Functional composition of the Amazonian tree flora and forests – supplementary data

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Supplementary Box 1 – traits used

1 Wood density (oven dry mass over green volume: g/cm^3) has been considered a **key functional trait in tree ecology**[1]. Wood density represents the investment in stem tissue and is related to a number of characteristics ref[2] and many references therein: 1) capacitance - lighter wood having a higher potential of storing water; 2) strength - heavier wood being stronger; 3) defence - heavier wood being better defended against structural and biotic damage; 4) growth - species with light wood invest less in structural material and show faster volumetric growth, but live shorter[3]. Heavy wood also has a disadvantage, trees cannot become too large, as they may buckle under their own weight: "*fat stems of low-density wood are much better able to resist buckling than thin stems of high-density wood*"[4] and are able to do this at less carbon per unit stem length[5]. Thus, many emergent trees have relatively light wood (e.g., *Ceiba, Parkia, Swietenia*) but interestingly some of the trees with very heavy wood are among the highest trees in Amazonia (*Dinizia excelsa*[6]).

It has long been thought that lighter wood results mainly from larger vessels, leading to better conductance. Recent studies indeed showed that WD is negatively correlated with hydraulic conductivity[7] and parameters of capacitance, conductivity per unit leaf area[8]. Higher hydraulic conductivity is associated with faster growth but lower drought resistance (**trade-off hydraulic efficiency and safety**[7]). Wood density is a good predictor for maximum growth rate of trees[9-11]. High wood density has been associated with low mortality and recruitment of trees in forest plots[2,12-14] and Amazonian forest plots with high average wood density tend to have slow turn-over (the average of recruitment and mortality) and low wood productivity[15]. Wood density is also part of the **stature–recruitment trade-off** (see seed mass below).

2 Specific Leaf Area (SLA: mm^2/mg), the inverse of Leaf Mass per Area (LMA), is arguably the **key characteristic of the leaf economic spectrum**[16-19]**.** SLA represents the investment in the area of leaf tissue and is positively related to: to: 1) max photosynthesis[17], and 2) herbivory and negatively related to 3) leaf longevity.

3 Leaf carbon content (C: mg/g) content of leaves is also a part of the **leaf economic spectrum**[16] and influences leaf growth (negatively) and leaf longevity (positively). Being related to toughness it is part of the **defence strategy** for leaves and should negatively influence herbivory[20].

4,5 Leaf nitrogen and phosphorus content (N, P: mg/g) are generally strongly positively correlated with SLA, and thus part of the **leaf economic spectrum**. Both are positively correlated to maximum photosynthesis and palatability[17]. "*Leaf nitrogen (N) is integral to the proteins of photosynthetic machinery, especially Rubisco*" and "*Leaf phosphorus (P) is found in nucleic acids, lipid membranes and bioenergetic molecules such as ATP*"[16]. Nitrogen in leaves is used for structural proteins, for photosynthetic proteins but can also be used for defence, in which case the relationship with photosynthesis may be blurred[18].

6 C:N ratio, the ratio between structural, non-nutritious leaf material and protein content is considered an important trait for **defence against herbivory**[21,22]. A high C:N ratio implies that the amount of structural material (defence) is high compared to the nitrogen return. Herbivores should favour leaves with a low C:N ratio. While this is true for generalist herbivores, specialized plant–herbivore relationships may weaken such generality[22].

7 Breeding systems. There are three major angiosperm sexual systems: hermaphroditism, where all flowers on all individuals are bisexual, that is bearing both pollen and ovules; dioecy where the flowers are unisexual, and individuals either bear pollen or ovules; and monoecy where unisexual flowers of both types are borne on the same individual. There are numerous variations on the basic sexual systems in many dioecious or monoecious species (for instance, gynodioecy and andromonoecy) but these function in a similar fashion. Sexual system is often consistent across a genus or family and in trees is closely related to flower type, and pollen and fruit dispersal mode[23]. The most important distinction is between dioecy and other systems, as **dioecious populations usually have fewer fruit-bearing individuals** than comparable hermaphroditic or monoecious populations, and a **sparser spatial distribution of potential breeding partners**. Perhaps to compensate for these disadvantages, **dioecious species commonly exhibit a number of floral and fruit traits which may increase their ecological success**[24] and key among these is that they mainly bear animal-dispersed fleshy fruit which promotes a wider dispersal range.

Box S1 – traits used - continued.

