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Appendix S2. Sample size for woody and non-woody species across climate regions, robustness test for the gap filling algorithm and examples of studies focused on multi-organ, multi-trait datasets.

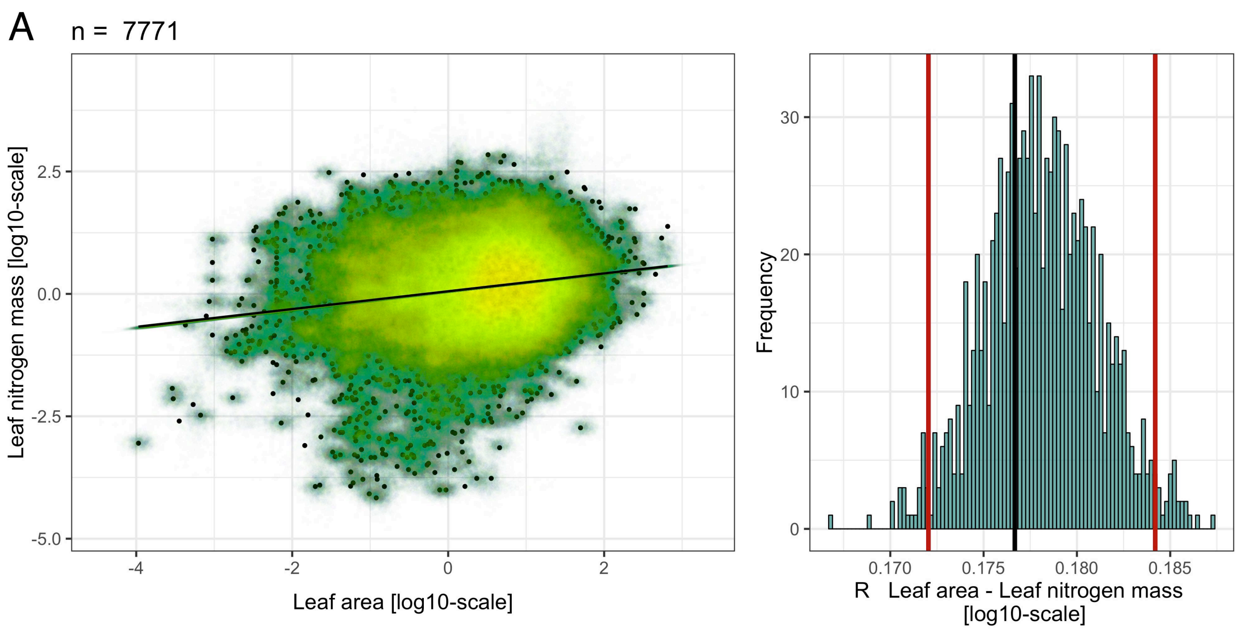
Table S2.1. Percentage of observation present by trait in the TRY subset used in this study. Traits in the table are order in ascendant order from the trait with the lowest coverage to the trait with the highest coverage in the dataset.

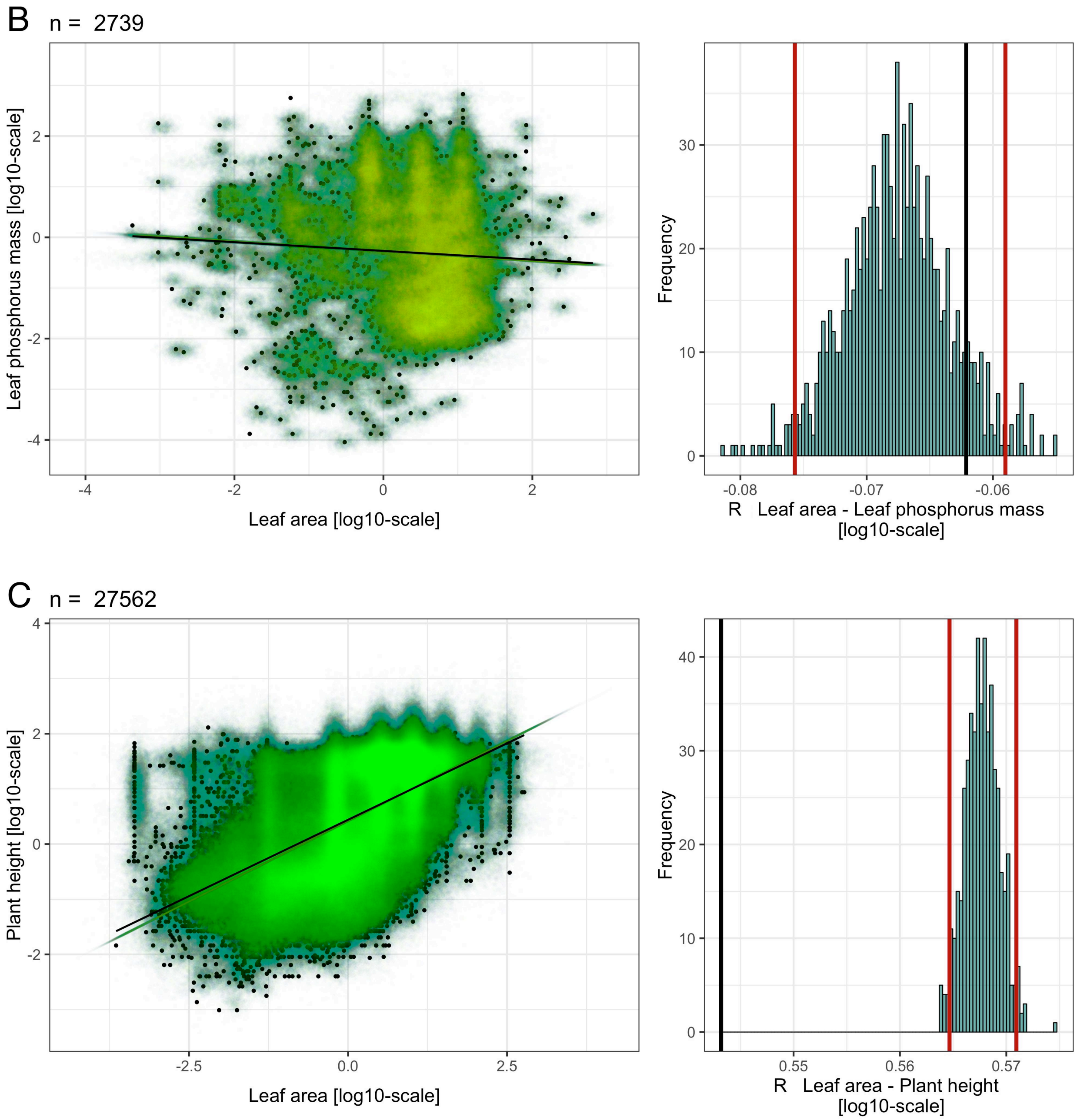
Trait	**Percentage observation present**
Leaf lifespan	0.6728772
Leaf phosphorus area	2.5561542
Leaf nitrogen area	5.7611659
Leaf phosphorus mass	6.8018047
Stem specific density	9.8029733
Leaf nitrogen mass	14.3595819
Seed mass	19.8256946
Leaf area	27.8021942
SLA	29.1242534
Plant height	35.6462607

Table S2.3 Number of species by growth form across five climate regions.

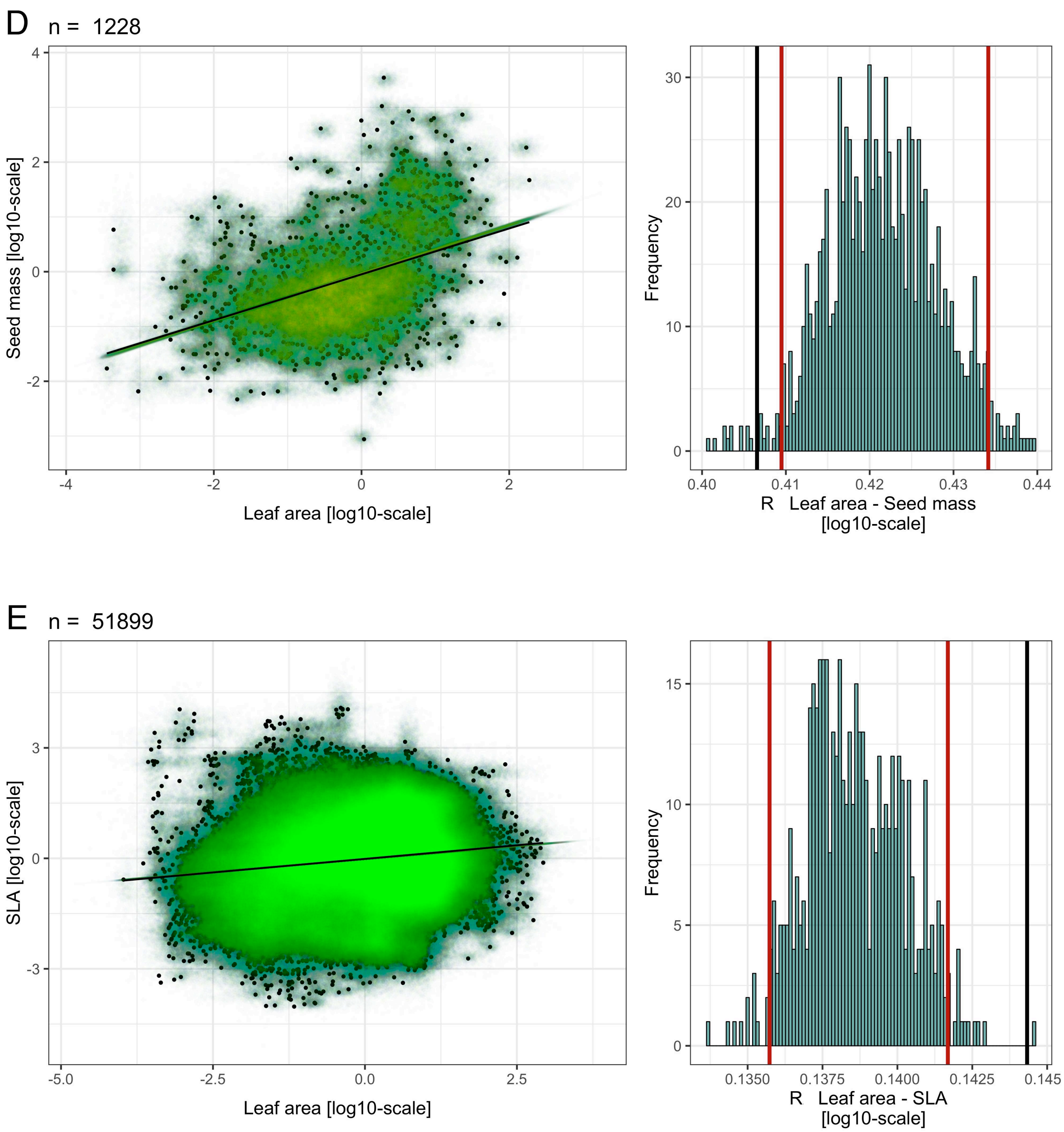
Climate region	Woody	Non-woody
Tropical	4414	537
Temperate	2695	2352
Arid	1046	873
Cold	752	2050
Polar	146	419

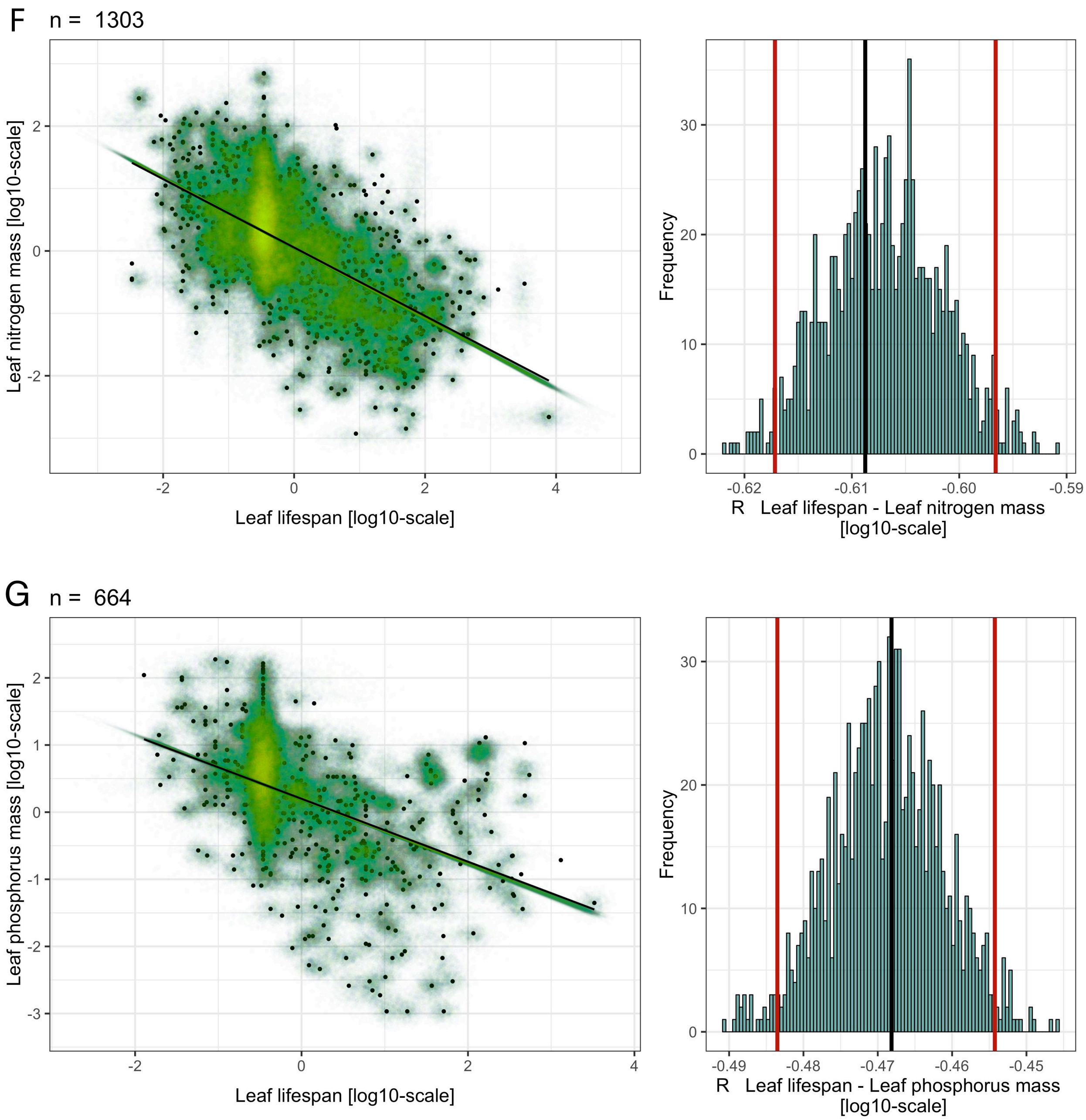
Figure S2.1 Comparison of trait-trait correlations using only gap-filled or only original trait values. Sample sizes (n) of the gap filled and original database are the same to ensure they are comparable. To test whether the gap-filling algorithm had an effect on trait-trait correlation we used a subset of 470769 observations from TRY for five traits (leaf area, SLA, leaf n, plant height and seed mass). We compare the trait-trait correlation for 1000 different gap-filled matrices with the trait-trait correlation of the original data. We did this comparison for trait-trait correlation with low and high sample size. We show that in most cases, the original trait-trait correlation lies inside the 95% CI of the 1000 gap-filled datasets. Sample size for each trait-trait correlation is given on the right top corner of each panel.





