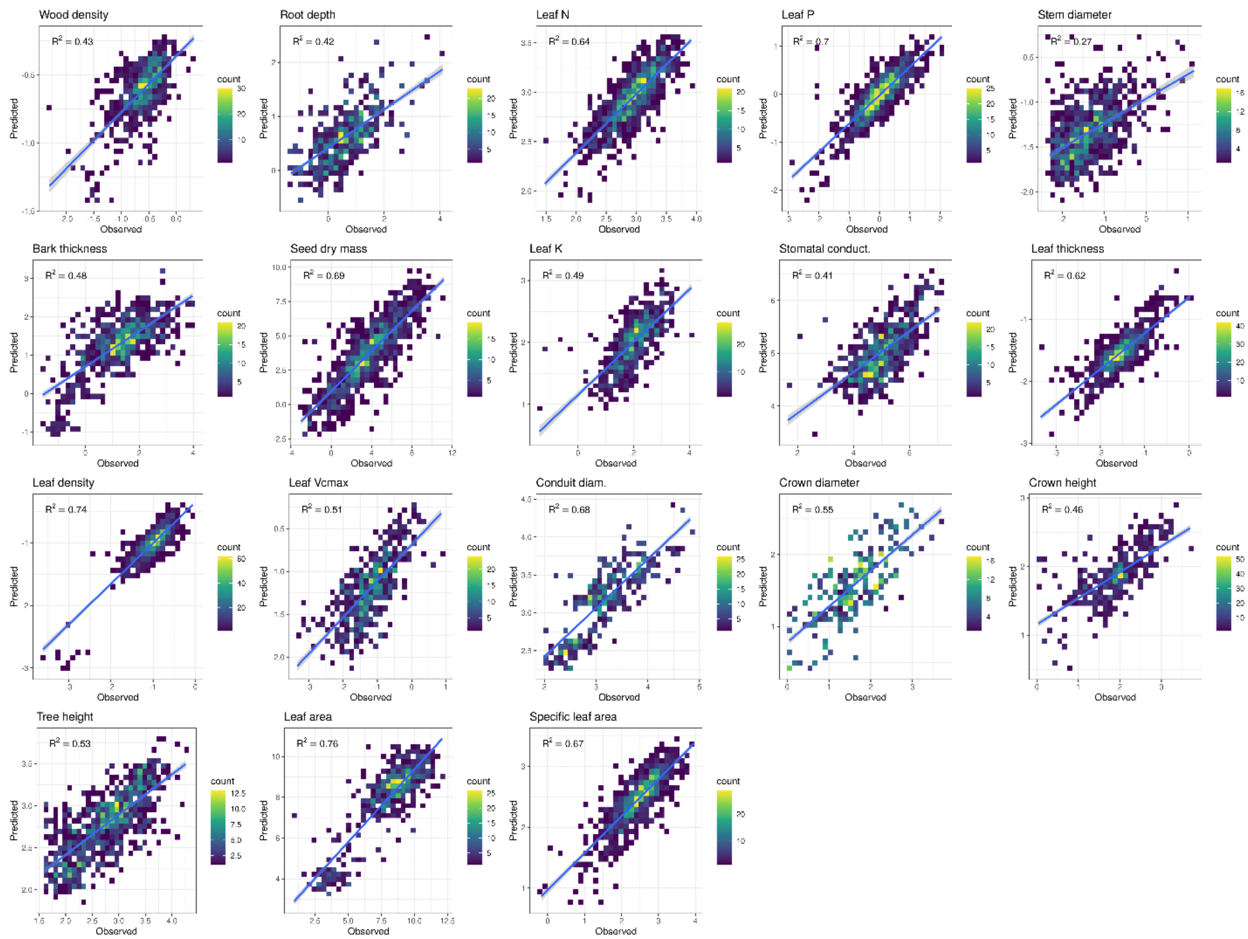

**Supplementary Figure 4.** Residual taxonomic autocorrelation (Moran's I) for all 18 traits, assessed using standard linear regression models.



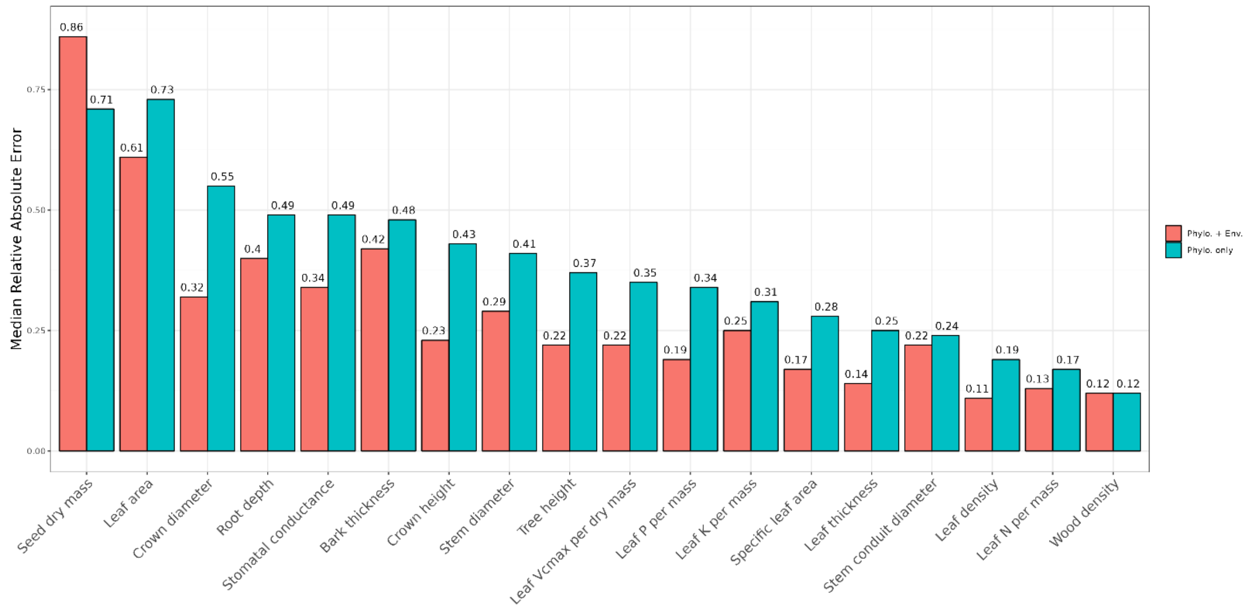

**Supplementary Figure 5**. The out-of-fit R2 as a function of the number of environmental and phylogenetic predictors in the random forest model. The final models used 10 environmental and phylogenetic predictors, which exhibited consistency high $R^2$ values while also prioritizing model parsimony to avoid overfitting.



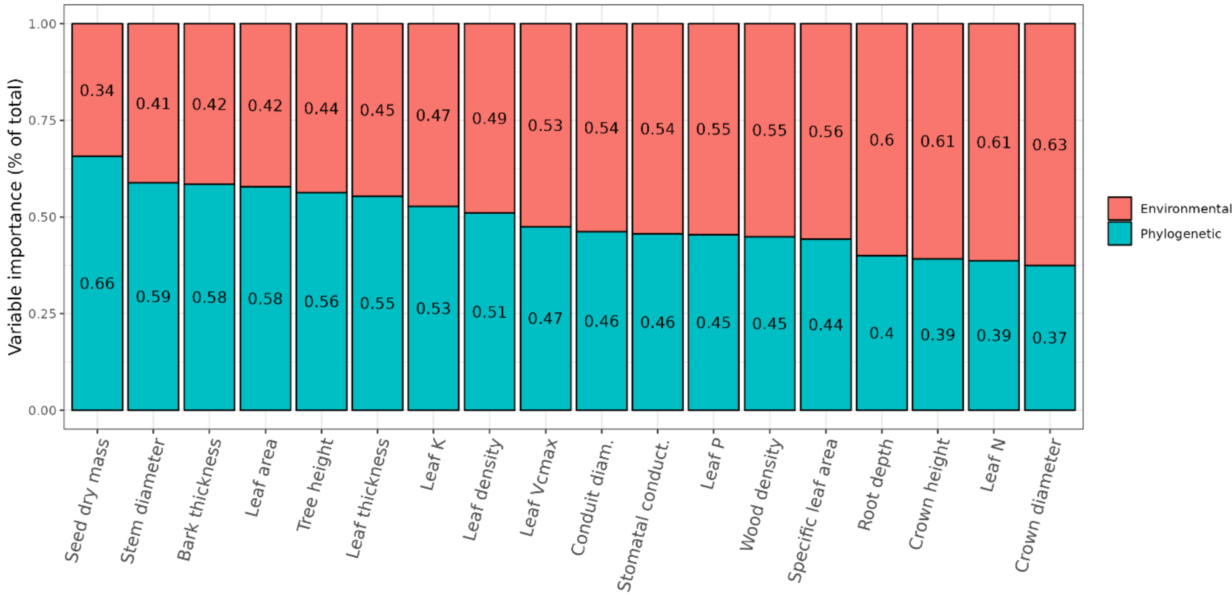

**Supplementary Figure 6.** The performance of the models ($R^2_{VEcv}$) with phylogenetic information only (green) vs. phylogenetic and environmental covariates included (red).



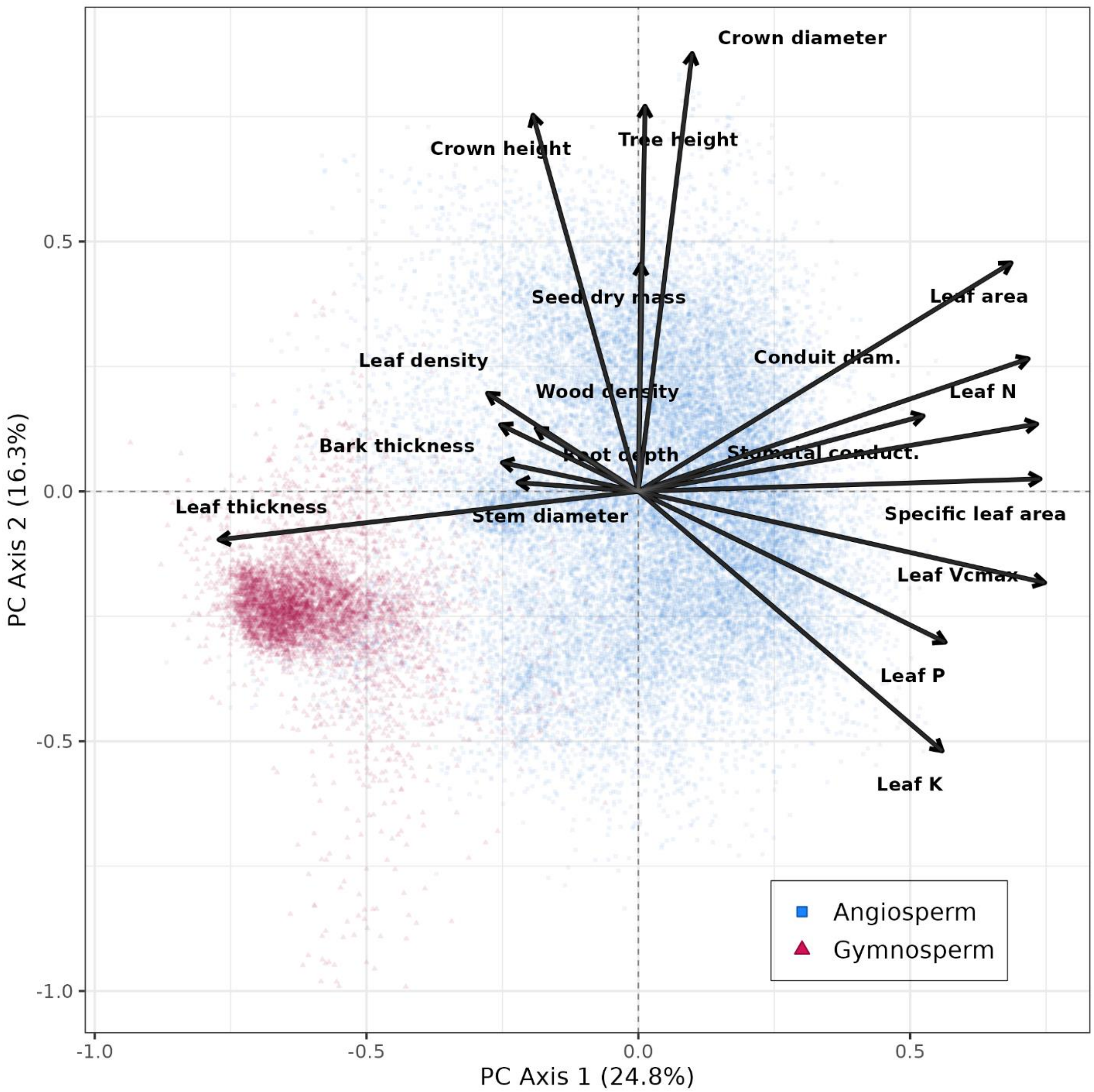

**Supplementary Figure 7**. The observed vs. predicted values for the out-of-fit data. The highest accuracy was with leaf area ($R^2 = 0.76$) with the lowest being stem diameter ($R^2 = 0.27$), with the latter reflecting the fact that stem diameter is closely related to tree age. Hence, for traits with strong ontogenetic variation (stem diameter, tree height, root depth, crown height, crown width) we used quantile random forest to predict the maximum values (see Methods). The points are shaded by density (yellow = many points in that pixel; blue = few). The line shows the standard linear regression fit, with the shaded region giving the 95% confidence interval for the mean.