8 Nectar production. Roughly 66% of all angiosperms are animal pollinated and three quarters of those produce nectar[25]. There is a strong gradient in the percentage of nectar producing, animal pollinated, plants from the arctic (95.5%) towards the tropics (77.6%). At the same time the diversity of floral resources (e.g oils, pollen, pheromones) increases[25]. On infertile soils, under conditions of high solar energy and abundant moisture but **low soil nutrients**, production of carbohydrate-rich exudates is favoured over other pollination rewards[26]. Flowers producing abundant nectar also tend to be large[27] and large flowers, being only rarely unisexual, are associated with hermaphroditic breeding systems. In contrast, wind-pollinated species produce large amounts of nitrogen-rich pollen[28], no nectar, and have mainly unisexual flowers.

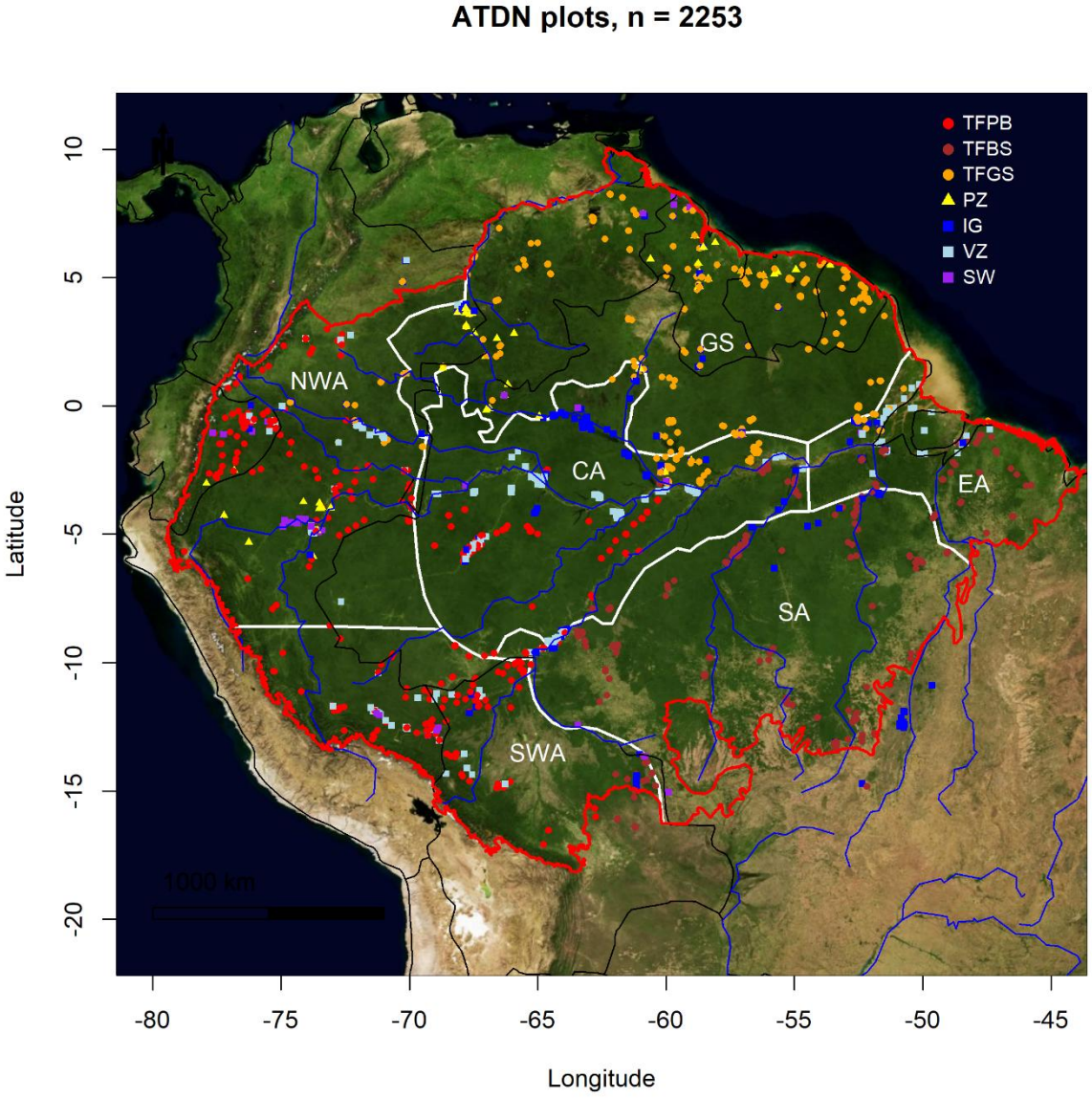
9 Fruit type, fleshiness of fruits has consequences for the type of dispersers and may thus influence dispersal[29]. **Fleshiness should be considered an investment** in dispersal[30] and in western Amazonia fleshy fruits are related to productive soils[31]. Alternatively, species can produce dry fruits with small seeds (e.g capsules) or large seeds (e.g nuts, pods).