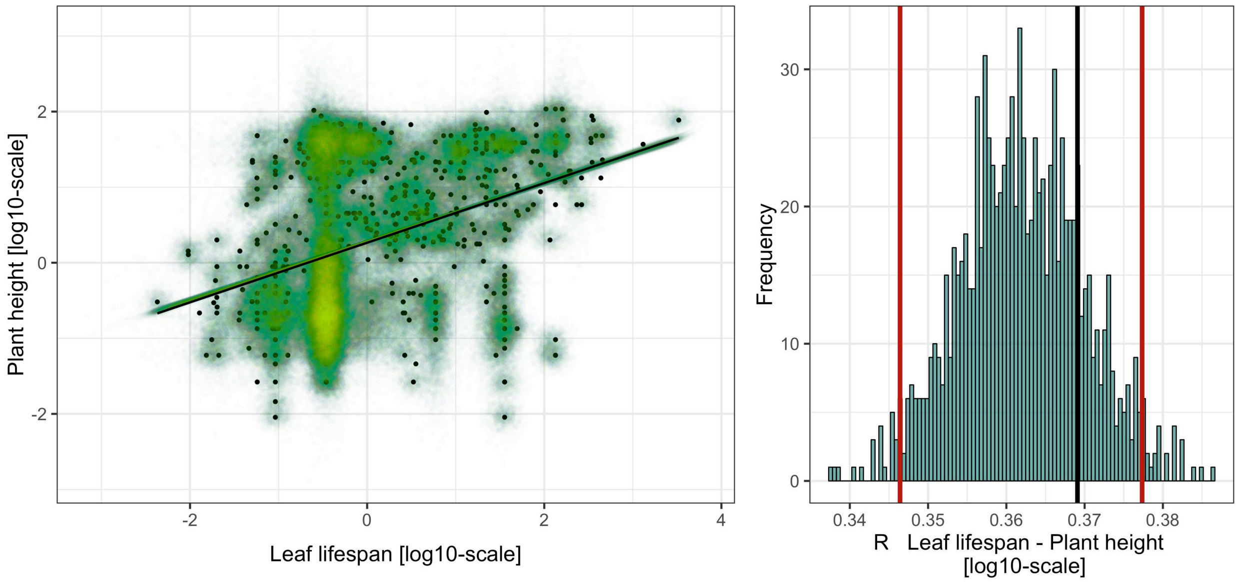
B
n = 2739
Leaf phosphorus mass [log10-scale]
Leaf area [log10-scale]
Frequency
R Leaf area - Leaf phosphorus mass
[log10-scale]
C
n = 27562
Plant height [log10-scale]
Leaf area [log10-scale]
Frequency
R Leaf area - Plant height
[log10-scale]


D
n = 1228
Seed mass [log10-scale]
Leaf area [log10-scale]
Frequency
R Leaf area - Seed mass
[log10-scale]
E
n = 51899
SLA [log10-scale]
Leaf area [log10-scale]
Frequency
R Leaf area - SLA
[log10-scale]

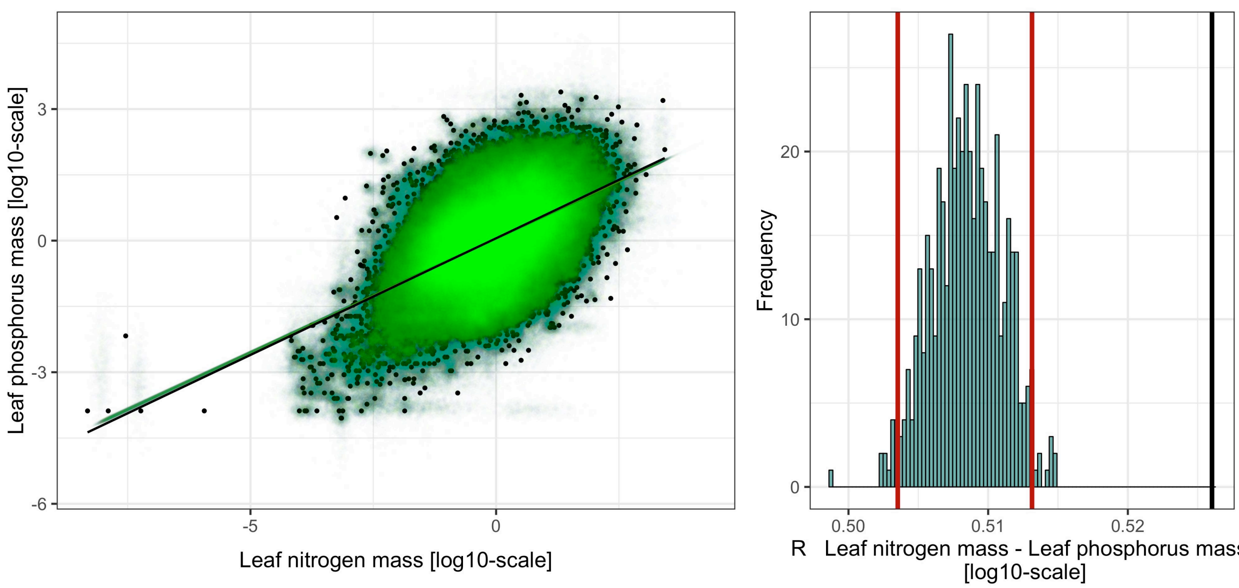


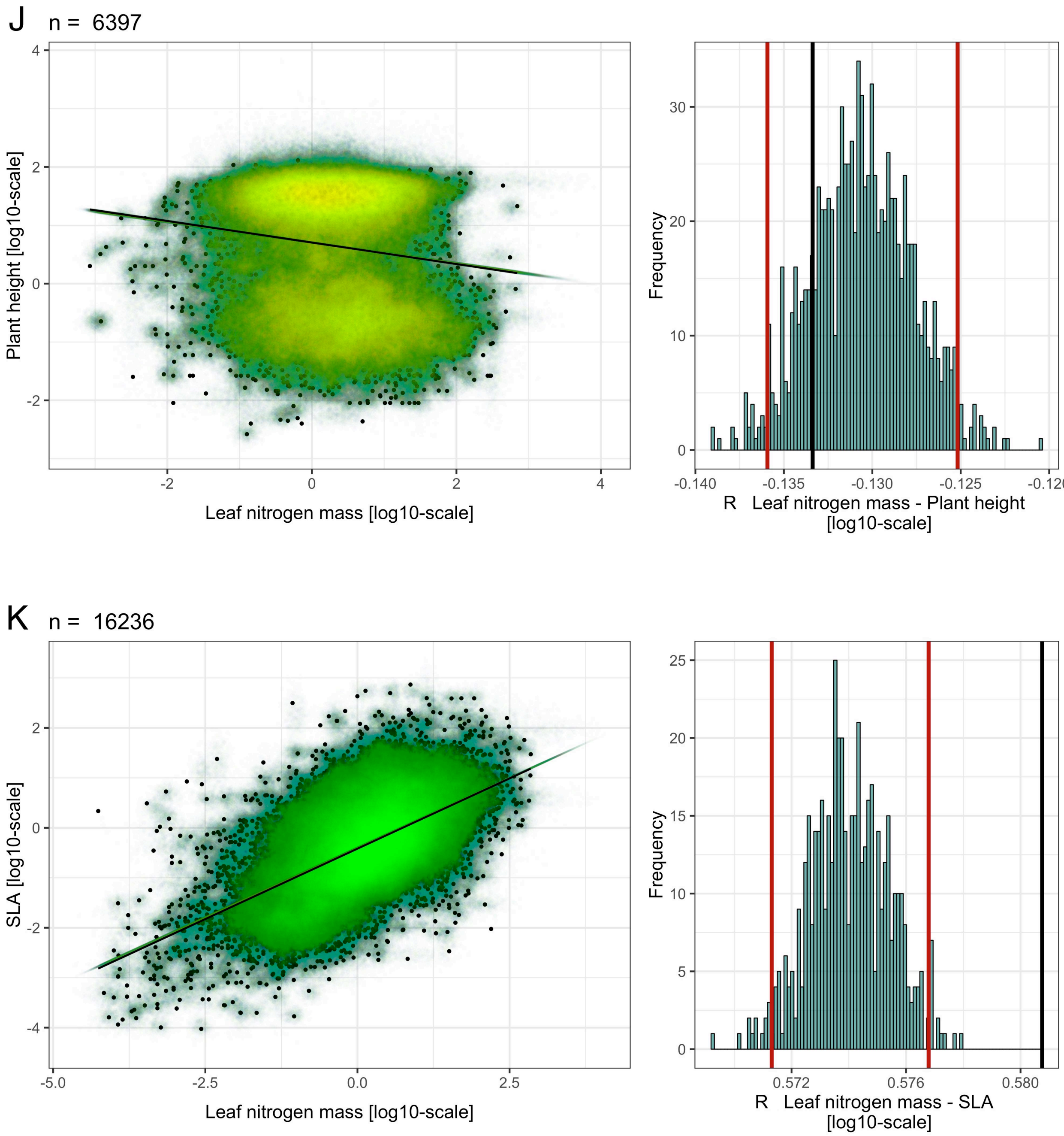
F
n = 1303
Leaf nitrogen mass [log10-scale]
Leaf lifespan [log10-scale]
Frequency
R Leaf lifespan - Leaf nitrogen mass
[log10-scale]
-0.62
-0.61
-0.60
-0.59
G
n = 664
Leaf phosphorus mass [log10-scale]
Leaf lifespan [log10-scale]
Frequency
R Leaf lifespan - Leaf phosphorus mass
[log10-scale]
-0.49
-0.48
-0.47
-0.46
-0.45