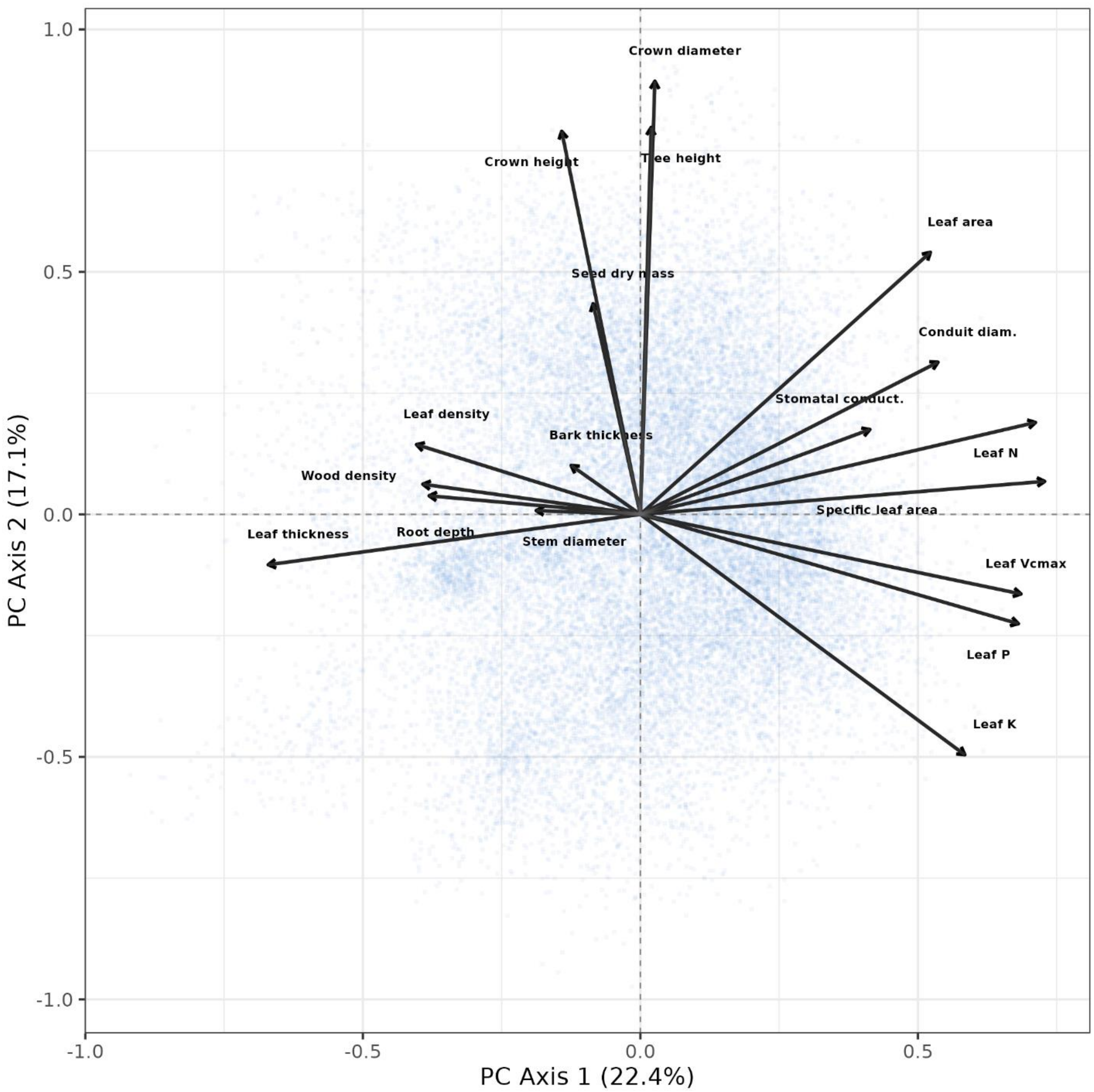

**Supplementary Figure 8.** Trait accuracy on the unlogged scale, assessed via median relative absolute error, with phylogenetic information only (green) vs. phylogenetic and environmental covariates included (red). Note that because most traits exhibit skewed log-normal distributions, where the sample variance for an observation is correlated with the mean, the relative error on the unlogged scale is largely an intrinsic artifact of the skewness of the data. Thus, regardless of the accuracy of the models (Supplementary Fig. 6), care should be taken when using these approaches to make inference about the unlogged trait expression of a specific tree in a specific location.



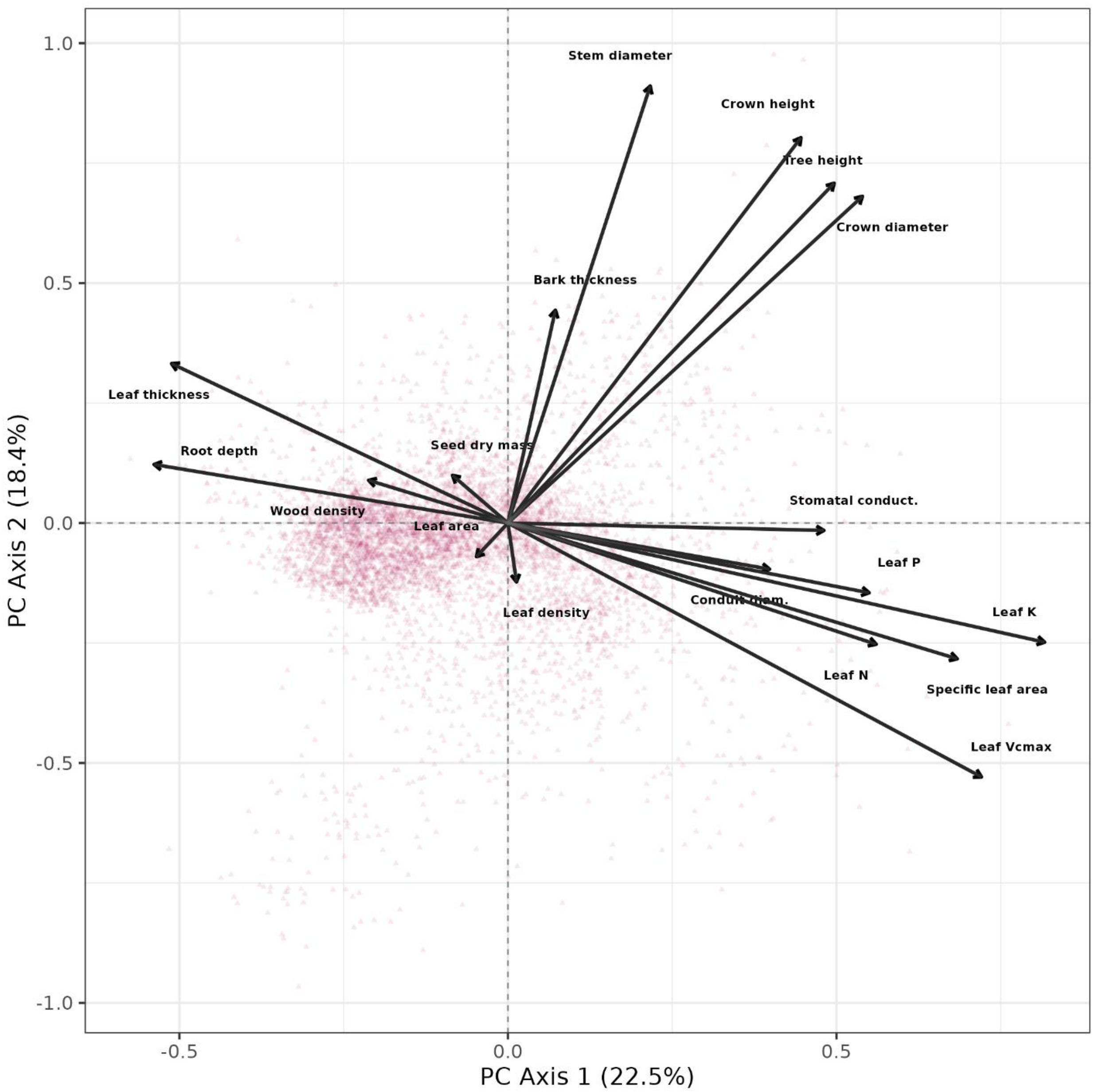

**Supplementary Figure 9.** The relative importance (scaled to 1) attributable to environmental variables vs. phylogenetic eigenvectors as predictors of trait expression.



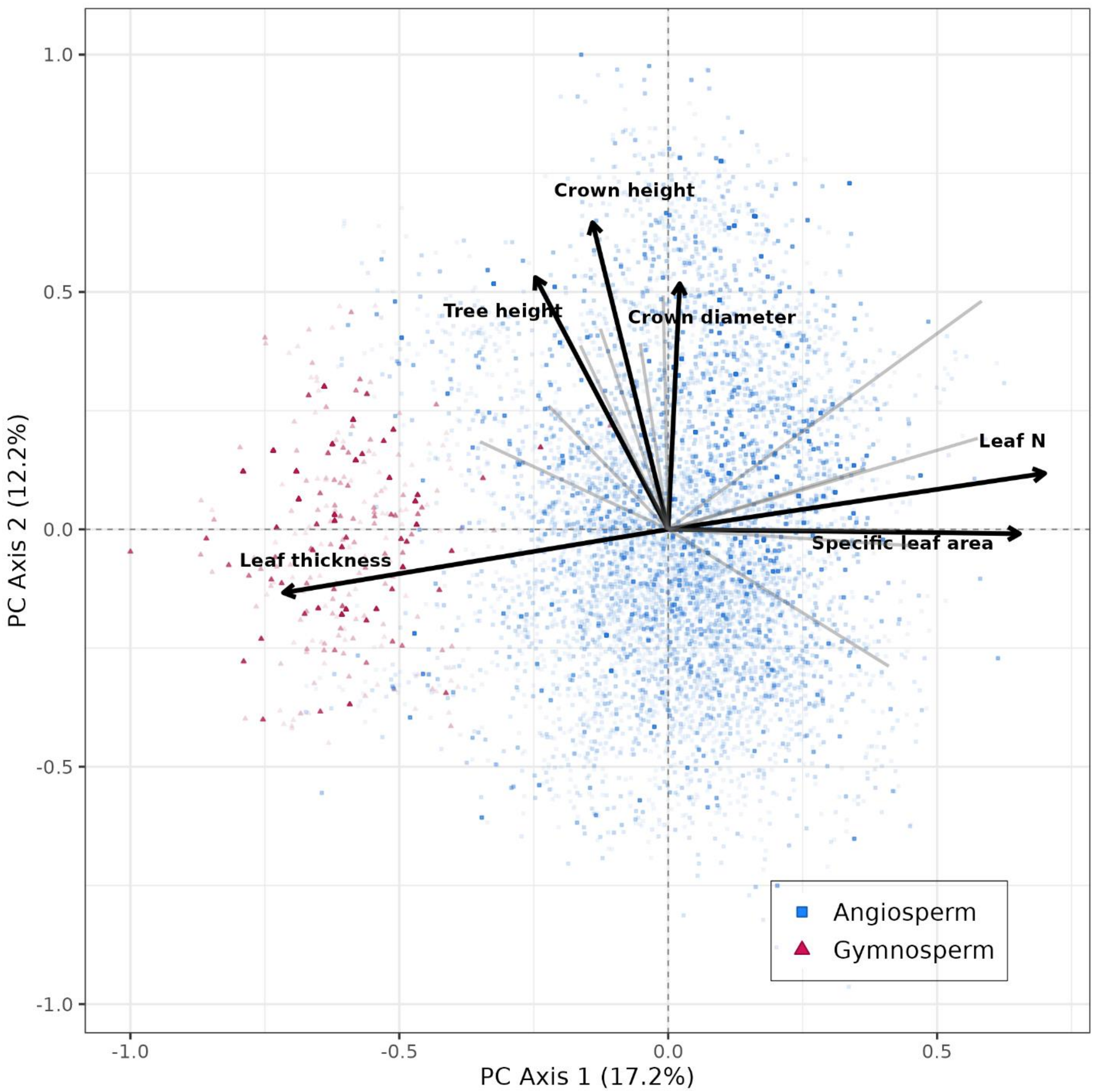

**Supplementary Figure 10.** The same PCA as in the main text (Fig. 2a), but with all trait axes labeled. See Supplementary Table 5 for the loadings.