10 Seed mass (here we use seed mass class[32,33]) is related to: 1) germination - generally large seeds germinate fast, while small seeds more often enter the seed bank; 2) dispersal type; 3) dispersal distance, small seeds being dispersed further than large seeds but see[34], 4) seedling mortality, species with large seeds generally having lower mortality[35]. Seed mass has been shown to vary across Amazonia with higher average community seed mass in eastern Amazonia. Compared to other families Fabaceae even have an even higher seed mass in eastern Amazonia[36]. It is expected that fitness of individual seeds should increase with increasing seed mass, given the higher parental investment per seed[37] and it has been suggested that large seeds should be heavily, chemically protected[38]. So, seed mass is part of **trade-off between dispersal and fast growth in gaps vs survival in shade**[3]. Seed mass is also together with adult tree height part of the **stature–recruitment trade-off**, which has been supported by several studies[39-41]

11 Atmospheric N-fixation may be considered an adaptation to poor soils and fixation leads to higher nitrogen in leaves of N-fixing species, especially in the wet tropics[42]. In an Amazonian-wide study, N-fixation was shown to be negatively related to poor soils, however[36]. Also, at the global scale N-fixation is more common on non-acid soils[43]. Although Fabaceae, the main N-fixing family [44], dominates on very poor white sand soils, the species that do so are not the N-fixing ones[36,45]. N-fixing, is especially common in dry forests[43], as it may increase leaf nitrogen concentration and water use efficiency, and in early succession as then there is sufficient light to provide rhizobial nitrogen fixing symbionts with photosynthates[46,47].

12 Ectomycorrhiza. Mycorrhiza assists plants with nutrient uptake. While ectomycorrhizal symbiosis (EM) is the dominant form of mycorrhiza and the majority of trees on earth (60%) are EM, most tropical trees have an association with vesicular-arbuscular mycorrhiza (VAM)[43]. In the tropics EM has been considered an adaptation to extremely poor soils[48-51] but is rare in Amazonia and only poorly linked to extremely poor white sands[45].

13 Aluminium accumulation. A small amount of plant species accumulates aluminium (Al) in their leaves. Plants are considered Al-accumulators if they accumulate Al to a level of at least 1000 mg/kg (1000 ppm)[52]. Al accumulation is considered a protection from soil aluminium[52-54], because Al is stored in plant parts where it does not interfere with growth at root and shoot tips[55]. Al-accumulators are common in the Brazilian Cerrado biome, arguably linked to the very high Al-saturation of Cerrado soils[56,57]. Al accumulation has been found in 52 plant families and is particularly found in a few clades of Amazon trees (e.g. *Cecropia*, Rubiaceae, Melastomataceae, Vochysiaceae).



Supplementary Fig. 1. ATDN plots in Amazonia. Plots (2,253) of the Amazon Tree Diversity Network (ATDN) inventory data used for analyses. Amazonian Regions[58,59]: GS, Guiana Shield; CA, central Amazonia; EA, eastern Amazonia; SA, southern Amazonia; NWA north-western Amazonia; SWA, south-western Amazonia. Plot forest types: TFPB, terra-firme Pebas formation (467 plots); TFBS, terra-firme Brazilian Shield (389); TFGS, terra-firme Guiana Shield (674); PZ, forests on white sand (112); IG, igapó (237); VZ, várzea (319); SW, swamp forest (55). Plots outside the Amazonian polygon were used to improve interpolation near the edges. Red polygon: Amazonian Biome limit[60]. Background: Visible Earth NASA (https://visibleearth.nasa.gov/ © NASA). Base map source (country.shp, rivers.shp), ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company). Map created with custom R[61] script.