H n = 906

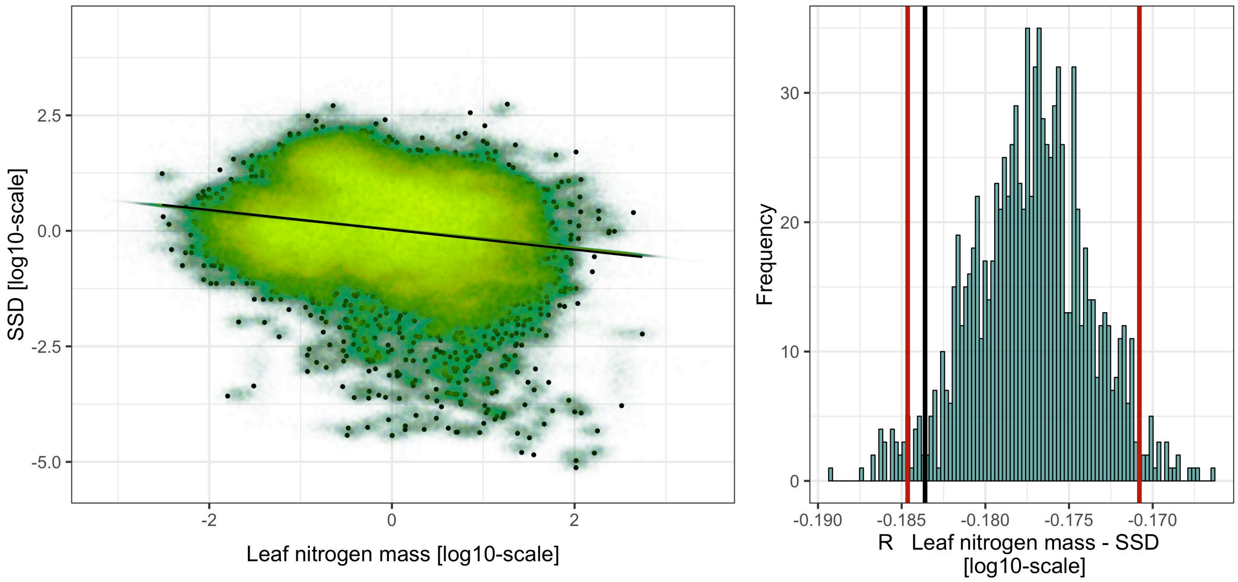


I n = 18301

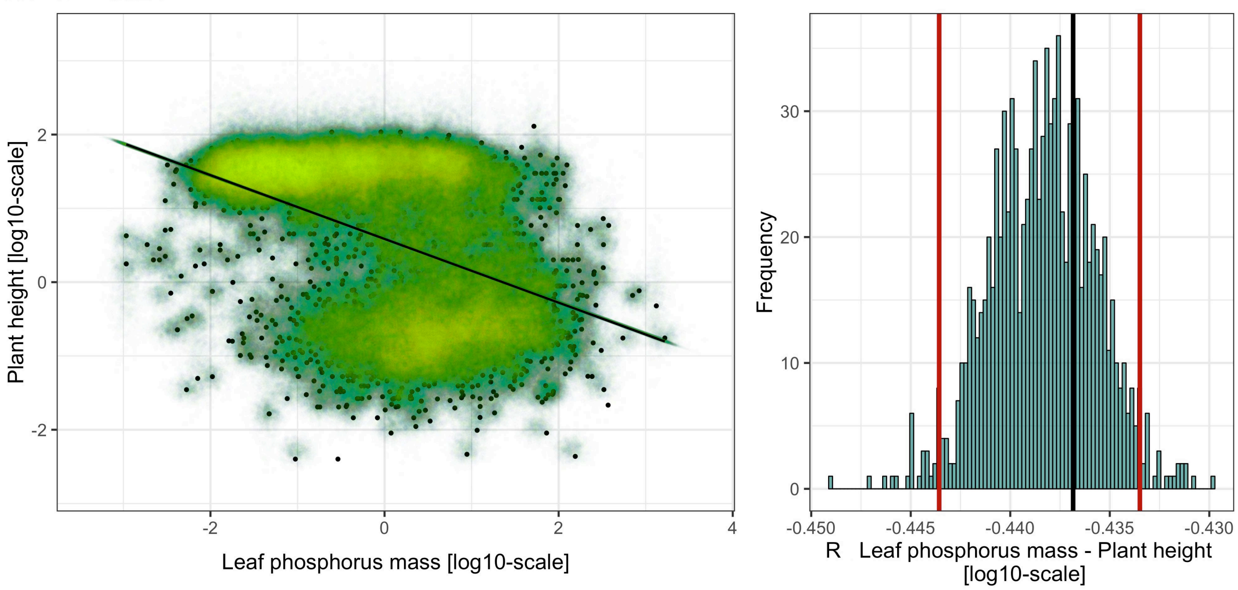



J
n = 6397
Plant height [log10-scale]
Leaf nitrogen mass [log10-scale]
4
2
0
-2
-2
0
2
4
Frequency
30
20
10
0
-0.140
-0.135
-0.130
-0.125
-0.120
R Leaf nitrogen mass - Plant height
[log10-scale]
K
n = 16236
SLA [log10-scale]
Leaf nitrogen mass [log10-scale]
2
0
-2
-4
-5.0
-2.5
0.0
2.5
Frequency
25
20
15
10
5
0
0.572
0.576
0.580
R Leaf nitrogen mass - SLA
[log10-scale]