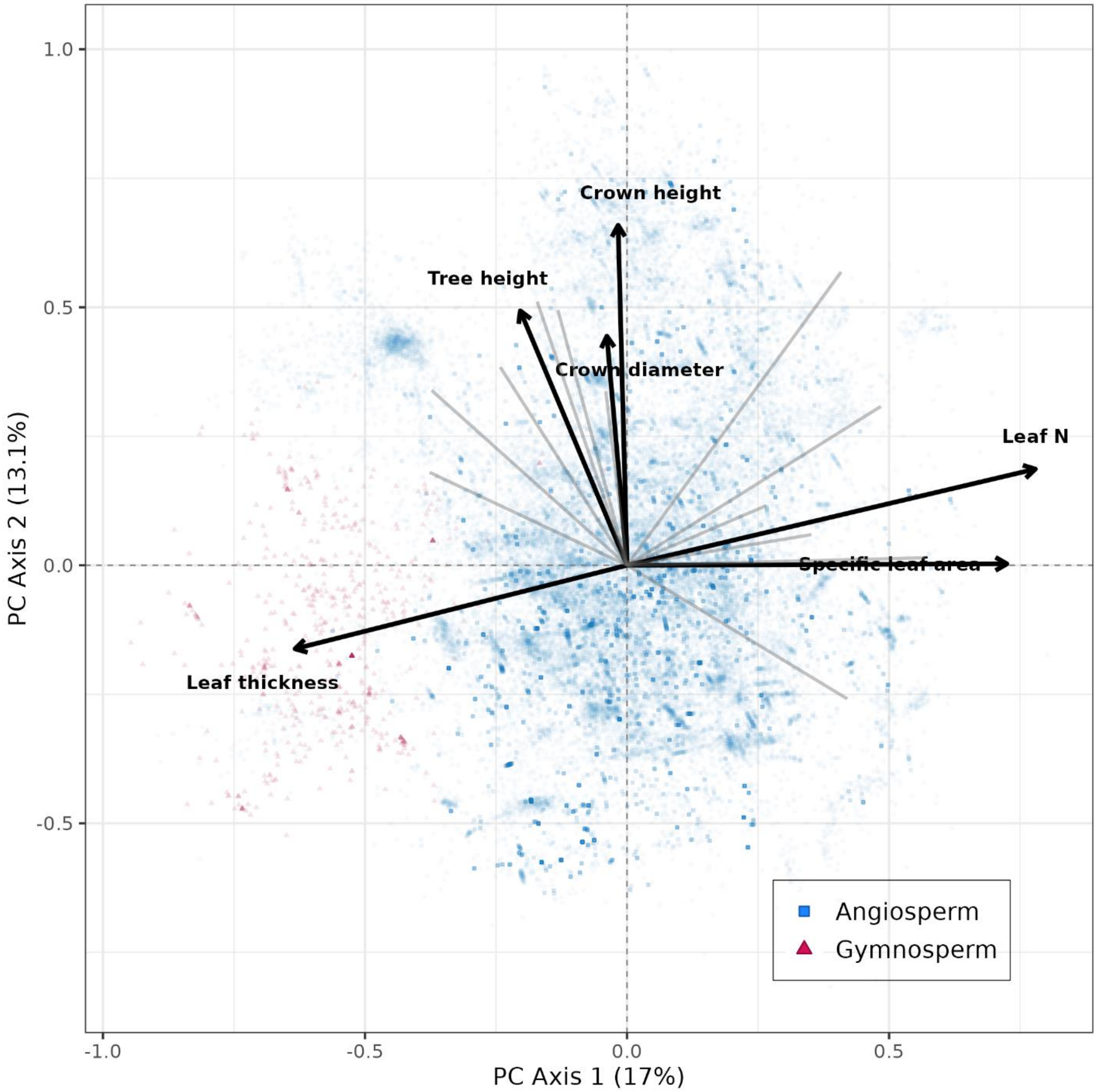

**Supplementary Figure 11.** The same PCA as in the main text (Fig. 2b), but with all trait axes labeled. See Supplementary Data 2 for the PC loadings table.



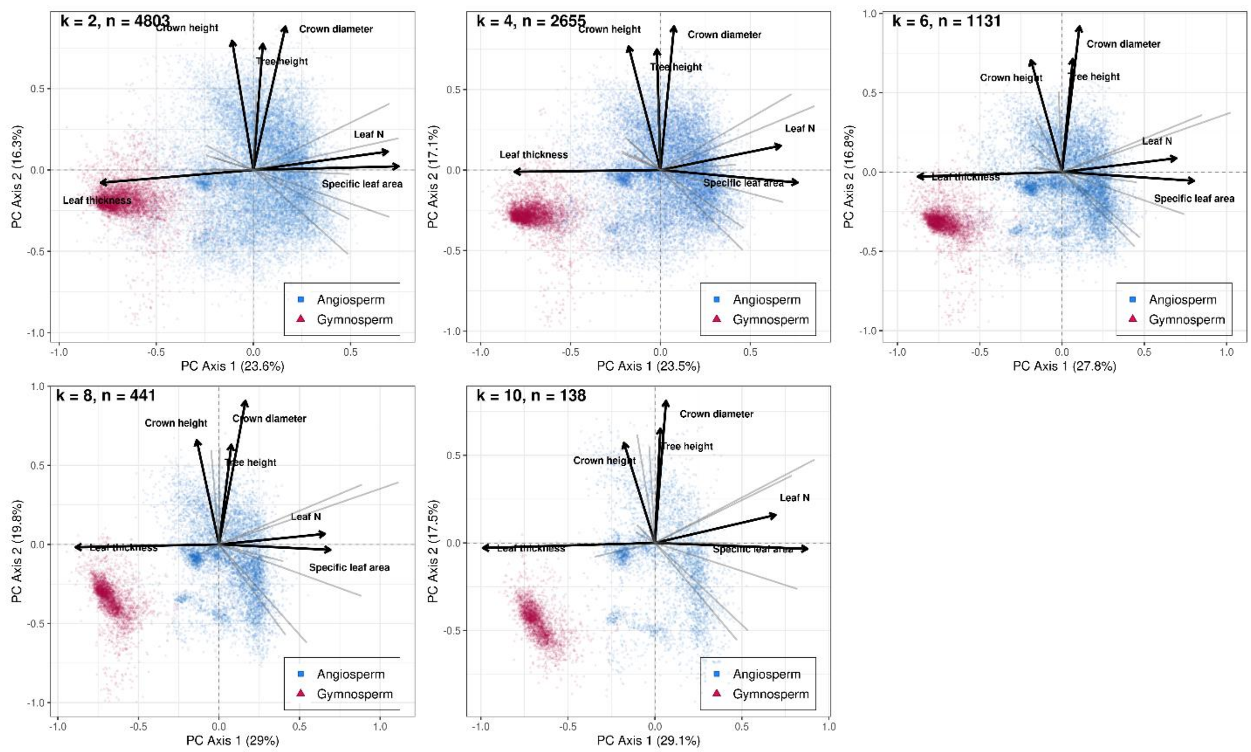

**Supplementary Figure 12**. The same PCA as in the main text (Fig. 2c), but with all trait axes labeled. See Supplementary Data 2 for the PC loadings table.



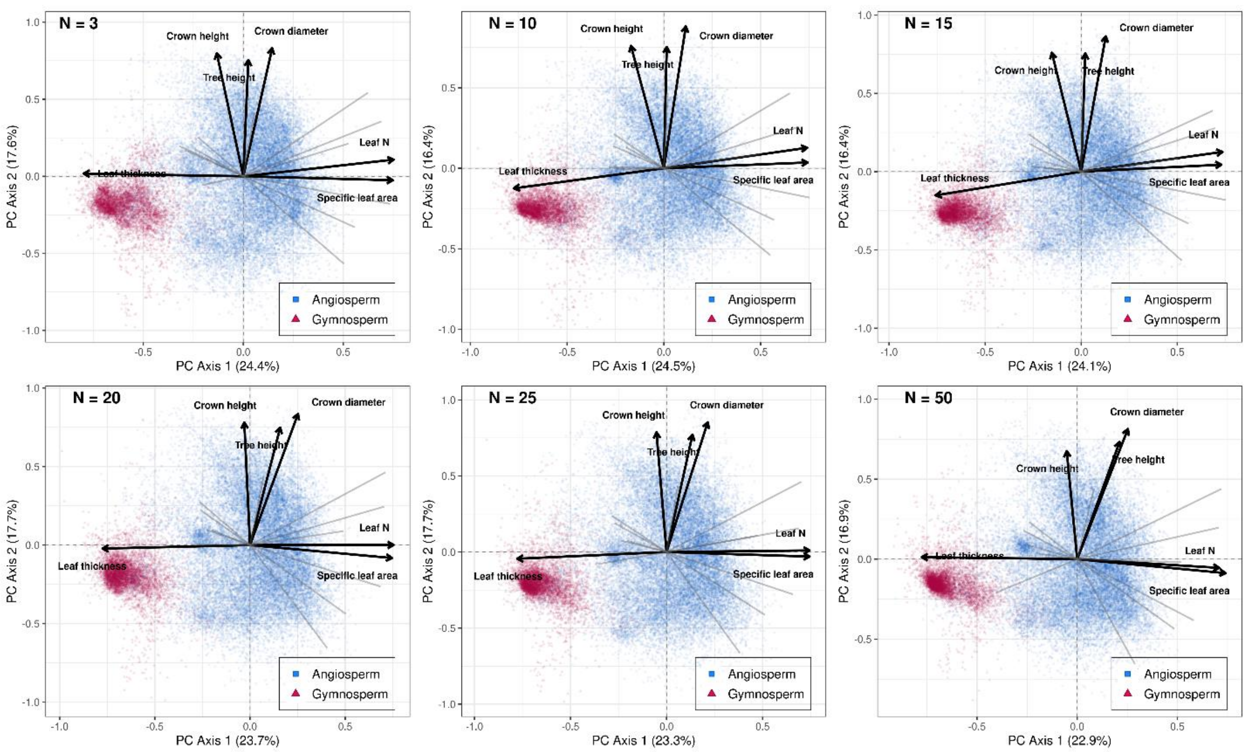

**Supplementary Figure 13**. The PCA using phylogeny-only models, showing the same trade-offs as with the environmental + phylogeny models, despite having substantially lower predictive accuracy of the trait models. See Supplementary Data 2 for the PC loadings table.