PCA on 13 functional traits of 353 tree genera in Amazonia, with data for all 13 traits

Supplementary Table 1a. Summary of PCA of Amazonian tree genera, using 13 traits (Fig 1, Supplementary table 1b. PC1 has an Eigenvalue of almost 3, PC2 of 1.75. All other PC's have an Eigenvalue close to or less than 1.

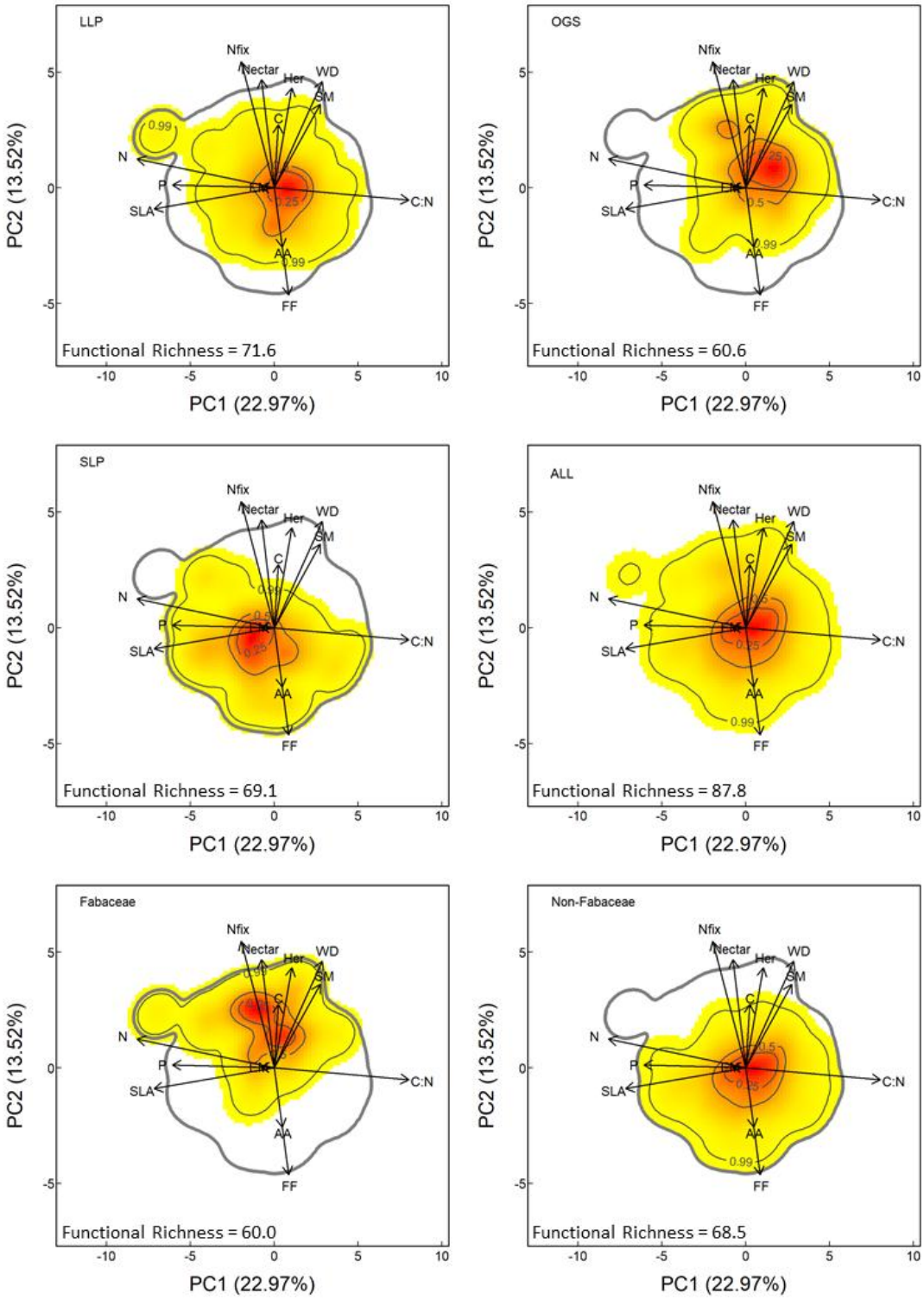
	PC1	PC2	PC3	PC4
Standard deviation	1.7257	1.3241	1.1911	1.0673
Eigenvalue	2.9782	1.7532	1.4187	1.1392
Proportion of Variance	0.2297	0.1352	0.1094	0.0879
Cumulative Proportion	0.2297	0.3650	0.4744	0.5623