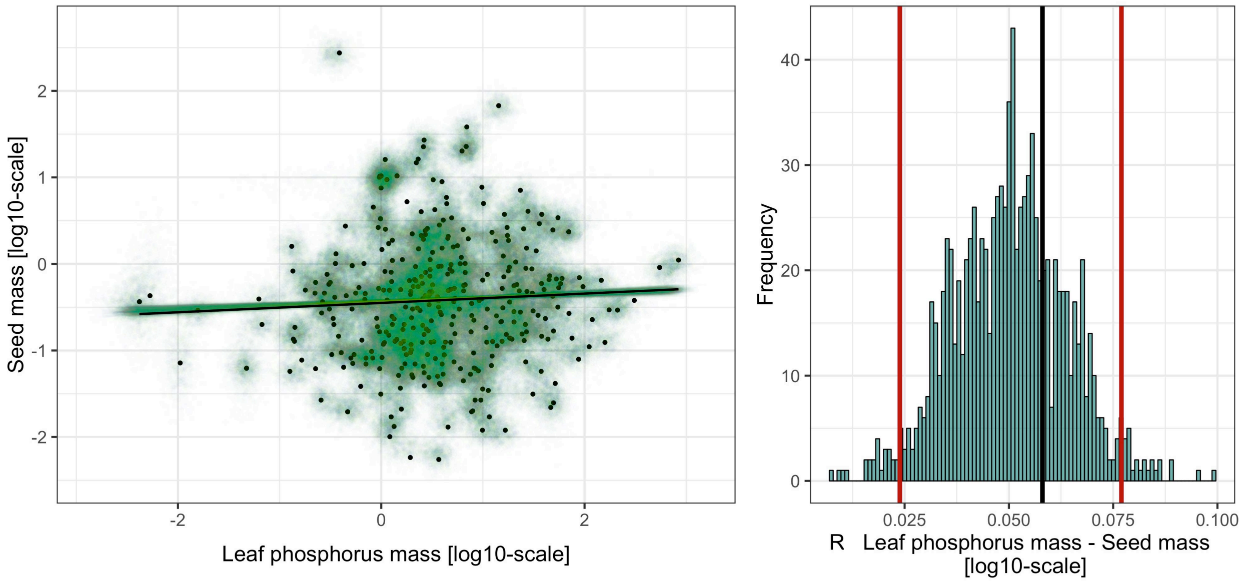
L n = 5904



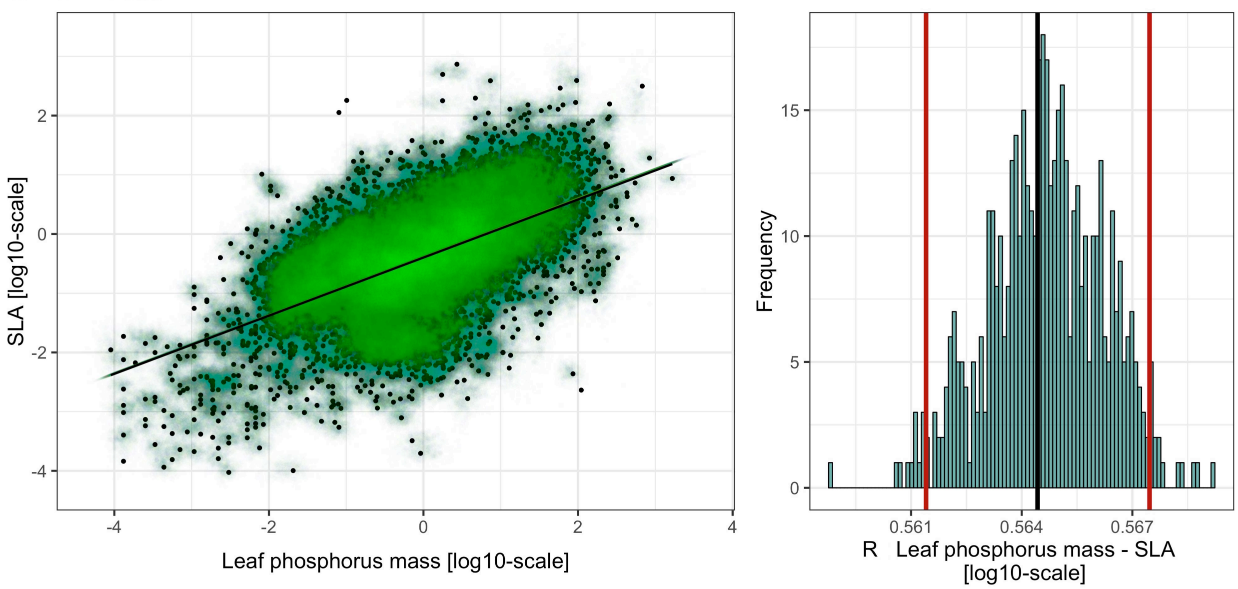
M n = 3324



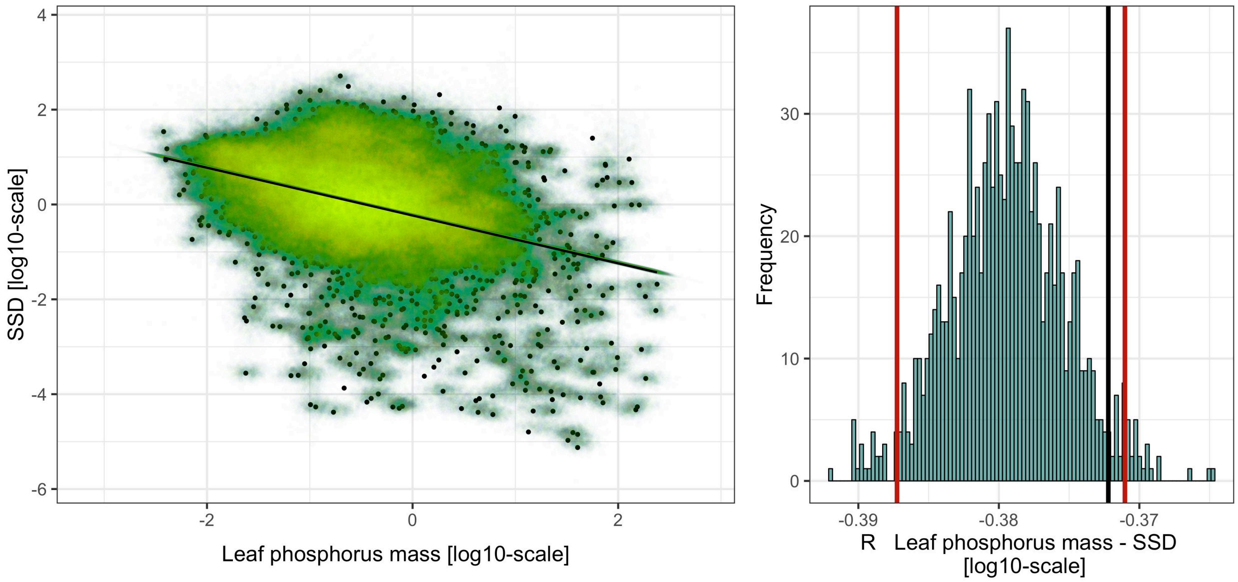
N n = 363



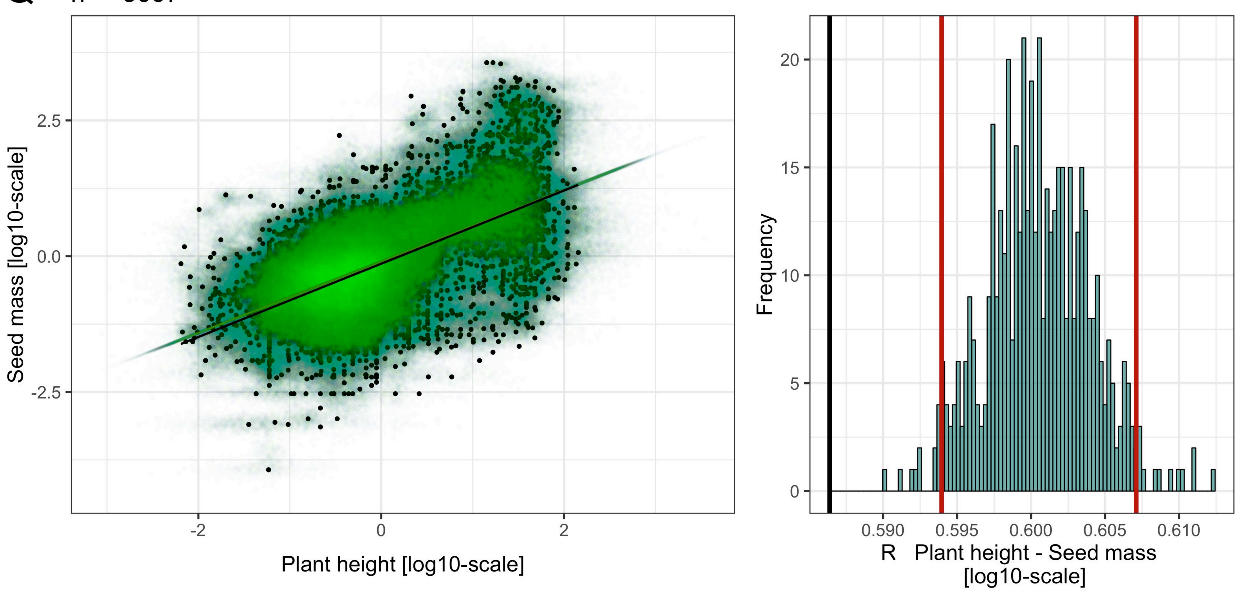
O n = 7036



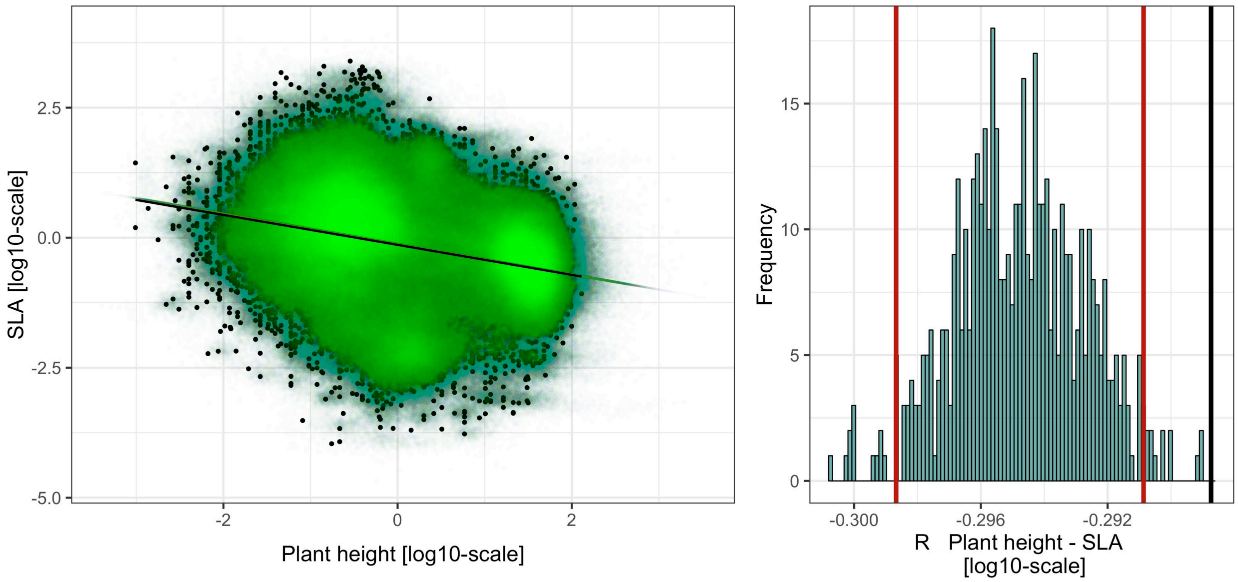
P n = 3774



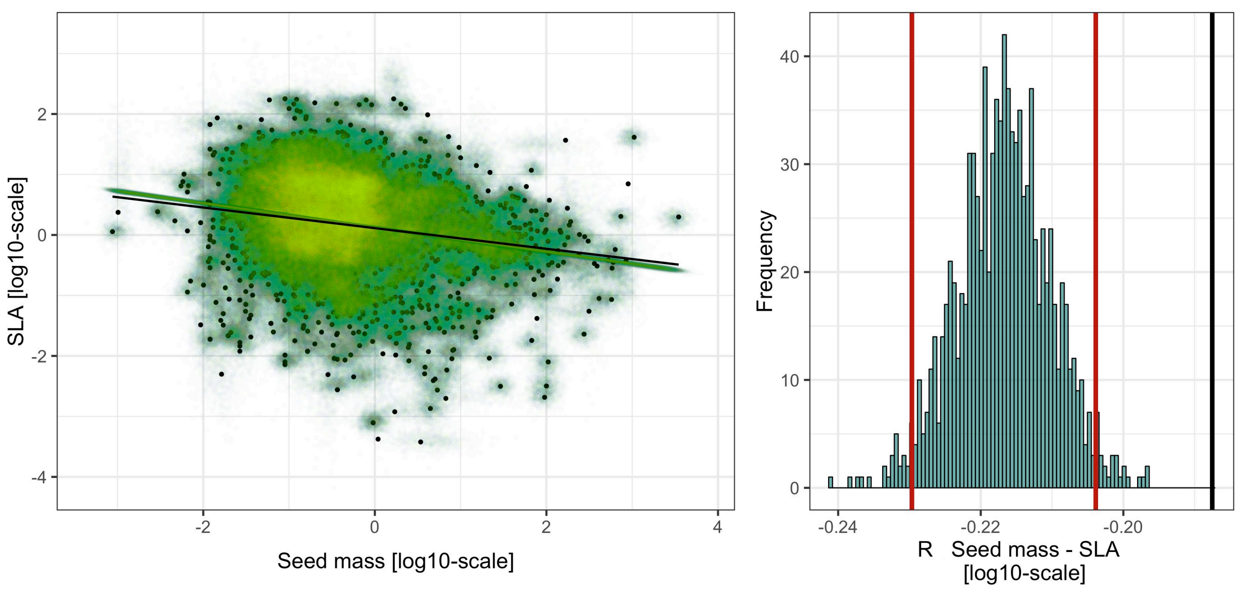
Q n = 5667



R n = 19606



S n = 1971



T

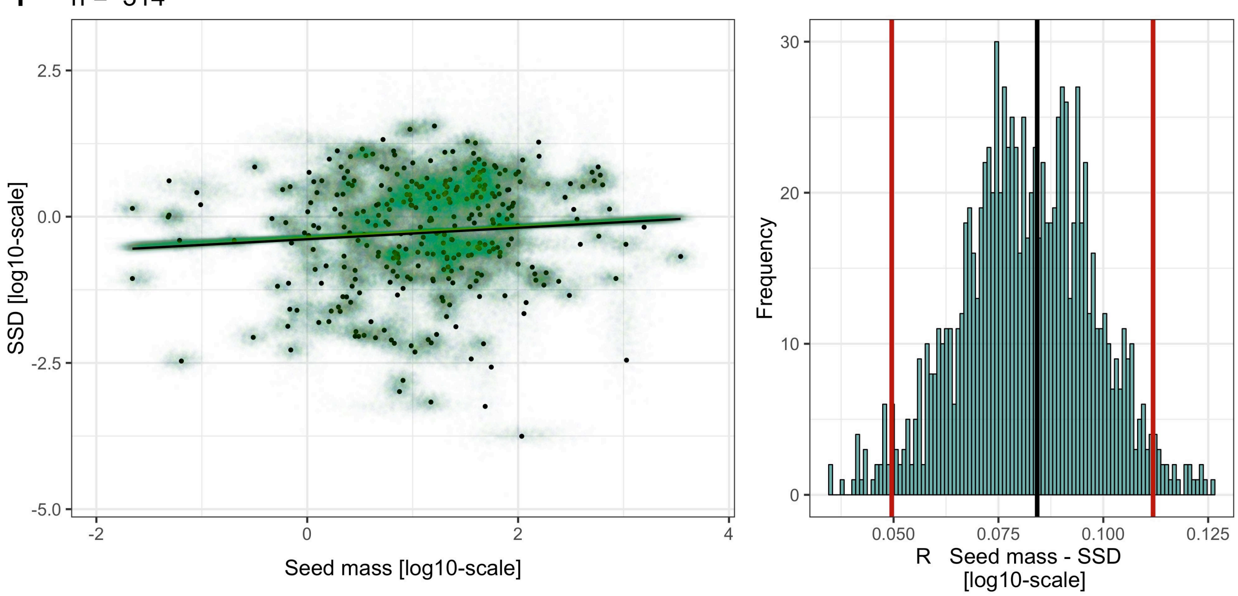

n = 314
SSD [log10-scale]
Seed mass [log10-scale]
2.5
0.0
-2.5
-5.0
-2
0
2
4
Frequency
30
20
10
0
0.050
0.075
0.100
0.125
R Seed mass - SSD
[log10-scale]

Figure S2.2 Correlation between Standard deviation and Root mean square error in dataset

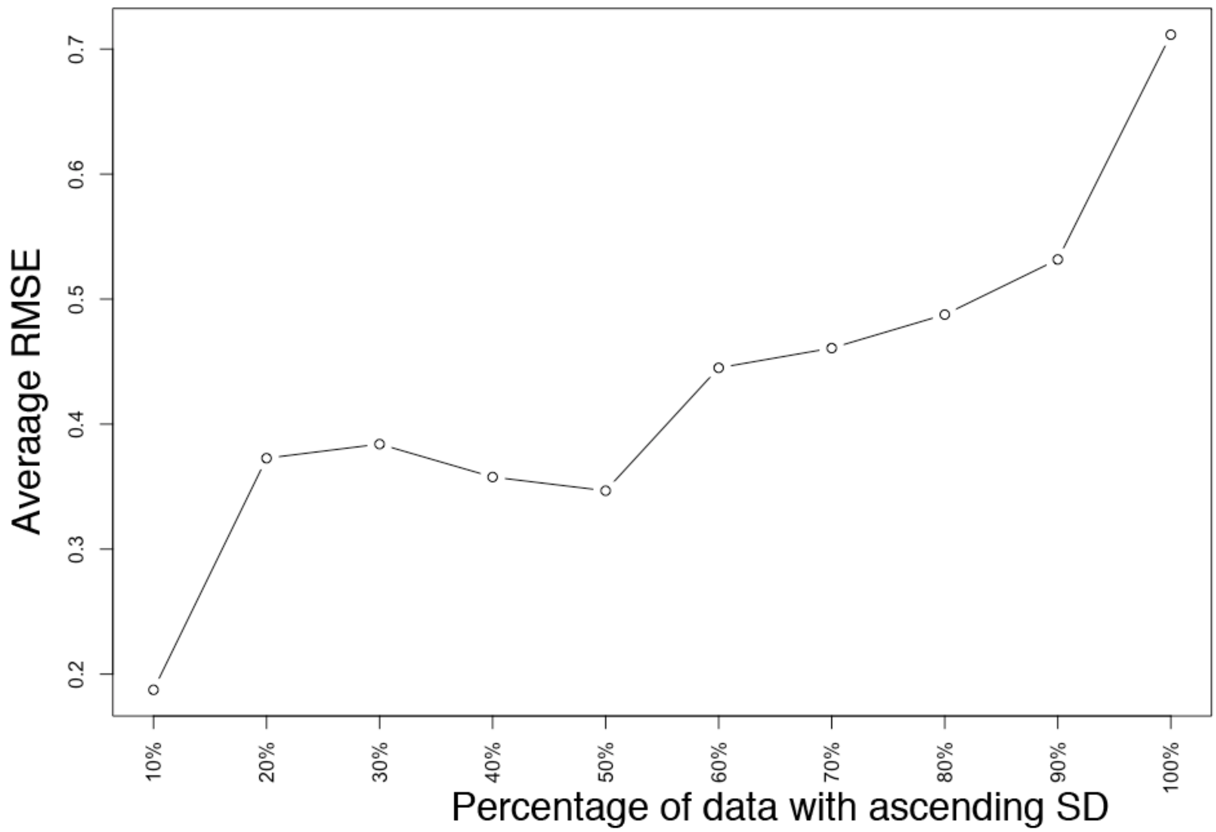


Table S2.3 Examples of studies focused on multi-organ, multi-trait datasets.

Study	Growing conditions of the plants	Spatial scale	Environmental gradients	Are environmental gradients explicitly considered?	Plant groups included	Plant groups taken into consideration?	Number of species	Life stage	Organs
Ackerly 2004	field	local	Water availability	no	woody evergreen, woody deciduous	yes	20	adults	leaf 23 stem 11 seed 2
Baraloto et al. 2010	field	regional	Precipitation, Soil nutrients	no	trees	no	668	adults	leaf 12 stem 5
Cheng et al. 2015	field	local	Temperature, Precipitation, Soil nutrients	yes	xerophytes, intermediate xerophytes, intermediate mesophytes, mesophytes shallow vs deep-rooted	yes	55	adults	leaf 1 roots 4
de la Riva et al. 2015	field	local	Humidity (soil water)	yes	woody		38	adults	leaf 7 stem 1 roots 5 seed 1
Diaz et al. 2004	field	regional	Precipitation, Temperature, Altitude	no	eudicotyledons, monocotyledons; Asteraceae; Fabaceae; Poaceae	yes	640	adults	leaf 5 stem 4 seed 2 other 2
Diaz et al. 2016	field	global	Precipitation, Temperature, Altitude	no	woody, non-woody; angiosperms, gymnosperms, pteridophyte	yes	46085	adults	
Fortunel et al. 2012	field	regional	Precipitation, Soil nutrients	yes	trees	no	758	adults	leaf 11 stem 2 root 1

Freschet et al. 2010	field	local	Soil nutrients (C &N), Temperature (soil litter), Humidity (soil litter), growing season	yes	woody evergreen, woody deciduous, fern allies, club mosses, monocots, terrestrial forbs, aquatic forbs	yes	40	adults	leaf 8 stem 7 roots 7
Ishida 2008	field			no	trees, creeping trees, ruderal trees, climber, C3 shrubs and forbs, CAM, palm		32	adults	leaf 14 stem 1
Jager et al. 2015	field	local	Terrain slope, Soil nutrients	yes	angiosperm trees, conifer trees, palm trees, fern trees	yes	30	> 10 dbh	leaf 8 stem 4 seed 1
Kramer et al. 2016	glasshouse	local, regional	Soil nutrients	yes	conifer, eudicot, palm, magnoliid, tree fern; AM(nodules)*, AM*, Non*, Dual AM/EM*, EM*, Ericoid*	yes	66	seedlings	leaf 2 stem 2 root 5
Li and Bao 2015	common garden				woody deciduous, woody xerophythic	no	23	1 year old	leaf 3 stem 1 roots 4
Wright 2007	field	regional	Precipitation	no	trees, shrubs, lianas	no	122	adults	leaf 2 stem 2 seed 2

When several plant group classifications were used, a semicolon divides them. The numbers next to the name of the organs included in the study in the 'Organs' column refers to the number of traits per organ. * Represent types of mychorrhizal association: arbuscular mychorrizal (AM), no mychorrhizal association (Non), ectomycorrhizal (EM), Dual (association with both arbuscular and ectomychorrizal).