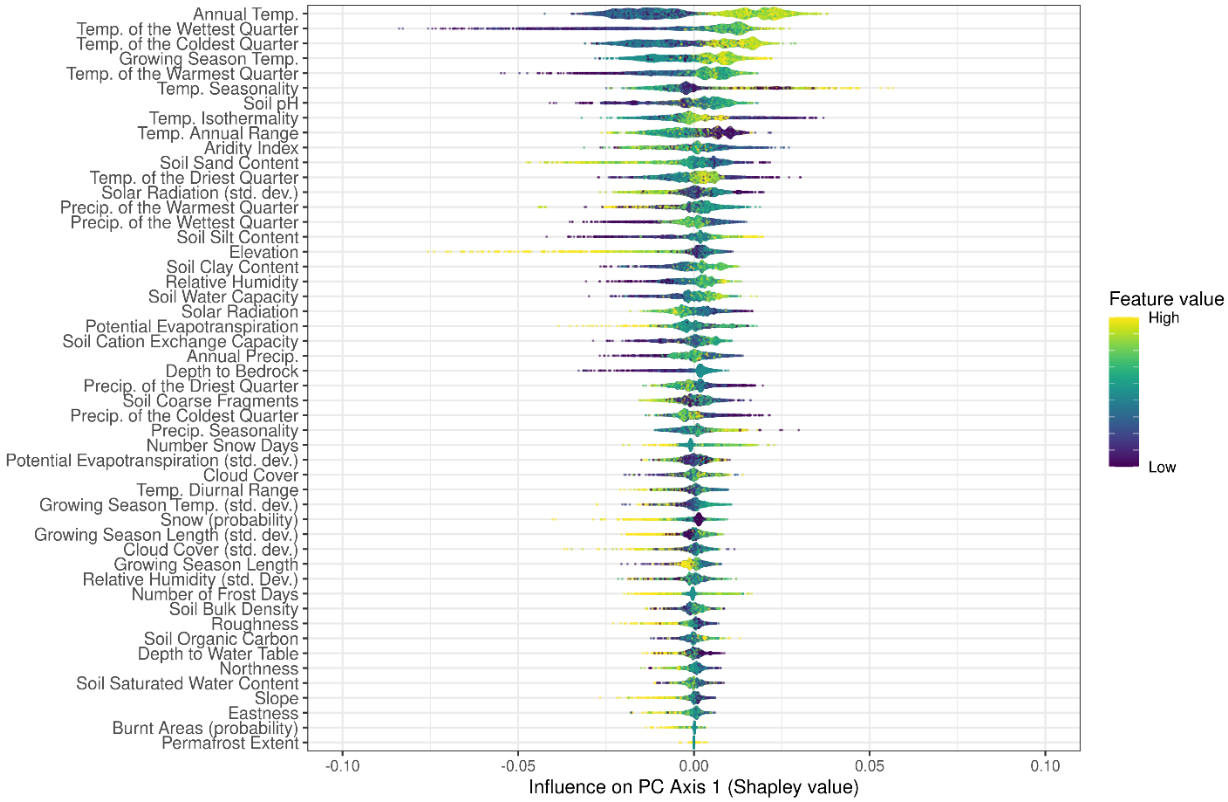

**Supplementary Figure 14**. The PCA for all 52,255 tree species matched in the reference phylogeny, using the phylogeny-only models, showing the same trade-offs as with the subset of species with georeferenced data. See Supplementary Data 2 for the PC loadings table.



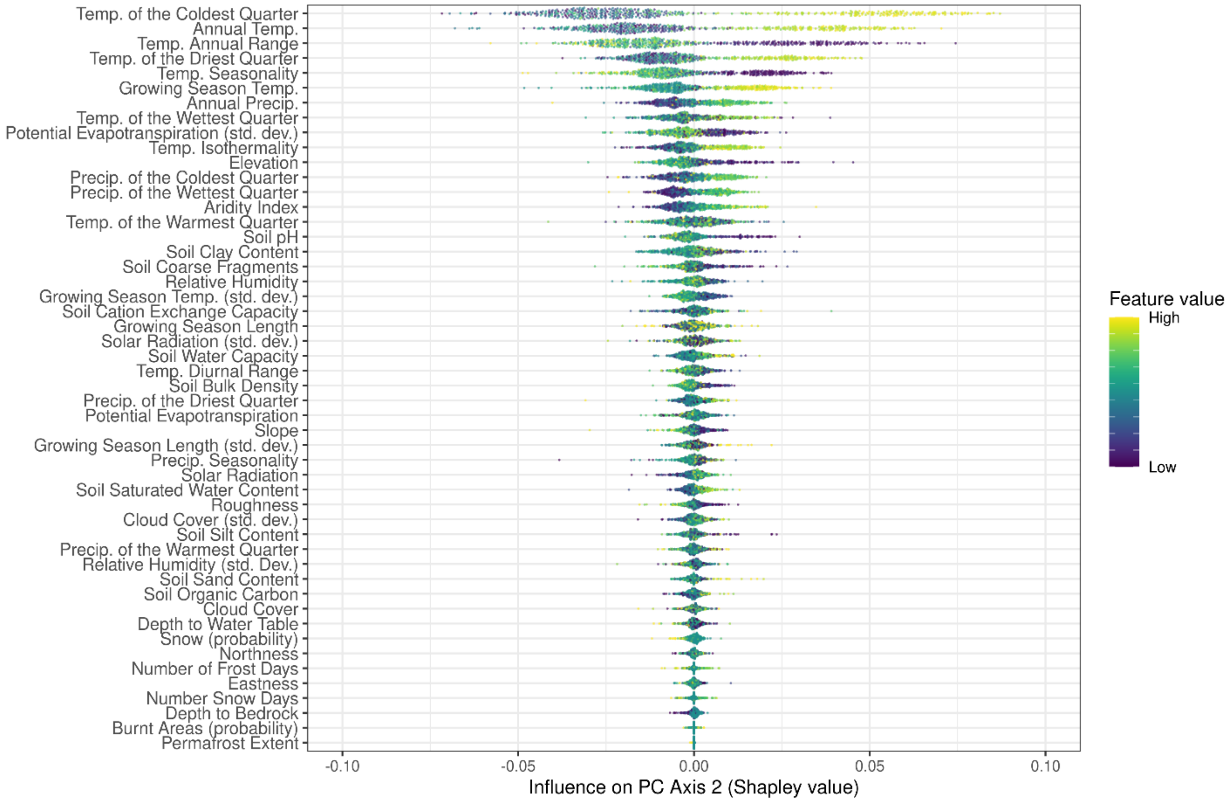

**Supplementary Figure 15**. The PCA results using decreasing levels of missingness in the dataset, ranging from all species with at least 2 traits measured (n = 4803), to only those with at least 10 unique traits measurements (n=138 species). The results are highly robust to the level of missingness in the data. See Supplementary Data 2 for the PC loadings table.




**Supplementary Figure 16**. The PCA results using increasing number of environmental covariates, ranging from 3 to 50 (each) phylogenetic and environmental covariates. N=10 is used throughout the main text (see Supplementary Fig. 5). The results are robust to the choice of variables. See Supplementary Data 2 for the PC loadings table.



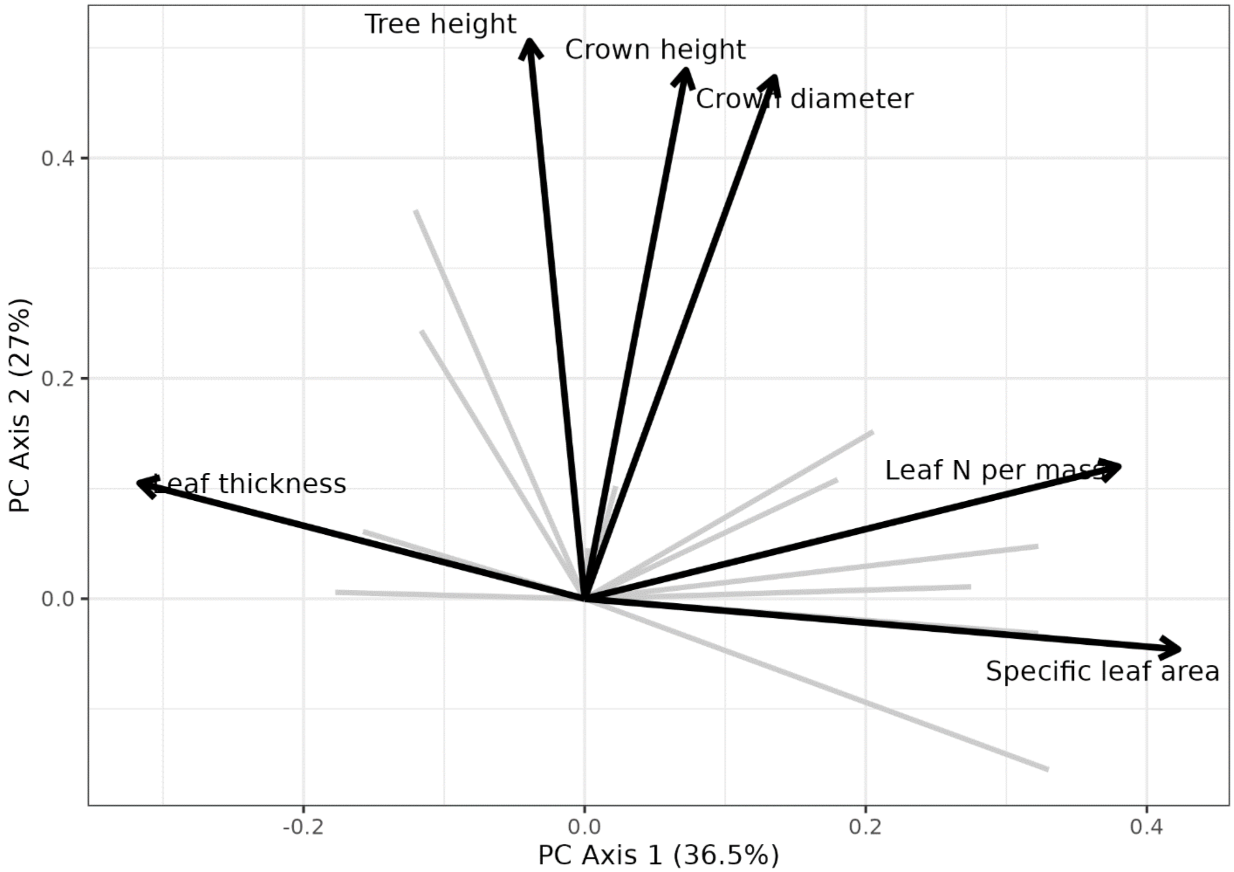

**Supplementary Figure 17**. The Shapley values for all 50 environmental variables' influence on PC 1, sorted by variable importance. Note that some of these variables are highly collinear, and thus reflect redundant patterns. See the main text for the 10 representative variables with low correlation.