Appendix S3. Trait network analyses across plant groups species and climate regions excluding leaf lifespan (LLS)

Table S3.1. Trait centrality (i.e. Degree) for all plants, woody, and non-woody species and 95% confidence interval (CI). We ran this analysis for each network of all plants, woody and non-woody species for 1000 bootstrapped trait matrices across 7 traits, excluding LLS.

Life form	Trait	2.5%	50%	97.5%
All	Plht	1.00	1.00	1.00
	SLA	1.00	1.00	1.00
	Sm	0.83	1.00	1.00
	SSD	0.83	1.00	1.00
	Leaf N	0.67	0.83	1.00
	Leaf P	0.67	0.83	0.83
	Leaf area	0.67	0.67	0.83
Non-woody	Leaf area	0.50	0.83	0.83
	Leaf N	0.67	0.83	0.83
	Leaf P	0.67	0.67	0.83
	Plht	0.67	0.67	0.83
	SLA	0.50	0.67	0.68
	Sm	0.67	0.67	0.83
	SSD	0.00	0.17	0.33
Woody	Sm	0.83	1.00	1.00
	Leaf area	0.83	0.83	0.83
	Leaf P	0.67	0.83	0.83
	SLA	0.83	0.83	0.83
	Leaf N	0.50	0.50	0.67
	Plht	0.50	0.50	0.50
	SSD	0.50	0.50	0.67

Table S3.2 Multiple-comparison adjusted 95% confidence interval (CI) from the trait centrality (i.e. degree) analyses for seven traits. We ran the trait centrality analyses for the trait of all plant species, woody and non-woody species across 1000 trait matrices. Differences in centrality between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	All plants		Woody		Non-woody	
Trait-pairs	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%
Leaf area-SLA	-0.17	0.00	-0.17	0.00	-0.17	0.33
Leaf area-Leaf N	0.17	0.33	0.17	0.33	-0.33	0.17
Leaf area-Leaf P	0.00	0.17	0.00	0.17	-0.33	0.17
Leaf area-Plht	0.33	0.33	0.33	0.33	-0.33	0.17
Leaf area-SSD	0.00	0.33	0.00	0.33	0.17	0.67
Leaf area-Sm	-0.17	0.00	-0.17	0.00	-0.33	0.17
SLA-Leaf N	0.17	0.33	0.17	0.33	-0.50	0.17
SLA-Leaf P	0.00	0.17	0.00	0.17	-0.33	0.17
SLA-Plht	0.33	0.50	0.33	0.50	-0.17	0.00
SLA-SSD	0.17	0.33	0.17	0.33	0.17	0.83
SLA-Sm	-0.17	0.00	-0.17	0.00	-0.33	0.17
Leaf N-Leaf P	-0.33	0.00	-0.33	0.00	-0.17	0.17
Leaf N-Plht	0.00	0.17	0.00	0.17	-0.17	0.33
Leaf N-SSD	0.00	0.00	0.00	0.00	0.33	0.83
Leaf N-Sm	-0.50	-0.17	-0.50	-0.17	-0.17	0.17
Leaf P-Plht	0.17	0.33	0.17	0.33	-0.17	0.33
Leaf P-SSD	0.00	0.33	0.00	0.33	0.33	0.83
Leaf P-Sm	-0.17	-0.17	-0.17	-0.17	-0.17	0.17
Plht-SSD	-0.17	0.00	-0.17	0.00	0.17	0.83
Plht-Sm	-0.50	-0.33	-0.50	-0.33	-0.17	0.17
SSD-Sm	-0.50	-0.17	-0.50	-0.17	-0.83	-0.33

Table S3.3 Edge density for woody and non-woody species and 95% confidence interval (CI). We ran this analysis for each network of woody and non-woody species across climate regions for 1000 bootstrapped trait matrices.

Life-form	Climate	2.5%	50%	97.5%
Woody	Arid	0.52	0.57	0.67
	Cold	0.43	0.52	0.57
	Polar	0.29	0.38	0.48
	Temperate	0.52	0.57	0.62
	Tropical	0.62	0.67	0.71
Non-woody	Arid	0.38	0.48	0.57
	Cold	0.52	0.62	0.67
	Polar	0.33	0.43	0.52
	Temperate	0.52	0.62	0.71
	Tropical	0.29	0.38	0.52

Table S3.4 Multiple-comparison adjusted 95% confidence interval (CI) from the edge density analyses among climate regions for woody and non-woody species. We ran the edge density comparison for woody and non-woody species across five climate regions for 1000 trait matrices. Differences in edge density between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	Woody		Non-woody	
Region-pairs	2.5%	97.5%	2.5%	97.5%
Arid-Cold	-0.05	0.19	-0.29	0.00
Arid-Polar	0.05	0.38	-0.19	0.19
Arid-Temperate	-0.14	0.14	-0.33	0.05
Arid-Tropical	-0.19	0.05	-0.14	0.24
Cold-Polar	0.00	0.29	0.00	0.33
Cold-Temperate	-0.19	0.05	-0.19	0.14
Cold-Tropical	-0.24	-0.05	0.00	0.38
Polar-Temperate	-0.38	-0.05	-0.33	0.05
Polar-Tropical	-0.43	-0.14	-0.19	0.24
Temperate-Tropical	-0.19	0.05	0.00	0.38

Table S3.5 Modularity for woody and non-woody species and 95% confidence interval (CI). We ran this analysis for each network of woody and non-woody species across climate regions for 1000 bootstrapped trait matrices.

Life-form	Climate	2.5%	50%	97.5%
Woody	Arid	0.06	0.15	0.22
	Cold	0.15	0.21	0.28
	Polar	0.17	0.27	0.37
	Temperate	0.10	0.15	0.21
	Tropical	0.02	0.06	0.10
Non-woody	Arid	0.10	0.20	0.31
	Cold	0.02	0.05	0.13
	Polar	0.13	0.20	0.32
	Temperate	0.02	0.05	0.13
	Tropical	0.09	0.22	0.32

Table S3.6 Multiple-comparison adjusted 95% confidence interval (CI) from the modularity analyses among climate regions for woody and non-woody species. We ran the modularity comparison for woody and non-woody species across five climate regions for 1000 trait matrices. Differences in modularity between regions is significant when the 95% CI for the differences between regions pairs does not overlap with zero.

	Woody		Non-woody	
Region pairs	2.5%	97.5%	2.5%	97.5%
Arid-Cold	-0.21	0.11	-0.02	0.33
Arid-Polar	-0.31	0.08	-0.24	0.22
Arid-Temperate	-0.15	0.16	0.00	0.34
Arid-Tropical	-0.04	0.20	-0.22	0.23
Cold-Polar	-0.23	0.13	-0.33	0.05
Cold-Temperate	-0.06	0.18	-0.11	0.16
Cold-Tropical	0.00	0.26	-0.30	0.06
Polar-Temperate	-0.06	0.30	0.00	0.34
Polar-Tropical	0.03	0.35	-0.19	0.21
Temperate-Tropical	-0.04	0.19	-0.32	0.00

Table S3.7. Trait centrality (i.e. Degree) for woody species across five climate regions and 95% confidence interval (CI). We ran this analysis over 1000 bootstrapped trait matrices.

Climate	Trait	2.50%	50%	97.50%
Tropical	Sm	0.83	1.00	1.00
	SLA	0.83	0.83	0.83
	Leaf area	0.67	0.67	0.67
	Leaf P	0.50	0.67	0.67
	Leaf N	0.50	0.50	0.67
	Plht	0.50	0.50	0.67
	SSD	0.50	0.50	0.67
Temperate	Leaf area	0.67	0.67	0.67
	SLA	0.67	0.67	0.83
	Sm	0.50	0.67	0.67
	Leaf N	0.33	0.50	0.50
	Leaf P	0.50	0.50	0.67
	Plht	0.50	0.50	0.67
	SSD	0.50	0.50	0.67
Arid	Leaf area	0.67	0.67	0.83
	SLA	0.67	0.67	1.00
	SSD	0.50	0.67	0.83
	Leaf P	0.50	0.50	0.67
	Plht	0.33	0.50	0.67
	Sm	0.50	0.50	0.67
	Leaf N	0.33	0.33	0.50
Cold	Plht	0.33	0.67	0.83
	SLA	0.50	0.67	0.67
	Leaf area	0.33	0.50	0.50
	Leaf P	0.50	0.50	0.67
	Sm	0.50	0.50	0.50
	SSD	0.33	0.50	0.50
	Leaf N	0.33	0.33	0.33
Polar	Leaf area	0.17	0.50	0.67
	Leaf P	0.17	0.50	0.67
	SLA	0.33	0.50	0.67
	Sm	0.33	0.50	0.50
	Leaf N	0.33	0.33	0.50
	Plht	0.17	0.33	0.50
	SSD	0.17	0.33	0.34

Table S3.8. Trait centrality (i.e. Degree) for non-woody species across five climate regions and 95% confidence interval (CI). We ran this analysis over 1000 bootstrapped trait matrices.

Climate	Trait	2.50%	50%	97.50%
Tropical	Leaf area	0.33	0.50	0.67
	Leaf N	0.50	0.50	0.67
	Sm	0.33	0.50	0.83
	Leaf P	0.17	0.33	0.67
	Plht	0.17	0.33	0.50
	SLA	0.17	0.33	0.50
	SSD	0.00	0.17	0.50
Temperate	Leaf N	0.67	0.83	1.00
	Leaf area	0.50	0.67	0.83
	Leaf P	0.33	0.67	0.83
	Plht	0.50	0.67	0.83
	Sm	0.67	0.67	0.83
	SLA	0.50	0.50	0.50
	SSD	0.00	0.17	0.33
Arid	Leaf area	0.50	0.50	0.67
	Leaf N	0.33	0.50	0.67
	SLA	0.33	0.50	0.67
	Sm	0.33	0.50	0.83
	Leaf P	0.33	0.33	0.67
	Plht	0.17	0.33	0.50
	SSD	0.17	0.17	0.33
Cold	Leaf area	0.67	0.83	0.83
	Leaf N	0.50	0.67	0.83
	SLA	0.50	0.67	0.83
	Sm	0.50	0.67	0.67
	Leaf P	0.50	0.50	0.67
	Plht	0.17	0.50	0.67
	SSD	0.17	0.33	0.50
Polar	Sm	0.50	0.67	0.83
	Leaf area	0.33	0.50	0.50
	Leaf N	0.50	0.50	0.67
	Leaf P	0.33	0.50	0.67
	SLA	0.33	0.50	0.50
	Plht	0.33	0.33	0.50
	SSD	0.00	0.17	0.33

Table S3.9 Multiple-comparison adjusted 95% confidence interval (CI) from the trait centrality (i.e. degree) analyses for seven traits of woody species across five climate regions. We ran the trait centrality analyses for the trait of woody species across five climate regions across 1000 trait matrices. Differences in centrality between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	Tropical		Temperate		Arid		Cold		Polar	
Trait-pairs	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%
Leaf area-SLA	-0.33	-0.17	-0.17	0.17	-0.33	0.33	-0.33	0.17	-0.50	0.33
Leaf area-Leaf N	0.00	0.17	0.17	0.33	0.17	0.50	0.00	0.33	-0.17	0.33
Leaf area-Leaf P	-0.17	0.17	0.00	0.33	0.00	0.17	-0.33	0.17	-0.50	0.33
Leaf area-Plht	0.00	0.17	0.00	0.33	0.00	0.50	-0.33	0.17	-0.17	0.50
Leaf area-SSD	-0.17	0.17	-0.17	0.33	-0.17	0.33	-0.17	0.17	-0.17	0.50
Leaf area-Sm	-0.33	-0.17	0.00	0.33	-0.17	0.33	-0.17	0.17	-0.33	0.33
SLA-Leaf N	0.17	0.50	0.17	0.50	0.00	0.67	0.00	0.50	-0.17	0.33
SLA-Leaf P	0.00	0.50	0.00	0.33	-0.17	0.50	-0.17	0.33	-0.33	0.33
SLA-Plht	0.17	0.50	0.00	0.33	0.00	0.50	-0.17	0.17	-0.17	0.50
SLA-SSD	0.17	0.33	0.00	0.33	-0.17	0.33	0.00	0.33	-0.17	0.50
SLA-Sm	-0.17	0.17	0.00	0.33	-0.17	0.33	0.00	0.33	-0.17	0.33
Leaf N-Leaf P	-0.33	0.17	-0.33	0.17	-0.50	0.00	-0.33	0.00	-0.33	0.33
Leaf N-Plht	-0.17	0.17	-0.33	0.17	-0.33	0.17	-0.50	0.00	-0.17	0.33
Leaf N-SSD	-0.17	0.00	-0.33	0.00	-0.50	0.00	-0.33	0.00	-0.17	0.33
Leaf N-Sm	-0.50	-0.17	-0.33	0.00	-0.33	-0.17	-0.33	0.00	-0.33	0.17
Leaf P-Plht	0.00	0.17	-0.17	0.17	-0.17	0.33	-0.33	0.17	-0.33	0.50
Leaf P-SSD	-0.33	0.33	-0.33	0.17	-0.33	0.17	-0.17	0.33	-0.17	0.50
Leaf P-Sm	-0.33	-0.17	-0.17	0.17	-0.33	0.33	-0.17	0.17	-0.33	0.50
Plht-SSD	-0.33	0.17	-0.17	0.17	-0.33	0.17	-0.17	0.50	-0.33	0.50
Plht-Sm	-0.50	-0.17	-0.33	0.17	-0.50	0.17	-0.17	0.33	-0.50	0.17
SSD-Sm	-0.50	0.00	-0.17	0.33	-0.17	0.33	-0.17	0.17	-0.50	0.17

Table S3.10. Multiple-comparison adjusted 95% confidence interval (CI) from the trait centrality (i.e. degree) analyses for seven traits of non-woody species across five climate regions. We ran the trait centrality analyses for the trait of non-woody species across five climate regions across 1000 trait matrices. Differences in centrality between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	Tropical		Temperate		Arid		Cold		Polar	
Trait-pairs	2.5%	99.9%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%
Leaf area-SLA	-0.17	0.50	-0.17	0.33	-0.17	0.33	0.00	0.17	-0.17	0.33
Leaf area-Leaf N	-0.17	0.17	-0.50	0.00	-0.33	0.33	-0.17	0.33	-0.33	0.17
Leaf area-Leaf P	-0.33	0.50	-0.33	0.33	-0.17	0.33	0.00	0.33	-0.17	0.17
Leaf area-Plht	-0.17	0.50	-0.33	0.33	0.00	0.50	0.00	0.67	-0.17	0.33
Leaf area-SSD	0.00	0.50	0.17	0.67	0.17	0.67	0.17	0.67	0.00	0.67
Leaf area-Sm	-0.50	0.50	-0.33	0.17	-0.33	0.50	0.00	0.33	-0.50	0.17
SLA-Leaf N	-0.50	0.17	-0.50	0.00	-0.33	0.50	-0.33	0.33	-0.33	0.17
SLA-Leaf P	-0.50	0.33	-0.33	0.17	-0.17	0.50	-0.17	0.33	-0.33	0.17
SLA-Plht	-0.17	0.33	-0.33	0.00	-0.17	0.67	-0.17	0.50	-0.17	0.33
SLA-SSD	-0.33	0.50	0.17	0.50	0.17	0.50	0.17	0.50	0.00	0.50
SLA-Sm	-0.50	0.17	-0.33	-0.17	-0.33	0.50	-0.17	0.33	-0.50	0.00
Leaf N-Leaf P	-0.33	0.50	-0.17	0.67	-0.17	0.50	-0.17	0.33	-0.17	0.33
Leaf N-Plht	0.00	0.50	-0.17	0.50	-0.17	0.50	0.00	0.50	0.00	0.33
Leaf N-SSD	0.00	0.67	0.33	0.83	0.00	0.50	0.17	0.50	0.00	0.67
Leaf N-Sm	-0.33	0.33	-0.17	0.33	-0.33	0.33	-0.17	0.33	-0.33	0.33
Leaf P-Plht	-0.17	0.50	-0.33	0.33	-0.17	0.33	0.00	0.33	0.00	0.50
Leaf P-SSD	-0.17	0.67	0.00	0.83	0.00	0.50	0.00	0.50	0.17	0.50
Leaf P-Sm	-0.50	0.33	-0.33	0.00	-0.50	0.33	-0.33	0.17	-0.50	0.17
Plht-SSD	-0.33	0.50	0.17	0.67	-0.17	0.50	-0.17	0.50	-0.17	0.50
Plht-Sm	-0.67	0.33	-0.33	0.17	-0.50	0.17	-0.33	0.00	-0.50	0.00
SSD-Sm	-0.67	0.00	-0.83	-0.33	-0.67	0.17	-0.50	0.00	-0.67	-0.17

Appendix S4 Conditional dependency and its determination through the calculation of precision matrix and its confidence interval.

Conditional Independency

Two random variables X and Y are independent if the occurrence of one variable does not affect the probability of the other or formally if their joint distribution equals the product of their probabilities:

$$p(X,Y) = p(X)p(Y)$$

Similarly, we say two random variables X and Y are conditionally independent given a third variable Z if the knowledge of one variable does not provide any information on the likelihood of the other after observing variable Z,or formally if their conditional joint distribution equals the product of their conditional probabilities:

$$p(X,Y \mid Z) = p(X|Z)p(Y|Z)$$

and the conditional mutual information of X and Y given Z, $I(X,Y|Z)$, is zero (i.e. the "amount of information" obtained about X through Y after observing Z is zero):

$$\begin{aligned} I(X,Y \mid Z) &= \int_{z\in Z} p(Z=z) \iint_{x\in X, y\in Y} p(X=x,Y=y) \log \frac{p(X=x,Y=y|Z=z)}{p(X=x|Z=z)p(Y=y|Z=z)} \\ &= \int_{z\in Z} p(Z=z) \iint_{x\in X, y\in Y} p(X=x,Y=y) \log \frac{p(X=x|Z=z)p(Y=y|Z=z)}{p(X=x|Z=z)p(Y=y|Z=z)} \\ &= 0 \end{aligned}$$

Intuitively, if X and Y are conditionally independent given Z, then any relationship that may exist between X and Y can be explained by Z. In other words, X and Y may appear to be correlated if Z is not considered, but if Z is controlled by holding it constant then any relationship between X and Ywould disappear.

Probabilistic Graphical Models

A graph $\mathrm{G} = (\mathrm{V}, \mathrm{E})$ is a data structure consisting of a set of nodes $\mathrm{V} = \{\mathrm{X}_1, \mathrm{X}_2, \dots, \mathrm{X}_\mathrm{p}\}$ and a set of edges E that connect pairs of nodes. A pair of nodes X_i and X_j can be connected by either a directed edge $\mathrm{X}_\mathrm{i} \rightarrow \mathrm{X}_\mathrm{j}$ or an undirected edge $\mathrm{X}_\mathrm{i} - \mathrm{X}_\mathrm{j}$. If all edges of the graph are directed edges, we say that the graph is directed. If all edges of graph are undirected edges, we say that the graph is undirected.

Graphs are an intuitive way of representing and visualizing the relationships between random variables, where nodes correspond to random variables, and edge represents dependency or relationship between variables. For example, correlation graphs (also called correlation networks) represent the pairwise correlation between variables. In a correlation graph, a pair of nodes X_i and X_j are connected if the pairwise correlation of the data associated with X_i and X_j is beyond a threshold.

Probabilistic graphical models (PGMs) use a graph-based representation as the basis for encoding a complex distribution over a high-dimensional space. In this representation, the edges correspond to direct probabilistic interactions between nodes. The graph is a compact representation of a set of conditional independencies that hold in the distribution. In particular, if there is no edge between two nodes X_i and X_j, then the random variable X_i is conditionally independent of the random variable X_j given all other variables. Two approaches for graphically representing the distributions are commonly used: (i) *Bayesian networks* that uses a directed graph (where the edges have a source and a target) and (ii) *Markov networks* which uses an undirected graph representation.

Precision Matrix

One special example of PGMs is Gaussian graphical models which gives an efficient and compact representation for Gaussian multivariate data. In particular, let $\mathbf{X} = \{X_1, X_2, \dots, X_p\}$ be a set of random variables with a multivariate Gaussian design ensemble (i.e., $\mathbf{X} \sim \mathcal{N}(0, \Sigma)$; for simplicity and without loss of generality, here we assume that the mean of $\boldsymbol{X}$ is zero). The precision matrix (the inverse of covariance matrix; $\Omega = \Sigma^{-1}$) reveals the statistical conditional independence structure among features i.e., if $\Omega_{ij} = 0$, then feature X_i is conditionally independent of X_j given all other variables and there is no edge in the undirected graph structure associated with X (Figure 1).

To illustrate the relationship between the precision matrix and the graph structure, we consider the probabilistic graphical models as a skeleton for compactly representing a high-dimensional distribution P. We "break" the distribution into smaller factors, each over a much smaller space of possibilities. Then, we can define the overall joint distribution as a product of these factors. The graph structure defines the factorization of a distribution P associated with it — the set of factors and the variables that they encompass.

In the Gaussian graphical models, the set of factors can be represented in terms of elements of the precision matrix Ω. Mainly, the density function of $\boldsymbol{X}$, is written as

$$
\begin{aligned}
f(\boldsymbol{X}) &= \frac{1}{\sqrt{(2\pi)^p\,|\Sigma|}}\,\exp\left\{-\frac{1}{2}\boldsymbol{X}^T\Sigma^{-1}\boldsymbol{X}\right\} \\
&= \frac{1}{\sqrt{(2\pi)^p\,|\Sigma|}}\exp\left\{-\frac{1}{2}\boldsymbol{X}^T\Omega\boldsymbol{X}\right\} \\
&= \frac{1}{\sqrt{(2\pi)^p\,|\Sigma|}}\exp\left\{-\frac{1}{2}\sum_{i,j=1}^{p} X_iX_j\Omega_{ij}\right\} \\
&= \frac{1}{\sqrt{(2\pi)^p\,|\Sigma|}}\prod_{i,j=1}^{p}\exp\left\{-\frac{1}{2}\,X_iX_j\Omega_{ij}\right\} \\
&= \frac{1}{\sqrt{(2\pi)^p\,|\Sigma|}}\prod_{i=1}^{p}\psi_i(X_i)\prod_{(i,j)\in E}\psi_{ij}(X_i,X_j)
\end{aligned}
$$

where $|\Sigma|$ is determinant of Σ, the second equality uses the fact that $\Omega = \Sigma^{-1}$, and the third equality is the expansion of matrix multiplication, $\psi_i(X_i) = \exp\left\{-\frac{1}{2}\,X_i^2\Omega_{ii}\right\}$ can be viewed as the node potential and $\psi_{ij}(X_i, X_j) = \exp\left\{-\frac{1}{2}\,X_iX_j\Omega_{ij}\right\}$ can be viewed as the edge potential. As shown in the above equation, the density function of $\boldsymbol{X}$ is factorized to a set factors written as $\exp\left\{-\frac{1}{2}\,X_iX_j\Omega_{ij}\right\}$. If $\Omega_{ij} = 0$, then the factor $\exp\left\{-\frac{1}{2}\,X_iX_j\Omega_{ij}\right\} = 1$ with no effect in the density of $\boldsymbol{X}$. In other words, if the edge potential $f_{ij}(X_i, X_j) = 0$, and there is no edge between nodes X_i and X_j in the graph structure, then we say that the feature X_i is conditionally independent of X_j given all other variables.

Interestingly, the elements of a precision matrix are related to the partial correlation. In particular, the partial correlation coefficient between variables X_i and X_j measures their conditional correlation after removing the effect of the variables $X_{-ij} = X - \{X_i, X_j\}$. The partial correlation values can be calculated by normalizing the off-diagonal entries of the precision matrix (Lauritzen 1996) as

$$r_{ij} = \frac{cov(X_i, X_j | X_{-ij})}{\sqrt{var(X_i | X_{-ij}) var(X_j | X_{-ij})}} = -\frac{\Omega_{ij}}{\sqrt{\Omega_{ii}\Omega_{jj}}}$$

Why are we not using sample covariance matrix and instead using Precision matrix?

Consider an independent and identically distributed random sample $\{\mathbf{X}_1, \mathbf{X}_2, \dots, \mathbf{X}_n\}$ from the distribution of $\boldsymbol{X}$. In the classical situation where number samples $n \to \infty$, the sample covariance matrix $\hat{\Sigma}_n = \sum_{i=1}^{n} \boldsymbol{X}_i \boldsymbol{X}_i^T$ is a consistent and well behaved estimator of $\Sigma = E[\boldsymbol{X}_i \boldsymbol{X}_i^T]$ and $\hat{\Omega}_n = \hat{\Sigma}_n^{-1}$ is a natural and good estimator of Ω. However, if the number of samples is not sufficient, then $\hat{\Sigma}_n$ is no longer a consistent estimate of Σ and in some cases (e.g., $p > n$), $\hat{\Sigma}_n$ is not invertible, thus $\hat{\Omega}_n$is not well-defined. Unlike the covariance matrix, the precision matrix is usually sparse (it contains many zero values). This characterization yields to several efficient and consistent algorithms for estimating Ω. Thus, in this paper, we focus on estimating Ω directly.

Difference between Correlation and Dependency Graphs

Correlation graphs capture the similarity between variables. Two variables are similar if their pairwise correlation exceeds a threshold. However, the similarity between two variables may come from a third source (e.g., another variable). Thus, the correlation graph captures indirect similarities. The covariance matrix essentially indicates the correlation between variables; if an element in the covariance matrix is zero, that means that two variables are not correlated or marginally independent without observing other variables. However, this kind of independency is rarely expected to happen in real world applications, because it reveals that two random variables have no active relationship even without observing other nodes.