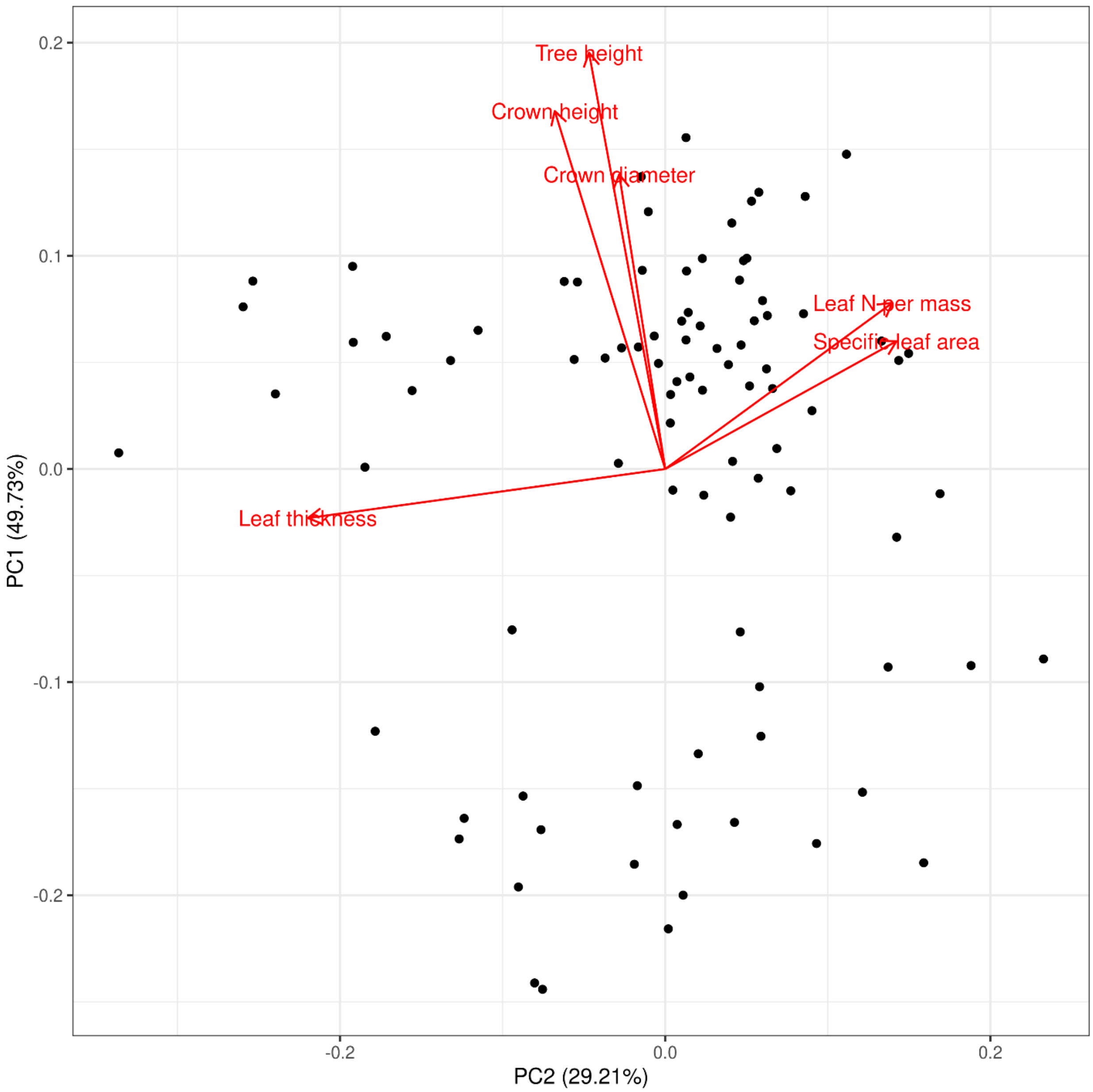

**Supplementary Figure 18**. The Shapley values for all 50 environmental variables' influence on PC 2, sorted by variable importance. Note that some of these variables are highly collinear, and thus reflect redundant patterns. See the main text for the 10 representative variables with low correlation.

| | Leaf density | Wood density | Root depth | Specific leaf area | Leaf thickness | Leaf N | Leaf K | Leaf P | Conduit diam. | Leaf Vcmax | Stomatal conduct. | Leaf area | Crown height | Crown diameter | Tree height | Seed dry mass | Bark thickness | Stem diameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Leaf density | | 0.43 | 0.2 | -0.48 | 0.23 | -0.28 | -0.31 | -0.31 | 0.06 | -0.1 | 0 | 0.02 | 0.03 | 0.05 | -0.01 | 0.22 | 0.26 | 0.08 |
| Wood density | 0.33 | | 0.27 | -0.22 | 0.08 | -0.16 | -0.26 | -0.31 | -0.01 | -0.07 | 0.04 | -0.03 | 0.02 | 0.08 | -0.07 | 0.15 | 0.05 | -0.01 |
| Root depth | 0.08 | 0.01 | | -0.2 | 0.11 | -0.07 | -0.23 | -0.26 | 0.02 | -0.08 | -0.14 | -0.06 | -0.06 | 0.06 | -0.01 | 0.17 | 0.04 | -0.01 |
| Specific leaf area | -0.42 | -0.14 | -0.18 | | -0.82 | 0.55 | 0.38 | 0.45 | 0.25 | 0.44 | 0.14 | 0.37 | -0.08 | 0.08 | 0.06 | 0.01 | -0.32 | -0.29 |
| Leaf thickness | 0.19 | 0.07 | 0.11 | -0.72 | | -0.51 | -0.31 | -0.42 | -0.26 | -0.41 | -0.1 | -0.36 | 0.04 | -0.1 | -0.06 | -0.1 | 0.35 | 0.29 |
| Leaf N | -0.24 | -0.09 | -0.1 | 0.39 | -0.31 | | 0.42 | 0.52 | 0.47 | 0.48 | 0.32 | 0.34 | 0.05 | 0.21 | 0.11 | 0.07 | -0.18 | -0.14 |
| Leaf K | -0.17 | -0.1 | -0.11 | 0.26 | -0.22 | 0.27 | | 0.71 | 0.26 | 0.56 | 0.25 | 0.04 | -0.43 | -0.41 | -0.36 | -0.22 | -0.07 | -0.01 |
| Leaf P | -0.22 | -0.14 | -0.16 | 0.32 | -0.3 | 0.34 | 0.58 | | 0.29 | 0.51 | 0.22 | 0.1 | -0.17 | -0.21 | -0.14 | -0.1 | -0.02 | 0.01 |
| Conduit diam. | 0.15 | 0.08 | 0.03 | 0.02 | 0.01 | 0.09 | 0.06 | 0.04 | | 0.64 | 0.59 | 0.62 | -0.06 | 0.21 | 0.1 | 0.12 | 0.24 | 0.11 |
| Leaf Vcmax | 0.01 | 0.07 | 0 | 0.3 | -0.27 | 0.22 | 0.33 | 0.26 | 0.44 | | 0.51 | 0.45 | -0.31 | -0.15 | -0.21 | -0.15 | 0.15 | 0.12 |
| Stomatal conduct. | 0.1 | 0.14 | -0.15 | -0.02 | 0.04 | 0.07 | 0.06 | 0.08 | 0.39 | 0.31 | | 0.45 | -0.05 | 0.14 | 0.1 | -0.05 | 0.18 | 0.09 |
| Leaf area | 0.09 | 0.11 | -0.06 | 0.15 | -0.12 | 0.05 | -0.16 | -0.1 | 0.54 | 0.31 | 0.31 | | 0.08 | 0.37 | 0.26 | 0.13 | 0.11 | -0.05 |
| Crown height | -0.06 | -0.06 | -0.21 | -0.07 | 0.06 | 0.08 | -0.3 | -0.14 | -0.14 | -0.33 | 0.05 | 0.06 | | 0.78 | 0.64 | 0.23 | 0.03 | 0.14 |
| Crown diameter | -0.05 | -0.03 | -0.19 | 0.04 | -0.03 | 0.11 | -0.33 | -0.18 | 0.06 | -0.2 | 0.14 | 0.29 | 0.74 | | 0.7 | 0.3 | -0.06 | -0.03 |
| Tree height | -0.06 | -0.09 | -0.11 | 0.02 | -0.01 | 0.04 | -0.29 | -0.12 | 0.01 | -0.24 | 0.14 | 0.16 | 0.52 | 0.58 | | 0.28 | 0.03 | 0.14 |
| Seed dry mass | 0.02 | -0.01 | 0.03 | -0.02 | 0.01 | -0.03 | -0.03 | -0.02 | 0 | -0.06 | 0.01 | 0.02 | 0.04 | 0.04 | 0.03 | | -0.05 | -0.11 |
| Bark thickness | 0.27 | 0.17 | 0.03 | -0.22 | 0.21 | -0.08 | -0.03 | -0.04 | 0.52 | 0.25 | 0.31 | 0.29 | -0.05 | -0.01 | 0.06 | -0.01 | | 0.51 |
| Stem diameter | 0 | -0.03 | -0.04 | -0.2 | 0.22 | -0.1 | -0.06 | -0.01 | 0.15 | 0.02 | 0.12 | 0.04 | 0.2 | 0.09 | 0.25 | -0.02 | 0.37 | |

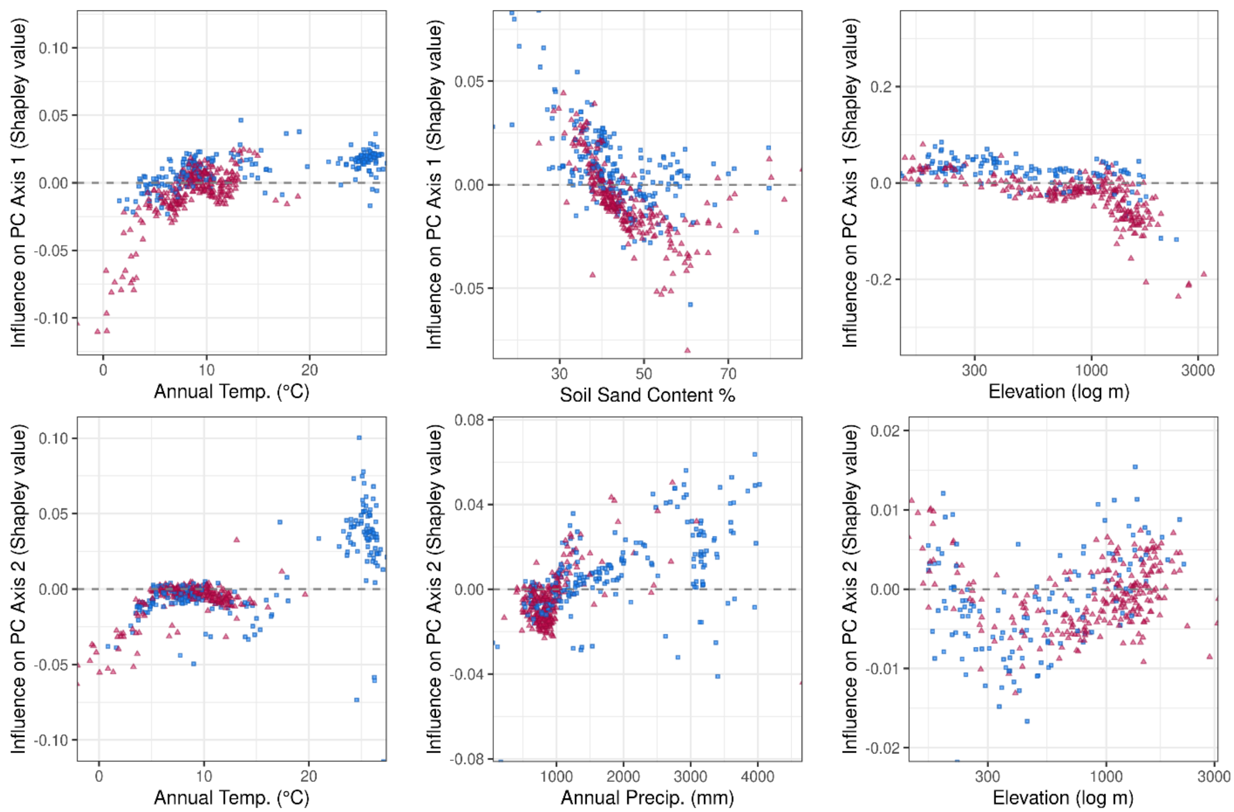
**Supplementary Figure 19**. The full set of correlations between the imputed trait values. The upper triangle gives the Spearman correlation between imputed values; the lower triangle gives the correlation between phylogenetic independent contrasts, thereby controlling for highly related species with similar phylogenetic histories.