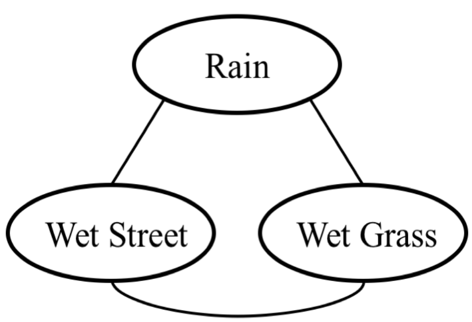
Precision matrices are related to the partial correlations, as they can calculate the correlation between two variables after removing the effect of other variables. Thus, the precision matrix provides information about the direct similarity between two variables. In particular, two variables that are connected in correlation graphs, may or may not be connected in a precision graph and vice versa. Below, we provide some examples to illustrate the difference between correlation graph and precision graph.

a. Example 1

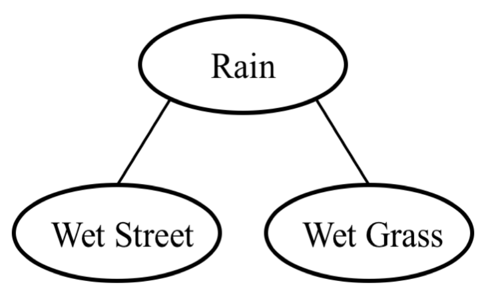
Consider three binary variables:

- Rain? (yes/no) i.e., set to yes if it was rainy today.
- Wet Grass? (yes/no) i.e., set to yes if it the grass is wet.
- Wet Street? (yes/no) i.e., set to yes if it the street is wet.

When it is raining there is a high chance that both the grass and the street get wet, yielding a high correlation between Rain-Wet Street, and Rain-Wet Grass. At the same time, if we calculate the correlation between Wet Grass -Wet Street, they will likely be highly correlated, however, neither Wet grass, nor Wet street is causing the occurrence of the other variable (Figure 1 a). Rain is the main reason that Wet Street and Wet Grass are correlated, and if we remove the effect of Rain from both variables, they will no longer be correlated. As a result, Wet Street and Wet Grass are not connected in the dependency graph i.e., they are conditionally independent given Rain (Figure 1 b).



a. Correlation Graph



b. Dependency Graph

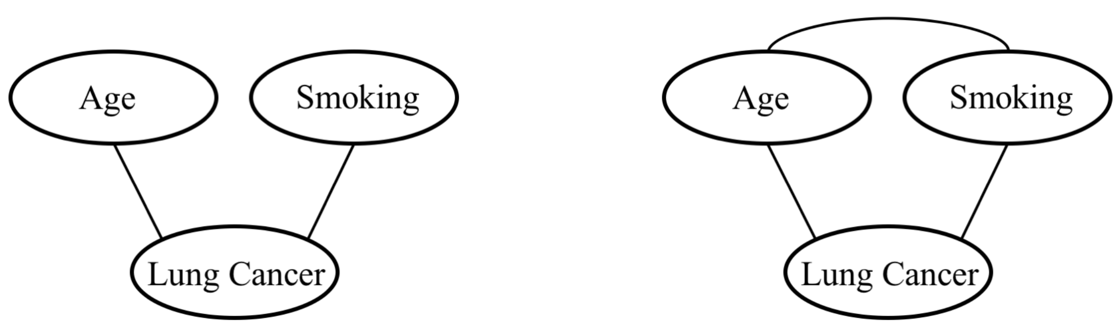
Figure 1. Rain Example. Wet Street and Wet Grass are connected in the correlation graph (highly correlated) but are independent given Rain in the dependency graph.

b. Example 2

Consider three variables:

- Lung Cancer? (yes/no) i.e., set to yes if the person has lung cancer.
- Age i.e., indicates the age of a person.
- Smoking? (yes/no) i.e., set to yes if it the person is smoking.

Whether a person gets lung cancer depends on several factors such as age and whether the person is smoking or not. As a result, in the correlation graph there is an edge between Lung Cancer-Age and Lung Cancer-Smoking. However, for the population considered in this example, Age and Smoking are not correlated i.e., the age of a person does not significantly impact whether he/she is smoking (Figure 2a). On the other hand, if a person with lung cancer diagnosis is young, this raises the chances that the person is smoking, as lung cancer patients often have at least one of the two major risk factors, increased age or are smokers. As a result, there is an edge between Age-Smoking in the dependency graph (Figure 2b).



a. Correlation Graph

b. Dependency Graph

Figure 2. Lung Cancer Example. Age and Smoking are not connected in the correlation graph (not correlated) but are dependent given Lung Cancer in the dependency graph.

Analysis

We estimated the precision matrix for each plant group (see methods section) separately. To estimate the precision matrix the glasso algorithm assumes a multi-variate Gaussian distribution and estimates the precision matrix by minimizing the negative log-likelihood among all measurements (in this case traits).

The log-likelihood of a Gaussian multivariate distribution is:

$$\begin{aligned}\log f(x) &= \log \left(\frac{1}{\sqrt{(2\pi)^p\,|\Sigma|}} \exp\left\{-\frac{1}{2}\boldsymbol{X}^T \Omega \boldsymbol{X}\right\}\right) \\ &= -\log\left(\sqrt{(2\pi)^p}\right) - \frac{1}{2}\log|\Sigma| - \frac{1}{2}Tr(\boldsymbol{X}^T\boldsymbol{X}\Omega) \\ &= -\log\left(\sqrt{(2\pi)^p}\right) + \frac{1}{2}\log|\Omega| - \frac{1}{2}Tr(\hat{\Sigma}\Omega)\end{aligned}$$

where the last equality is from the determinant property: $|\Sigma| = \frac{1}{|\Sigma^{-1}|} = \frac{1}{|\Omega|}$. Thus, ignoring the constants, glasso finds the precision matrix Ω, by solving the following optimization problem:

$$\arg\min_{\Omega} - \log|\Omega| + Tr\left(\hat{\Sigma}\Omega\right) + \lambda \parallel \Omega \parallel_1$$

where $\parallel \Omega \parallel_1$ is the L_1 norm of Ω.

Selecting penalty parameter λ

Since the precision matrix is usually sparse (i.e. most of the precision matrix elements are zero), glasso adds a penalty term (L_1norm) to the objective function which encourages to have a sparse precision matrix. The glasso algorithm includes a penalty parameter λ, which controls the sparsity level of the precision matrix. If $\lambda = 0$, then all of the elements of the precision matrix are non-zero. In contrast, with a very large value of λ, all the elements become zero. Following Jankova and van de Geer (2015), we accounted for differences in sample size across precision matrices and their effect on λ as follows: λ = 2 √(log *p*/ *n*), where *n* refers to the sample size and *p* denotes the number of variables, in this case traits (Appendix S4).

Significance of trait-trait connections in the trait network

Given a data sample matrix $X \in \Re^{n\times p}$ and estimated precision matrix $\Omega \in \Re^{p\times p}$, the test statistic is defined as $T = \Omega + \lambda\Omega Z\Omega$ where $Z \in \Re^{p\times p}$ is the sub-gradient of norm $\parallel \Omega \parallel_1$, and its variance $\sigma_{ij}^2 = \Omega_{ii}\Omega_{jj} + \Omega_{ij}^2$. Then under this scenario, thresholding T_{ij} at level $\Phi^{-1}(1 - \frac{\alpha}{p(p-1)})\frac{\hat{\sigma}_{ij}}{\sqrt{n}}$ for all i, j will remove all zero entries (i.e., non-significant trait-trait interactions) with probability $1 - \alpha$ asymptotically (Jankova & van de Geer, 2015).

Specifically, considering the data for a particular group represented in a matrix $X \in \Re^{n \times p}$ which contains the trait information for p traits. First, we fix λ at a particular value and estimate the precision matrix $\Omega \in \Re^{p \times p}$ by running glasso. Next, we estimate the $(1-\alpha)\%$ asymptotic confidence interval of all the obtained edges as

$$I_{ij} = \left[T_{ij} - \Phi^{-1}\left(1 - \frac{\alpha}{p(p-1)}\right)\frac{\hat{\sigma}_{ij}}{\sqrt{n}},\ T_{ij} + \Phi^{-1}(1 - \frac{\alpha}{p(p-1)})\frac{\hat{\sigma}_{ij}}{\sqrt{n}}\right]$$

References

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Appendix S5. Analysis of trait network across plant growth forms and climate regions.

Table S5.1. Trait centrality (i.e. Degree) for all plants, woody, and non-woody species and 95% confidence interval (CI). We ran this analysis for each network of all plants, woody and non-woody species for 1000 bootstrapped trait matrices.

Life form	Trait	2.50%	50%	97.50%
All	LLS	1	1	1
	SSD	1	1	1
	SLA	0.86	1	1
	Seed mass	0.86	0.86	0.86
	Plant height	0.71	0.86	0.86
	Leaf area	0.71	0.71	0.86
	Leaf p	0.71	0.71	0.86
	Leaf n	0.71	0.71	0.71
Non-woody	Leaf n	0.71	0.71	0.86
	Leaf area	0.57	0.71	0.86
	Leaf p	0.57	0.71	0.86
	LLS	0.57	0.71	0.86
	Plant height	0.57	0.57	0.86
	Seed mass	0.57	0.57	0.86
	SLA	0.43	0.57	0.57
	SSD	0.29	0.29	0.43
Woody	LLS	0.86	0.86	1
	Leaf area	0.86	0.86	0.86
	Seed mass	0.71	0.86	0.86
	Leaf n	0.71	0.71	0.71
	Leaf p	0.71	0.71	0.71
	SLA	0.57	0.71	0.71
	Plant height	0.57	0.57	0.57
	SSD	0.43	0.43	0.57

Table S5.2. Multiple-comparison adjusted 95% confidence interval (CI) from the trait centrality (i.e. degree) analyses for eight traits. We ran the trait centrality analyses for the trait of all plant species, woody and non-woody species across 1000 trait matrices. Differences in centrality between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	All		Woody		Non-woody	
Trait-pairs	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%
Leaf area-SLA	-0.29	0	0	0.29	-0.14	0.29
Leaf area-Leaf n	0	0.14	0	0.29	-0.29	0.14
Leaf area-LLS	-0.29	-0.14	-0.14	0	-0.29	0.29
Leaf area-Leaf p	-0.14	0	0.14	0.14	-0.29	0.29
Leaf area-Plant height	-0.14	0.14	0.14	0.43	-0.29	0.29
Leaf area-SSD	-0.29	-0.14	0.14	0.43	0.29	0.43
Leaf area-Seed mass	-0.29	0	0	0.14	-0.29	0.29
SLA-Leaf n	0.14	0.29	-0.29	0.14	-0.43	0
SLA-LLS	-0.14	0	-0.43	0	-0.43	0.14
SLA-Leaf p	0	0.29	-0.14	0.14	-0.43	0.14
SLA-Plant height	0.14	0.14	0	0.29	-0.29	0.14
SLA-SSD	-0.14	0	-0.14	0.43	0	0.43
SLA-Seed mass	0	0.14	-0.14	0	-0.29	0.14
Leaf n-LLS	-0.29	-0.29	-0.29	0	-0.14	0.29
Leaf n-Leaf p	-0.29	0	-0.14	0.14	-0.14	0.29
Leaf n-Plant height	-0.14	0	0	0.29	0	0.14
Leaf n-SSD	-0.29	-0.29	0	0.29	0.29	0.57
Leaf n-Seed mass	-0.29	-0.14	-0.29	0.14	-0.14	0.29
LLS-Leaf p	0	0.29	0.14	0.29	-0.14	0.29
LLS-Plant height	0.14	0.29	0.14	0.57	-0.14	0.29
LLS-SSD	0	0	0.14	0.43	0.14	0.71
LLS-Seed mass	0	0.14	0	0.29	-0.14	0.29
Leaf p-Plant height	-0.14	0.14	0	0.29	-0.14	0.29
Leaf p-SSD	-0.29	0	0	0.29	0.14	0.57
Leaf p-Seed mass	-0.14	0	-0.14	0	-0.14	0.14
Plant height-SSD	-0.29	-0.14	-0.14	0.29	0.14	0.57
Plant height-Seed mass	-0.14	0	-0.43	0	-0.29	0.29
SSD-Seed mass	0	0.14	-0.43	0	-0.57	-0.14

Table S5.3. Edge density for woody and non-woody species and 95% confidence interval (CI). We ran this analysis for each network of woody and non-woody species across climate regions for 1000 bootstrapped trait matrices.

Life form	**Climate**	**2.50%**	**50%**	**97.50%**
Woody	Tropical	0.61	0.64	0.68
	Temperate	0.61	0.68	0.71
	Arid	0.61	0.64	0.68
	Cold	0.53	0.57	0.64
	Polar	0.29	0.39	0.46
Non-woody	Tropical	0.29	0.36	0.46
	Temperate	0.5	0.57	0.64
	Arid	0.39	0.46	0.57
	Cold	0.57	0.61	0.68
	Polar	0.36	0.43	0.5

Table S5.4. Multiple-comparison adjusted 95% confidence interval (CI) from the edge density analyses among climate regions for woody and non-woody species. We ran the edge density comparison for woody and non-woody species across five climate regions for 1000 trait matrices. Differences in edge density between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	Woody		Non-woody	
Regions-pairs	2.5%	97.5%	2.5%	97.5%
Arid-Cold	-0.04	0.18	-0.29	0.04
Arid-Polar	0.14	0.39	-0.11	0.21
Arid-Temperate	-0.11	0.07	-0.29	0.07
Arid-Tropical	-0.07	0.11	-0.07	0.29
Cold-Polar	0.04	0.36	0.07	0.32
Cold-Temperate	-0.21	0.04	-0.11	0.18
Cold-Tropical	-0.18	0.07	0.07	0.39
Polar-Temperate	-0.43	-0.14	-0.29	0.04
Polar-Tropical	-0.39	-0.11	-0.14	0.21
Temperate-Tropical	-0.07	0.14	0.04	0.39

Table S5.5. Modularity for woody and non-woody species and 95% confidence interval (CI). We ran this analysis for each network of woody and non-woody species across climate regions for 1000 bootstrapped trait matrices.