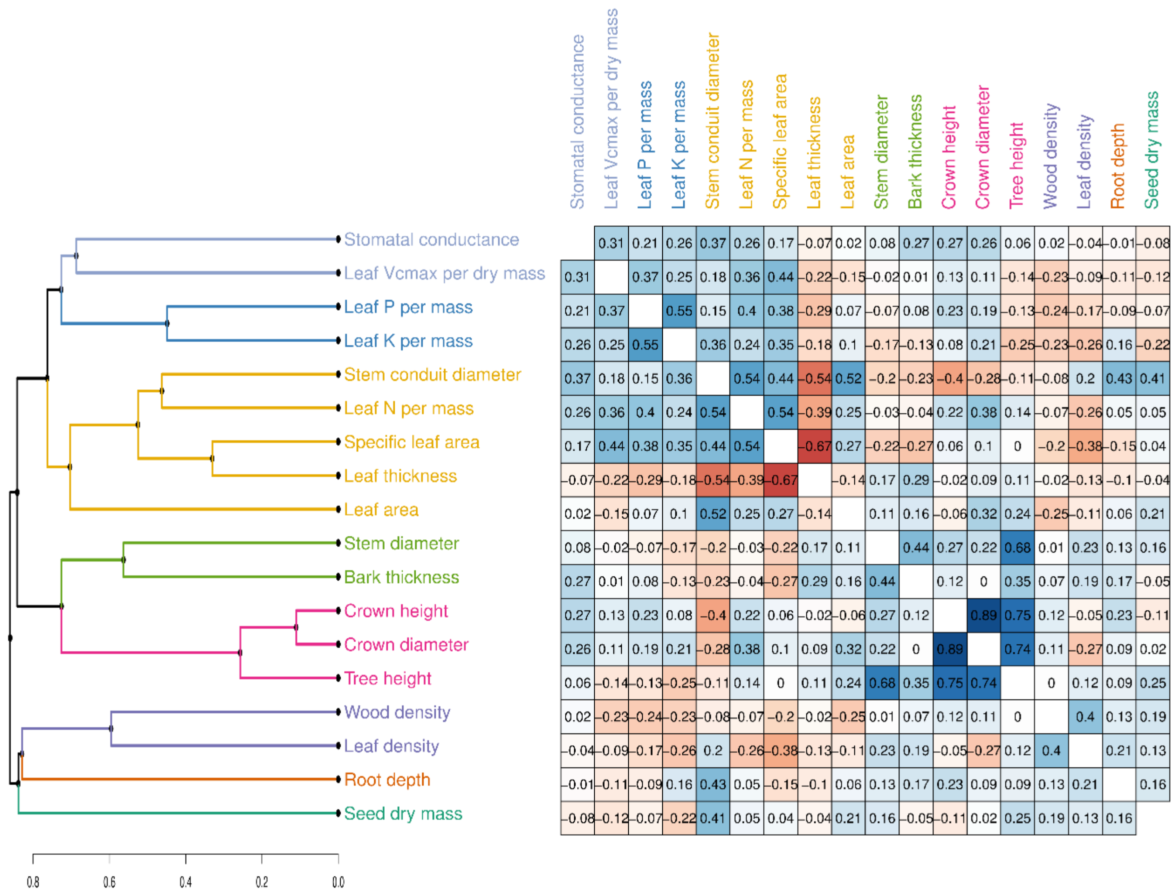

**Supplementary Figure 20**. The PCA using raw data only. Since PCA is implemented via calculating the eigenvectors of the correlation matrix, we can recreate this PCA using only the raw data. Here, we calculated the correlations using only the pairwise complete raw observations for each pair of traits. We then took the eigen-decomposition of this correlation matrix, with the first two eigenvectors show here, along with % variation. Using raw data only, we see the identical 6 traits load most heavily on the two axes.



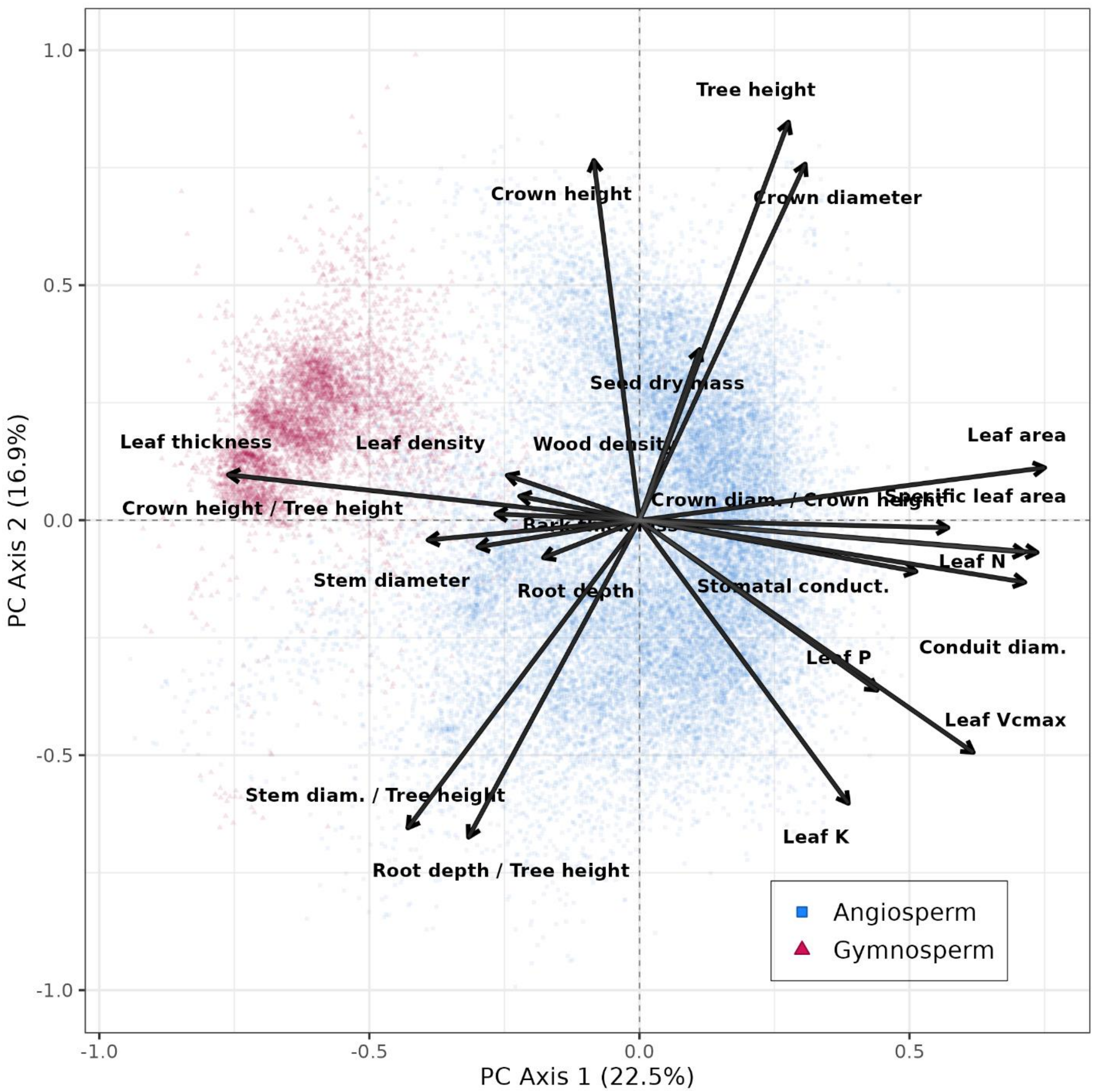

**Supplementary Figure 21**. The PCA results when restricted to the 91 species which have complete trait values for the six dominant traits underpinning the PC axes in the full dataset. Using this small subset of data, we see the same orthogonality of the trait axes. Moreover, we recover the same environmental patterns using these PC results (Supplementary Fig. 22).



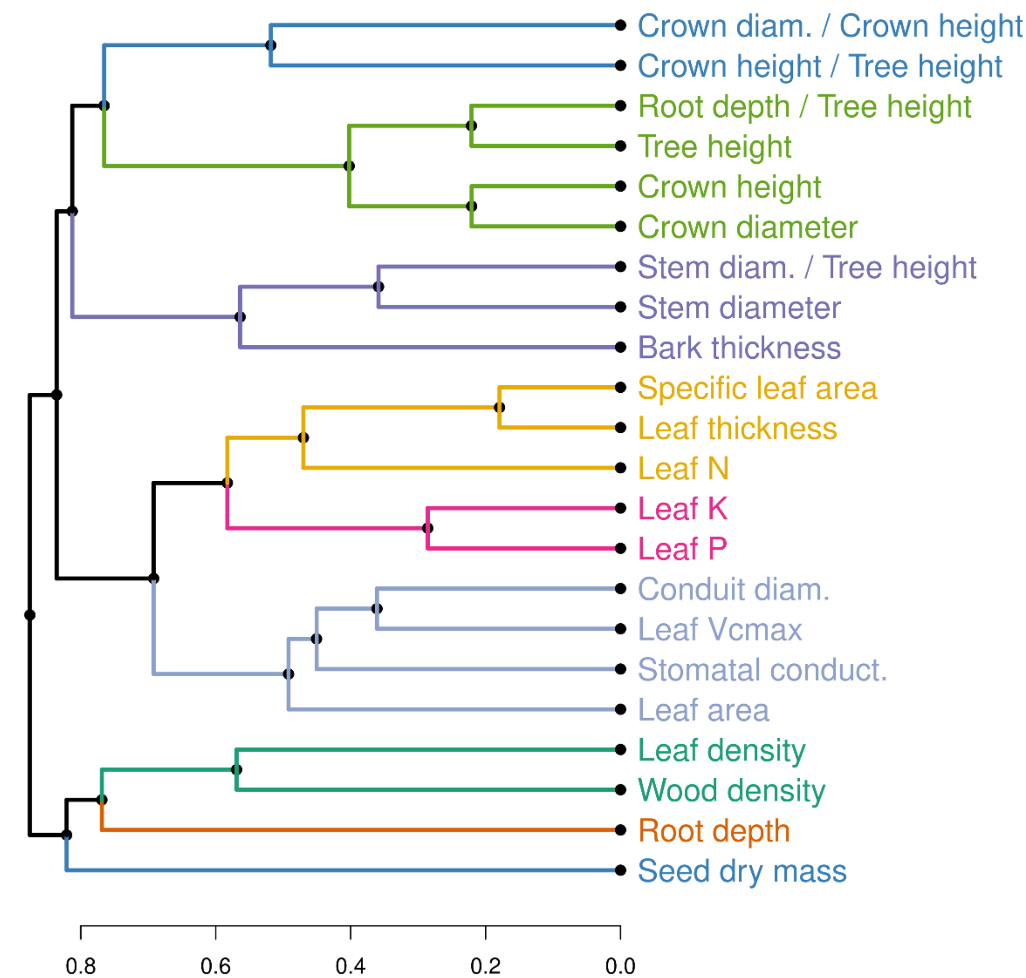

**Supplementary Figure 22.** The relationships between the first two PC axes and the dominant environmental drivers shown in the main text, obtained using raw data only, using the 91 species and 3319 observations where we had complete data for the dominant 6 traits underpinning the PC axes (see Supplementary Fig. 21).




**Supplementary Figure 23**. The functional dendrogram obtained using pairwise-complete raw observations. The results show nearly the identical trends and relationships to the full set of imputed data, despite being species-level averages.




**Supplementary Figure 24**. The trait PC when adding four allometric relationship estimated using the imputed data (crown height / tree height; stem diameter / tree height; root depth / tree height, crown diameter / crown height). The dominant axes and representative traits are unchanged, highlighting that these allometric ratios contribute no new information to the dominant axes underpinning trait relationships. Note that these allometric ratios are estimated and their accuracy cannot be assessed directly, and so caution should be exercised when interpreting them.




**Supplementary Figure 25**. The functional dendrogram when four allometric ratios (Supplementary Fig. 24) are added to the dataset. The ratios "root depth / tree height" and "stem diam. / tree height" ratio join within existing groups, whereas "crown diam. / crown height" and "crown height. / tree height" form their own unique cluster reflecting crown architecture. Note that these allometric ratios are estimated and their accuracy cannot be assessed directly, and so caution should be exercised when interpreting them.

**Supplementary Table 1.** The number of observations per trait by continental region, with the percentage in parentheses denoting the proportion of these observations taken on angiosperm species. For reference, angiosperms account for ~99% of all extant tree species[20,21].

| Trait | Global | South America | Eurasia | Africa | Oceania | North America | No spatial coords. |
|---|---|---|---|---|---|---|---|
| **All** | 491001 (85%) | 200578 (99.8%) | 94585 (57.8%) | 16736 (99.6%) | 15036 (92.8%) | 61755 (62.4%) | 102311 (91.2%) |
| **Bark thickness** | 6786 (73.4%) | 3945 (99.5%) | 390 (97.7%) | 86 (100%) | 303 (93.1%) | 1484 (14.7%) | 578 (15.1%) |
| **Crown diameter** | 4293 (68.3%) | 939 (100%) | 1373 (70.6%) | 862 (100%) | 64 (100%) | 1043 (8.1%) | 12 (100%) |
| **Crown height** | 5218 (57.6%) | 1035 (99.8%) | 2430 (63.3%) | 112 (100%) | 101 (100%) | 1486 (11.9%) | 54 (83.3%) |
| **Leaf area** | 14002 (96.9%) | 5476 (100%) | 2668 (96.1%) | 444 (100%) | 770 (100%) | 4329 (93.1%) | 315 (88.9%) |
| **Leaf density** | 21810 (97.6%) | 17041 (100%) | 862 (83.9%) | 648 (100%) | 479 (96.5%) | 2055 (81.8%) | 725 (100%) |
| **Leaf K per mass** | 7204 (75.2%) | 2543 (100%) | 1253 (89.1%) | 430 (100%) | 2 (50%) | 1597 (12.5%) | 1379 (81.7%) |
| **Leaf N per mass** | 60617 (81.2%) | 21752 (99.6%) | 17410 (67.8%) | 2815 (99.4%) | 2287 (88.2%) | 9719 (67.1%) | 6634 (66.1%) |
| **Leaf P per mass** | 26411 (73.3%) | 7552 (99.9%) | 10152 (62.5%) | 821 (100%) | 1023 (93.7%) | 2535 (31.7%) | 4328 (66.6%) |
| **Leaf thickness** | 55497 (98.3%) | 42351 (100%) | 1326 (85.7%) | 6412 (100%) | 486 (99%) | 3575 (79.9%) | 1347 (98.1%) |
| **Leaf Vcmax per dry mass** | 2028 (91%) | 561 (98.9%) | 322 (66.5%) | 674 (100%) | 193 (77.2%) | 154 (84.4%) | 124 (99.2%) |
| **Root depth** | 2346 (68.6%) | 151 (100%) | 396 (51%) | 466 (97%) | 82 (63.4%) | 604 (46.9%) | 647 (72.6%) |
| **Seed dry mass** | 42650 (96.2%) | 291 (100%) | 100 (88%) | 28 (100%) | 38 (97.4%) | 96 (85.4%) | 42097 (96.2%) |
| **Specific leaf area** | 70968 (90.6%) | 26810 (99.7%) | 16459 (82%) | 2109 (99%) | 3286 (92.6%) | 17220 (82.5%) | 5084 (93.7%) |
| **Stem conduit diameter** | 508 (68.5%) | 179 (99.4%) | 113 (46%) | 20 (95%) | 24 (62.5%) | 168 (48.2%) | 4 (75%) |
| **Stem diameter** | 53168 (85.6%) | 36422 (99.9%) | 7550 (72.3%) | 220 (90.9%) | 829 (86%) | 7995 (33.6%) | 152 (57.2%) |
| **Stomatal conductance** | 29084 (39.6%) | 1491 (98.3%) | 18778 (14.8%) | 30 (100%) | 3772 (96.9%) | 4401 (67.2%) | 612 (99.7%) |
| **Tree height** | 41865 (84.9%) | 25718 (99.7%) | 6276 (45.7%) | 251 (100%) | 1259 (89.8%) | 2584 (45.8%) | 5777 (77.2%) |
| **Wood density** | 46546 (88.7%) | 6321 (99.4%) | 6727 (43.7%) | 308 (100%) | 38 (63.2%) | 710 (48.3%) | 32442 (96.8%) |

**Supplementary Table 2.** The number of species per trait by continental region, with the percentage in parentheses denoting the proportion of these species that are angiosperms. For reference, angiosperms account for ~99% of all extant tree species[20,21].

| Trait | Global | South America | Eurasia | Africa | Oceania | North America | No spatial coords. |
|---|---|---|---|---|---|---|---|
| **All** | 13189 (96.9%) | 3559 (99.1%) | 2063 (93.5%) | 597 (98.5%) | 585 (92.8%) | 542 (83.8%) | 10644 (96.3%) |
| **Bark thickness** | 1134 (80.8%) | 725 (97.8%) | 70 (90%) | 9 (100%) | 131 (84.7%) | 34 (47.1%) | 196 (6.6%) |
| **Crown diameter** | 182 (87.9%) | 58 (100%) | 85 (92.9%) | 19 (100%) | 2 (100%) | 19 (10.5%) | 2 (100%) |
| **Crown height** | 289 (88.9%) | 111 (98.2%) | 148 (92.6%) | 1 (100%) | 8 (100%) | 22 (13.6%) | 3 (66.7%) |
| **Leaf area** | 733 (94.4%) | 327 (100%) | 165 (91.5%) | 56 (100%) | 4 (100%) | 49 (93.9%) | 289 (87.9%) |
| **Leaf density** | 1566 (97.6%) | 918 (100%) | 186 (90.9%) | 93 (100%) | 119 (95%) | 169 (90.5%) | 145 (100%) |
| **Leaf K per mass** | 1587 (96.2%) | 658 (100%) | 385 (95.6%) | 127 (100%) | 2 (50%) | 132 (93.2%) | 391 (88.7%) |
| **Leaf N per mass** | 4777 (96.9%) | 2309 (99.4%) | 1356 (94.8%) | 425 (99.1%) | 261 (96.2%) | 356 (85.7%) | 1037 (91.2%) |
| **Leaf P per mass** | 3165 (96%) | 1253 (99.8%) | 989 (93.7%) | 233 (100%) | 195 (95.9%) | 203 (83.7%) | 1020 (92.1%) |
| **Leaf thickness** | 1942 (97.6%) | 1133 (99.8%) | 282 (92.6%) | 127 (100%) | 124 (96%) | 215 (90.7%) | 310 (97.7%) |
| **Leaf Vcmax per dry mass** | 550 (94.9%) | 323 (98.5%) | 50 (82%) | 42 (100%) | 99 (96%) | 36 (72.2%) | 21 (95.2%) |
| **Root depth** | 794 (83.5%) | 60 (100%) | 132 (48.5%) | 103 (94.2%) | 19 (89.5%) | 95 (74.7%) | 554 (79.1%) |
| **Seed dry mass** | 5468 (95.1%) | 285 (100%) | 50 (84%) | 28 (100%) | 35 (97.1%) | 41 (70.7%) | 5327 (94.9%) |
| **Specific leaf area** | 4896 (97.2%) | 2497 (99.4%) | 1362 (96%) | 275 (98.9%) | 414 (96.1%) | 441 (85.3%) | 551 (88.6%) |
| **Stem conduit diameter** | 259 (72.6%) | 70 (98.6%) | 60 (60%) | 18 (94.4%) | 21 (71.4%) | 94 (54.3%) | 4 (75%) |
| **Stem diameter** | 2063 (96.4%) | 1509 (99.7%) | 433 (92.4%) | 41 (97.6%) | 25 (96%) | 89 (60.7%) | 55 (65.5%) |
| **Stomatal conductance** | 915 (94.4%) | 508 (98.4%) | 129 (89.9%) | 7 (100%) | 144 (96.5%) | 136 (80.1%) | 25 (96%) |
| **Tree height** | 3313 (92.6%) | 1154 (99.7%) | 378 (89.7%) | 75 (100%) | 154 (91.6%) | 127 (71.7%) | 1865 (87.6%) |
| **Wood density** | 7491 (96.6%) | 1256 (99.5%) | 211 (86.3%) | 62 (100%) | 34 (67.6%) | 121 (57.9%) | 6858 (96.7%) |

**Supplementary Table 3.** The 30 functional traits and corresponding TRY trait IDs and sub-trait IDs. Of these 30 putative traits, the 18 traits used in final the analysis (indicated with *) were selected based on uniqueness, consistency of assay conditions, taxonomic coverage, geographic coverage, and overall sample size. Note that several traits (e.g., Trait 4, wood density) have multiple corresponding sub-trait IDS. Data are included from more than 130 publications (Supplementary Data 1).

| TRY Trait ID | Sub-trait Data IDs | Trait Name |
|---:|---:|---|
| 4* | 4<br>1629<br>1739<br>2568 | Stem specific density (SSD) or wood density |
| 6* | 7 | Root rooting depth |
| 9 | 10 | Root/shoot ratio |
| 14* | 15 | Leaf nitrogen (N) content per leaf dry mass |
| 15* | 16 | Leaf phosphorus (P) content per leaf dry mass |
| 21* | 24 | Stem diameter |
| 24* | 28 | Bark thickness |
| 26* | 30 | Seed dry mass |
| 41 | 46 | Leaf respiration rate in the dark per leaf dry mass |
| 44* | 49 | Leaf potassium (K) content per leaf dry mass |
| 45* | 50 | Stomatal conductance per leaf area |
| 46* | 53 | Leaf thickness |
| 48* | 55 | Leaf density (leaf tissue density, leaf dry mass per leaf volume) |
| 56 | 100 | Leaf nitrogen/phosphorus (N/P) ratio |
| 80 | 272 | Root nitrogen (N) content per root dry mass |
| 144 | 446 | Leaf length |
| 145 | 447 | Leaf width |
| 146 | 455 | Leaf carbon/nitrogen (C/N) ratio |
| 185* | 549<br>2382 | Leaf photosynthesis carboxylation capacity (Vcmax) per leaf dry mass |
| 270 | 664 | Leaf photosynthesis electron transport capacity (Jmax) per leaf dry mass |
| 281* | 713 | Stem conduit diameter (vessels, tracheids) |
| 324* | 818 | Crown (canopy) length: diameter along the longest axis |
| 413 | 996 | Leaf chlorophyll content per leaf area |
| 773* | 1695 | Crown (canopy) height (base to top) |
| 1055 | 1950 | Root carbon/nitrogen (C/N) ratio |
| 1229 | 2657 | Wood nitrogen (N) content per wood dry mass |
| 3106* | 19<br>448<br>504 | Plant height vegetative |
| 3110* | 6577 | Leaf area (in case of compound leaves: leaf, petiole included) |
| 3117* | 6584<br>6598 | Leaf area per leaf dry mass (specific leaf area, SLA or 1/LMA) |
| 3120 | 2261 | Leaf water content per leaf dry mass (not saturated) |