Life form	Climate	2.5%	50%	97.5%
Woody	Tropical	0.05	0.08	0.11
	Temperate	0.05	0.08	0.11
	Arid	0.08	0.11	0.15
	Cold	0.10	0.14	0.19
	Polar	0.16	0.25	0.39
Non-woody	Tropical	0.12	0.22	0.34
	Temperate	0.07	0.12	0.19
	Arid	0.09	0.19	0.28
	Cold	0.04	0.09	0.13
	Polar	0.13	0.21	0.34

Table S5.6. Multiple-comparison adjusted 95% confidence interval (CI) from the modularity analyses among climate regions for woody and non-woody species. We ran the modularity comparison for woody and non-woody species across five climate regions for 1000 trait matrices. Differences in modularity between regions is significant when the 95% CI for the differences between regions pairs does not overlap with zero.

	Woody		Non-woody	
Regions-pairs	2.5%	97.5%	2.5%	97.5%
Arid-Cold	-0.14	0.06	-0.04	0.25
Arid-Polar	-0.32	0.01	-0.25	0.17
Arid-Temperate	-0.07	0.11	-0.08	0.25
Arid-Tropical	-0.05	0.09	-0.21	0.16
Cold-Polar	-0.29	0.03	-0.33	0.03
Cold-Temperate	-0.02	0.17	-0.14	0.07
Cold-Tropical	-0.02	0.15	-0.3	0.02
Polar-Temperate	0.03	0.34	-0.06	0.32
Polar-Tropical	0.04	0.32	-0.2	0.22
Temperate-Tropical	-0.08	0.07	-0.28	0.07

Table S5.7. Trait centrality (i.e. Degree) for woody species across five climate regions and 95% confidence interval (CI). We ran this analysis over 1000 bootstrapped trait matrices.

Climate	Trait	2.5%	50%	97.5%
Tropical	Sm	0.86	0.86	0.86
	Leaf area	0.57	0.71	0.71
	LLS	0.57	0.71	0.86
	SLA	0.71	0.71	0.86
	Leaf N	0.57	0.57	0.71
	Leaf P	0.57	0.57	0.57
	Plht	0.57	0.57	0.71
	SSD	0.43	0.43	0.57
Temperate	LLS	0.71	0.86	1.00
	Leaf area	0.71	0.71	0.86
	Leaf P	0.43	0.71	0.86
	SLA	0.57	0.71	0.71
	Sm	0.71	0.71	0.71
	Leaf N	0.57	0.57	0.71
	Plht	0.43	0.57	0.71
	SSD	0.43	0.57	0.71
Arid	LLS	0.71	0.86	0.86
	Leaf area	0.71	0.71	0.86
	SLA	0.57	0.71	0.71
	Sm	0.57	0.71	0.71
	Leaf N	0.43	0.57	0.57
	Leaf P	0.43	0.57	0.71
	SSD	0.43	0.57	0.71
	Plht	0.43	0.43	0.57
Cold	LLS	0.57	0.71	1.00
	Plht	0.57	0.71	0.86
	Leaf area	0.57	0.57	0.57
	Leaf P	0.43	0.57	0.71
	SLA	0.57	0.57	0.71
	Sm	0.43	0.57	0.57
	Leaf N	0.43	0.43	0.57
	SSD	0.29	0.43	0.57
Polar	Leaf area	0.29	0.43	0.57
	Leaf N	0.29	0.43	0.43
	Leaf P	0.14	0.43	0.57
	LLS	0.29	0.43	0.57
	SLA	0.43	0.43	0.57
	Sm	0.29	0.43	0.43
	Plht	0.14	0.29	0.43
	SSD	0.14	0.29	0.29

Table S5.8. Trait centrality (i.e. Degree) for non-woody species across five climate regions and 95% confidence interval (CI). We ran this analysis over 1000 bootstrapped trait matrices.

Climate	Trait	2.5%	50%	97.5%
Tropical	Leaf area	0.29	0.43	0.57
	Leaf N	0.43	0.43	0.71
	LLS	0.14	0.43	0.57
	Sm	0.29	0.43	0.71
	Leaf P	0.14	0.29	0.71
	Plht	0.29	0.29	0.57
	SLA	0.14	0.29	0.57
	SSD	0.00	0.14	0.43
Temperate	Leaf N	0.57	0.71	0.86
	LLS	0.57	0.71	0.86
	Sm	0.57	0.71	0.86
	Leaf area	0.43	0.57	0.57
	Leaf P	0.43	0.57	0.86
	Plht	0.43	0.57	0.71
	SLA	0.43	0.43	0.43
	SSD	0.14	0.29	0.43
Arid	Leaf area	0.43	0.57	0.71
	Leaf N	0.43	0.57	0.86
	LLS	0.43	0.57	0.71
	SLA	0.29	0.57	0.71
	Sm	0.29	0.43	0.71
	Leaf P	0.29	0.29	0.57
	Plht	0.14	0.29	0.57
	SSD	0.29	0.29	0.43
Cold	Leaf area	0.71	0.86	0.86
	Leaf N	0.71	0.71	0.86
	LLS	0.57	0.71	0.86
	Sm	0.57	0.71	0.71
	Leaf P	0.43	0.57	0.71
	SLA	0.43	0.57	0.71
	Plht	0.29	0.43	0.57
	SSD	0.29	0.43	0.57
Polar	Leaf N	0.57	0.57	0.71
	Sm	0.43	0.57	0.71
	Leaf area	0.29	0.43	0.43
	Leaf P	0.29	0.43	0.57
	LLS	0.29	0.43	0.57
	Plht	0.29	0.43	0.57
	SLA	0.29	0.43	0.57
	SSD	0.00	0.14	0.43

Table S5.9. Multiple-comparison adjusted 95% confidence interval (CI) from the trait centrality (i.e. degree) analyses for eight traits of woody species across five climate regions. We ran the trait centrality analyses for the trait of woody species across five climate regions across 1000 trait matrices. Differences in centrality between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	Tropical		Temperate		Arid		Cold		Polar	
Trait-pairs	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%
Leaf area-SLA	-0.29	0.14	-0.14	0.29	-0.14	0.29	-0.14	0.14	-0.43	0.43
Leaf area-Leaf N	-0.14	0.14	0	0.29	0	0.43	0	0.14	-0.29	0.43
Leaf area-LLS	-0.14	0.14	-0.29	0.14	-0.29	0.14	-0.43	0	-0.29	0.29
Leaf area-Leaf P	-0.14	0.14	0	0.29	0	0.29	-0.14	0.29	-0.29	0.57
Leaf area-Plht	-0.14	0.29	0	0.43	0.14	0.43	-0.3	0.14	-0.14	0.43
Leaf area-SSD	-0.14	0.29	0	0.43	-0.01	0.43	0	0.29	-0.14	0.57
Leaf area-Sm	-0.43	-0.14	0	0.14	-0.14	0.29	-0.14	0.14	-0.29	0.43
SLA-Leaf N	0	0.43	-0.14	0.29	-0.01	0.29	0	0.29	-0.14	0.43
SLA-LLS	-0.14	0.29	-0.43	0	-0.29	0	-0.43	0.14	-0.29	0.43
SLA-Leaf P	0	0.43	-0.29	0.29	-0.14	0.29	-0.16	0.43	-0.29	0.43
SLA-Plht	0	0.43	-0.14	0.29	0	0.29	-0.29	0.14	-0.14	0.57
SLA-SSD	0	0.43	0	0.29	0	0.29	0	0.43	0	0.57
SLA-Sm	-0.29	0.14	-0.14	0.14	-0.14	0.14	-0.14	0.29	-0.29	0.43
Leaf N-LLS	-0.29	0.14	-0.43	0	-0.43	-0.14	-0.57	0	-0.29	0.29
Leaf N-Leaf P	-0.14	0.14	-0.29	0.29	-0.29	0.14	-0.29	0.14	-0.43	0.29
Leaf N-Plht	-0.14	0.14	-0.14	0.29	-0.14	0.14	-0.43	0	-0.14	0.43
Leaf N-SSD	0	0.29	-0.14	0.29	-0.29	0.29	-0.14	0.14	-0.14	0.43
Leaf N-Sm	-0.43	-0.14	-0.14	0.14	-0.14	0	-0.29	0.14	-0.29	0.29
LLS-Leaf P	-0.14	0.29	0	0.43	0.13	0.43	0	0.57	-0.29	0.43
LLS-Plht	0.14	0.57	-0.29	0.43	-0.29	0.43	0	0.57	-0.14	0.29
LLS-SSD	0	0.43	0.14	0.57	-0.14	0.57	0.14	0.43	-0.14	0.43
LLS-Sm	0	0.3	0	0.43	-0.29	0.43	0	0.29	-0.43	0
Leaf P-Plht	0	0.29	-0.43	0.01	-0.29	0.43	-0.14	0.29	-0.14	0.14
Leaf P-SSD	-0.16	0.29	-0.14	0.3	-0.14	0.43	-0.29	0.43	-0.14	0.29
Leaf P-Sm	-0.29	0.14	-0.29	0.29	-0.29	0.43	-0.29	0.14	-0.29	-0.14
Plht-SSD	-0.16	0.14	0	0.57	-0.14	0.43	-0.29	0.29	-0.14	0.29
Plht-Sm	-0.29	0	-0.14	0.43	-0.43	0.29	-0.29	0.14	-0.43	-0.14
SSD-Sm	-0.29	0.14	-0.29	0.14	-0.43	0.14	-0.29	0.14	-0.57	-0.14

Table S5.10. Multiple-comparison adjusted 95% confidence interval (CI) from the trait centrality (i.e. degree) analyses for eight traits of non-woody species across five climate regions. We ran the trait centrality analyses for the trait of non-woody species across five climate regions across 1000 trait matrices. Differences in centrality between trait pairs significant when the 95% CI for the differences between trait pairs does not overlap with zero.

	Tropical		Temperate		Arid		Cold		Polar	
Trait-pairs	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%	2.5%	97.5%
Leaf area-SLA	-0.29	0.57	-0.14	0.29	-0.14	0.29	0	0.29	-0.29	0.29
Leaf area-Leaf N	-0.29	0.14	-0.43	0.14	-0.43	0.29	-0.14	0.29	-0.43	0
Leaf area-LLS	-0.29	0.43	-0.43	0.14	-0.29	0.29	-0.29	0.43	-0.29	0.29
Leaf area-Leaf P	-0.43	0.57	-0.29	0.29	-0.14	0.43	0	0.43	-0.29	0.14
Leaf area-Plht	-0.29	0.43	-0.29	0.29	0	0.57	0.14	0.71	-0.29	0.29
Leaf area-SSD	-0.14	0.57	0	0.57	0	0.57	0.14	0.57	-0.14	0.43
Leaf area-Sm	-0.43	0.43	-0.43	0.14	-0.29	0.57	-0.14	0.43	-0.43	0.14
SLA-Leaf N	-0.57	0.29	-0.57	0	-0.43	0.29	-0.43	0.14	-0.43	0.14
SLA-LLS	-0.29	0.43	-0.43	0	-0.43	0.29	-0.43	0.14	-0.29	0.29
SLA-Leaf P	-0.43	0.43	-0.43	0.14	-0.29	0.57	-0.29	0.29	-0.43	0.29
SLA-Plht	-0.29	0.29	-0.43	0	-0.14	0.57	-0.14	0.43	-0.29	0.29
SLA-SSD	-0.29	0.71	-0.14	0.57	-0.14	0.43	0	0.43	-0.14	0.57
SLA-Sm	-0.43	0.29	-0.43	0	-0.29	0.43	-0.29	0.14	-0.43	0.14
Leaf N-LLS	-0.14	0.43	-0.29	0.29	-0.29	0.43	-0.29	0.29	0	0.57
Leaf N-Leaf P	-0.43	0.57	-0.29	0.57	-0.14	0.57	0	0.43	0	0.43
Leaf N-Plht	-0.14	0.43	-0.14	0.43	-0.14	0.57	0.14	0.57	0	0.43
Leaf N-SSD	-0.14	0.57	0.14	0.71	0.14	0.43	0.14	0.57	0	0.71
Leaf N-Sm	-0.29	0.43	-0.29	0.29	-0.14	0.57	-0.14	0.29	-0.14	0.43
LLS-Leaf P	-0.43	0.29	-0.29	0.43	-0.14	0.57	-0.14	0.29	-0.43	0.29
LLS-Plht	-0.29	0.29	-0.29	0.43	-0.14	0.57	0	0.57	-0.29	0.14
LLS-SSD	-0.29	0.43	0.14	0.71	-0.14	0.57	0	0.57	-0.14	0.43
LLS-Sm	-0.57	0.29	-0.29	0.29	-0.29	0.57	-0.14	0.29	-0.43	0.14
Leaf P-Plht	-0.29	0.43	-0.29	0.29	-0.29	0.43	-0.14	0.43	-0.29	0.43
Leaf P-SSD	-0.29	0.57	-0.14	0.86	-0.14	0.43	-0.14	0.29	-0.14	0.43
Leaf P-Sm	-0.43	0.43	-0.43	0.14	-0.43	0.43	-0.29	0.14	-0.43	0.43
Plht-SSD	-0.14	0.57	0	0.57	-0.29	0.29	-0.29	0.29	-0.14	0.57
Plht-Sm	-0.43	0.29	-0.43	0.29	-0.43	0.29	-0.43	0	-0.43	0.14
SSD-Sm	-0.57	0.14	-0.86	-0.14	-0.43	0.29	-0.43	0	-0.57	0