**Supplementary Table 4**. The full set of 50 environmental covariates used as predictors in the random forest models.

| Variable | Source | Type | Units | Resolution |
|---|---|---|---|---|
| Annual Temp. | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. of the Coldest Quarter | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. of the Driest Quarter | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. of the Warmest Quarter | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. of the Wettest Quarter | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. Annual Range | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. Seasonality | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Temp. Isothermality | 1 | Climatic | Unitless | 30 arcsec (≈900m at equator) |
| Temp. Diurnal Range | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Aridity Index | 2 | Climatic | AI Value | ≈1km |
| Potential Evapotranspiration | 2 | Climatic | PET Value (mm) | ≈1km |
| Annual Precip. | 1 | Climatic | mm | 30 arcsec (≈900m at equator) |
| Precip. of the Coldest Quarter | 1 | Climatic | mm | 30 arcsec (≈900m at equator) |
| Precip. of the Driest Quarter | 1 | Climatic | mm | 30 arcsec (≈900m at equator) |
| Precip. of the Warmest Quarter | 1 | Climatic | mm | 30 arcsec (≈900m at equator) |
| Precip. of the Wettest Quarter | 1 | Climatic | mm | 30 arcsec (≈900m at equator) |
| Precip. Seasonality | 1 | Climatic | mm | 30 arcsec (≈900m at equator) |
| Potential Evapotranspiration (std. dev.) | 1 | Climatic | PET Value (mm) | 30 arcsec (≈900m at equator) |
| Relative Humidity | 1 | Climatic | % * 100 | 30 arcsec (≈900m at equator) |
| Relative Humidity (std. Dev.) | 1 | Climatic | % * 100 | 30 arcsec (≈900m at equator) |
| Growing Season Length | 1 | Climatic | number of days | 30 arcsec (≈900m at equator) |
| Growing Season Length (std. dev.) | 1 | Climatic | number of days | 30 arcsec (≈900m at equator) |
| Growing Season Temp. | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Growing Season Temp. (std. dev.) | 1 | Climatic | ºC | 30 arcsec (≈900m at equator) |
| Number of Frost Days | 1 | Climatic | Number of days | 30 arcsec (≈900m at equator) |
| Number of Snow Days | 1 | Climatic | number of days | 30 arcsec (≈900m at equator) |
| Solar Radiation | 1 | Climatic | kJ m-2 | 30 arcsec (≈900m at equator) |
| Solar Radiation (std. dev.) | 1 | Climatic | kJ m-2 | 30 arcsec (≈900m at equator) |
| Cloud Cover | 3 | Climatic | % cloudy days | 30 arcsec (≈900m at equator) |
| Cloud Cover (std. dev.) | 3 | Climatic | % cloudy days | 30 arcsec (≈900m at equator) |
| Burnt Areas (probability) | 4 | Climatic | Proportion of burned areas | ≈500m |
| Snow (probability) | 4 | Climatic | Proportion of snow occurrence | ≈500m |
| Permafrost Extent | 5 | Climatic | Unitless | 30 arcsec (≈900m at equator) |
| Depth to Water Table | 6 | Geological | m below land surface | 30 arcsec (≈900m at equator) |
| Depth to Bedrock | 7 | Geological | cm (up to 200) | ≈250m |
| Soil Bulk Density | 7 | Soil | kg / cubic–meter | ≈250m |
| Soil Cation Exchange Capacity | 7 | Soil | cmolc/kg | ≈250m |
| Soil Clay Content | 7 | Soil | mass fraction in % | ≈250m |
| Soil Coarse Fragments | 7 | Soil | % | ≈250m |
| Soil Water Capacity | 7 | Soil | % | ≈250m |
| Soil Organic Carbon | 7 | Soil | g per kg | ≈250m |
| Soil Sand Content | 7 | Soil | mass fraction in % | ≈250m |
| Soil Saturated Water Content | 7 | Soil | % | ≈250m |
| Soil Silt Content | 7 | Soil | mass fraction in % | ≈250m |
| Soil pH | 7 | Soil | pH x 10 | ≈250m |
| Eastness | 3 | Topography | eastness index (-1 to 1) | 30 arcsec (≈900m at equator) |
| Elevation | 3 | Topography | meters | 30 arcsec (≈900m at equator) |
| Northness | 3 | Topography | northness index (-1 to 1) | 30 arcsec (≈900m at equator) |
| Roughness | 3 | Topography | (see reference) | 30 arcsec (≈900m at equator) |
| Slope | 3 | Topography | (see reference) | 30 arcsec (≈900m at equator) |

1. CHELSA [22,23]
2. CGIAR [24]
3. EarthEnv [25]
4. ESA CCI [26]
5. Obu *et al.* 2019
6. Fan *et al.* 2013
7. Soilgrids [29]

**Supplementary Table 5.** The PCA loading for each of the 18 traits and the 18 PC axes, along with the % variances explained by each axis. The variable that loads most heavily on each axis is shown in gray.

| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 | PC13 | PC14 | PC15 | PC16 | PC17 | PC18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **% Variance Explained** | **24.8** | **16.3** | **11.4** | **9.3** | **5.3** | **5.2** | **4.3** | **4** | **3.5** | **2.9** | **2.6** | **2.2** | **2.1** | **1.9** | **1.4** | **1.3** | **0.8** | **0.7** |
| **Bark thickness** | -0.25 | 0.06 | -0.5 | -0.45 | 0.17 | -0.05 | -0.05 | 0.03 | -0.07 | 0.54 | -0.03 | 0.11 | -0.06 | 0.1 | 0.1 | 0.04 | -0.04 | 0.02 |
| **Conduit diam.** | 0.72 | 0.27 | -0.47 | 0.03 | -0.1 | -0.04 | -0.15 | -0.05 | 0.01 | -0.09 | -0.13 | -0.07 | -0.12 | -0.02 | -0.01 | 0.36 | 0.02 | -0.09 |
| **Crown diameter** | 0.1 | 0.88 | 0.14 | -0.08 | -0.08 | -0.07 | 0.14 | -0.07 | -0.14 | -0.03 | -0.13 | -0.01 | 0.08 | 0.11 | -0.04 | 0.07 | 0.12 | 0.24 |
| **Crown height** | -0.19 | 0.75 | 0.25 | -0.29 | 0.11 | -0.08 | 0.18 | -0.01 | -0.15 | -0.1 | -0.14 | 0.07 | 0.21 | 0.14 | 0.05 | -0.02 | -0.08 | -0.2 |
| **Leaf area** | 0.69 | 0.46 | -0.31 | 0.06 | -0.2 | 0.26 | -0.2 | 0.1 | 0.05 | 0.12 | -0.19 | -0.3 | 0.08 | -0.05 | 0.02 | -0.23 | -0.02 | -0.02 |
| **Leaf density** | -0.28 | 0.2 | -0.59 | 0.26 | 0.44 | 0.24 | -0.08 | 0.08 | -0.42 | -0.18 | 0.12 | 0.01 | -0.08 | 0 | 0.02 | -0.07 | 0.09 | -0.02 |
| **Leaf K** | 0.56 | -0.52 | -0.03 | -0.21 | 0.18 | -0.19 | 0.04 | -0.09 | 0.01 | -0.12 | 0.02 | -0.23 | -0.1 | 0.42 | 0.01 | -0.06 | 0 | 0.01 |
| **Leaf N** | 0.73 | 0.13 | 0.14 | -0.01 | 0.1 | -0.25 | 0.17 | -0.15 | -0.09 | -0.03 | -0.21 | 0.17 | -0.36 | -0.16 | 0.09 | -0.15 | -0.02 | 0 |
| **Leaf P** | 0.56 | -0.3 | 0.13 | -0.25 | 0.41 | -0.23 | 0.11 | -0.13 | -0.15 | 0.09 | 0.06 | -0.23 | 0.24 | -0.27 | -0.02 | 0.05 | 0.02 | 0.01 |
| **Leaf thickness** | -0.77 | -0.1 | -0.19 | -0.33 | -0.15 | -0.07 | 0 | -0.37 | 0.05 | 0.03 | -0.13 | -0.07 | -0.07 | -0.04 | -0.17 | -0.08 | 0.21 | -0.09 |
| **Leaf Vcmax** | 0.75 | -0.18 | -0.38 | -0.1 | -0.04 | -0.06 | 0.04 | 0.12 | -0.04 | 0 | -0.01 | 0.27 | 0.12 | 0.04 | -0.36 | -0.07 | -0.04 | 0.01 |
| **Root depth** | -0.19 | 0.13 | -0.34 | 0.41 | -0.34 | -0.72 | -0.04 | 0.1 | -0.15 | 0.04 | 0.15 | -0.05 | 0.07 | 0 | 0.06 | -0.06 | 0.01 | -0.02 |
| **Seed dry mass** | 0 | 0.46 | 0.01 | 0.35 | 0.46 | -0.21 | -0.41 | -0.25 | 0.37 | 0 | 0 | 0.1 | 0.07 | 0.04 | -0.02 | -0.04 | 0 | 0.01 |
| **Specific leaf area** | 0.74 | 0.02 | 0.39 | 0.13 | 0.03 | 0.05 | 0.02 | 0.27 | 0.08 | 0.18 | 0.1 | 0.12 | 0.03 | 0.07 | 0.08 | 0 | 0.26 | -0.1 |
| **Stem diameter** | -0.22 | 0.02 | -0.31 | -0.67 | 0.09 | -0.19 | -0.09 | 0.42 | 0.25 | -0.29 | -0.06 | 0.03 | 0.02 | -0.1 | 0.1 | -0.04 | 0.05 | 0.04 |
| **Stomatal conduct.** | 0.52 | 0.15 | -0.48 | -0.21 | -0.2 | 0.17 | 0.19 | -0.39 | 0.14 | -0.1 | 0.32 | 0.12 | 0.11 | -0.01 | 0.17 | -0.05 | 0.01 | 0.01 |
| **Tree height** | 0.01 | 0.77 | 0.23 | -0.3 | 0.03 | -0.03 | 0.02 | 0.1 | 0.06 | 0.06 | 0.4 | -0.15 | -0.24 | -0.04 | -0.17 | -0.01 | -0.04 | -0.03 |
| **Wood density** | -0.25 | 0.13 | -0.42 | 0.44 | 0.21 | 0 | 0.61 | 0.13 | 0.32 | 0.06 | -0.08 | -0.1 | -0.01 | 0 | -0.04 | 0.02 | 0 | -0.01 |

## Supplementary Notes

### *Extended discussion of the two-trait clusters in Fig. 4*

Intermediate to the two largest clusters in Fig. 4 (main text) is a constellation containing stem conduit diameter and stomatal conductance, demonstrating leaf/wood water regulation (Fig. 4, yellow). This constellation loads most strongly on PC 1, as moisture regulation, nutrient-use, and photosynthesis are closely interrelated. Nevertheless, conduit diameter, in particular, correlates moderately with traits indicative of light interception, notably leaf area ($\rho = 0.48$) and tree height ($\rho = 0.25$). Although the largest differences in stem conduit size are observed between angiosperms and gymnosperms, wider conduits confer greater conducting efficiency regardless of architecture[1]. Indeed, these patterns hold within clades as well, particularly when comparing conduit diameter to leaf area ($\rho = 0.43$ vs 0.38 for angiosperms vs. gymnosperms). The associations between water regulation and light interception highlights that leaf area and tree height induce important physiological and mechanical demands on organism-level water availability, which prevent against cavitation and desiccation.

Tree diameter and bark thickness also emerge as a distinct two-trait cluster. Recent research has shown that bark thickness is mainly driven by plant size (mainly stem diameter). This strong association likely reflects, not only bark accumulation as trees age, but also functional/metabolic needs as plants grow taller and increase in total leaf area[2,3]. From an ecological perspective, thick bark can be critical for defense against fire and pest damage (mainly a thick outer bark region), and for storage and photosynthate transport (mainly a thick inner bark region)[4,5]. Moreover, because older individuals are more likely to have been exposed to multiple disturbances across their lifetime, large-diameter trees in older forests can exhibit survivorship bias towards thick-bark individuals which were able to withstand historical stressors[3,6]. However, such relationships are strongly ecosystem-dependent, leading to weak overall relationships between climate, fire regimes, and bark thickness at the global scale, with stem diameter emerging as the strongest single predictor[2].

The final two-trait cluster is comprised of wood density and leaf density. Both traits are key indicators of “slow” life-history strategies in trees, correlating negatively with growth rate and water transport, but positively with abiotic stress tolerance and resilience to disturbance[7]. Thick leaves and thick wood each protect against herbivory and pests while protecting against desiccation risk and mechanical damage[8–11]. Wood density has been identified as a particularly important multi-functional indicator of tree form and function, reflecting various aspects of tree hydraulics, pest resistance, decay rate, structural stability, tree size, growth rate, and tree mortality[9,12–15]. The production of dense wood and leaves is, however, more energetically costly, limiting growth rate but increasing life span[12,16]. The fact that wood and leaf density emerge as an independent trait constellation reinforces previous inference that these traits are aligned at one end of the slow-fast spectrum, and uniquely integrate multiple physiological and ecological pressures[7,12,16].

***Exploration of invasive species in the dataset***

We explored the level of invasiveness in our dataset by combining the GloNAF[17] and Kew[18] invasive species databases to identify whether each observation was occurring within that species' native or invasive range. The average proportion of invasive species observations was less than half a percent across all traits (0.3%), with leaf area having the highest proportion (0.814%), equating to 11 species out of 1352 species with a measurement taken at a location outside their native range. There was only one species with more than 5 measurements for a given trait taken out outside of its native range: *Castanea sativa* had 28, 20 and 22 measurements taken for wood density, leaf N and leaf P, making up significantly less than 0.5% of observations for each trait. Moreover, these locations where *C. sativa* is invasive are located in France, Spain, Germany, and the UK. And while these lie outside of its estimated original range, it has since been established in these regions for more than 1000 years[19]. Such results demonstrate the challenges exploring trait variation between invasive and native populations, in part due to widely different definitions of "invasive" across databases.

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