Supplementary Table 1b (= Table 1). Percentage of variance of the PC axes explained by the traits of Amazonian trees. Traits are ordered in proportion to the variance of the axes they explain. N, leaf Nitrogen concentration; C:N, ratio of leaf Carbon to leaf Nitrogen; SLA, specific leaf area; SM, seed mass; P, leaf phosphorus concentration; AA, aluminium accumulation; Nfix, Atmospheric N-fixation; Her, hermaphroditism; FF, Fleshy fruit; WD, wood density; C, leaf Carbon concentration; Nectar, nectar producing; EM, Ectomycorrhiza. LES, leaf economic spectrum; WES, wood economic spectrum; dispersal, trait important for dispersal; roots, root trait; Breeding, breeding system. For units see Supplementary Box 1. Important traits are given in bold. R^2 proportion of variance explained by environmental variable; p, significance level. Type: LES, leaf economic spectrum; SR, stature-recruitment trade-off; SES, Stem economic spectrum; roots, Roots, root trait (Nfix, EM, AA); Breeding, breeding type; Dispersal, trait important for dispersal.

trait	PC1	PC2	PC3	R^2	p	type
N	0.824	0.019	0.004	0.847	0.001	LES
C:N	0.791	0.003	0.000	0.795	0.001	LES
SLA	0.630	0.010	0.010	0.650	0.001	LES
SM	0.091	0.160	0.382	0.634	0.001	SES/SR
P	0.452	0.000	0.066	0.519	0.001	LES
AA	0.003	0.080	0.353	0.437	0.001	roots
Nfix	0.048	0.366	0.007	0.422	0.001	roots
Her	0.014	0.230	0.152	0.396	0.001	Breeding
FF	0.009	0.263	0.123	0.394	0.001	dispersal
WD	0.101	0.260	0.018	0.379	0.001	SES/SR
C	0.001	0.092	0.248	0.341	0.001	LES
Nectar	0.007	0.269	0.038	0.314	0.001	Breeding
EM	0.008	0.000	0.016	0.024	0.464	roots

Supplementary Table 1c. Loadings of and variance explained by life history. Life histories are mainly related to axis 2, due to their definition based on seed mass and wood density[62]. OGS, old growth species, wood density > 0.7 g/cm^3; LLP, long lived pioneers, wood density < 0.7 g/cm^3 and seed mass over 0.1 g; SLP, short lived pioneers, wood density < 07 g/cm^3 and seed mass under 0.1 g. R^2 proportion of variance explained by environmental variable; p, significance level.

trait	PC1	PC2	R^2	p
SLP	-0.599	-0.801	0.267	0.001
LLP	0.521	-0.853	0.020	0.054
OGS	0.400	0.917	0.290	0.001
Max	0.068	0.998	0.050	0.002



Supplementary Fig. 2. Functional trait space of three life history strategies of Amazonian trees by life history strategy and Fabaceae. Only complete cases are used (353 genera, 91% of all individuals). Colours indicate the probabilistic distribution of trait combinations in the functional trait space defined by the PCA (red, high probability; yellow, low probability). Contour lines indicate 0.99, 0. 50, and 0.25 quantiles of the probability distribution. PC1 is the leaf economic spectrum, PC2 is the stature-recruitment trade-off (Fig. 1). LLP, long lived pioneers; OGS, old growth species; SLP, short lived pioneers; ALL, all genera; Fabaceae, all genera of Fabaceae; Non-Fabaceae, genera of all other families; N, leaf nitrogen concentration; C:N, ratio of leaf carbon to leaf nitrogen; SLA, specific leaf area; SM, seed mass; P, leaf phosphorus concentration; AA, aluminium accumulation; Nfix, atmospheric N-fixation; WD, wood density (overlapping with OGS); C, leaf carbon content; FF, fleshy fruit; EM, ectomycorrhiza; Her, hermaphroditic, Nectar, nectar producing.

Supplementary Table 2a. Summary of PCA of community weighted means of 13 traits of 2054 plots in Amazonia. Used were 13 traits (Fig. 1b). PC1 has an Eigenvalue of 4.23 (=equal to 4.23 variables) and explains 35.3% of the trait variance, PC2 has an Eigenvalue of 2.0 and explains 17% of all trait variance. All other PC's are close to or less than 1. PC1 is the leaf economic spectrum, PC2 is the stature-recruitment trade-off (Fig. 1).

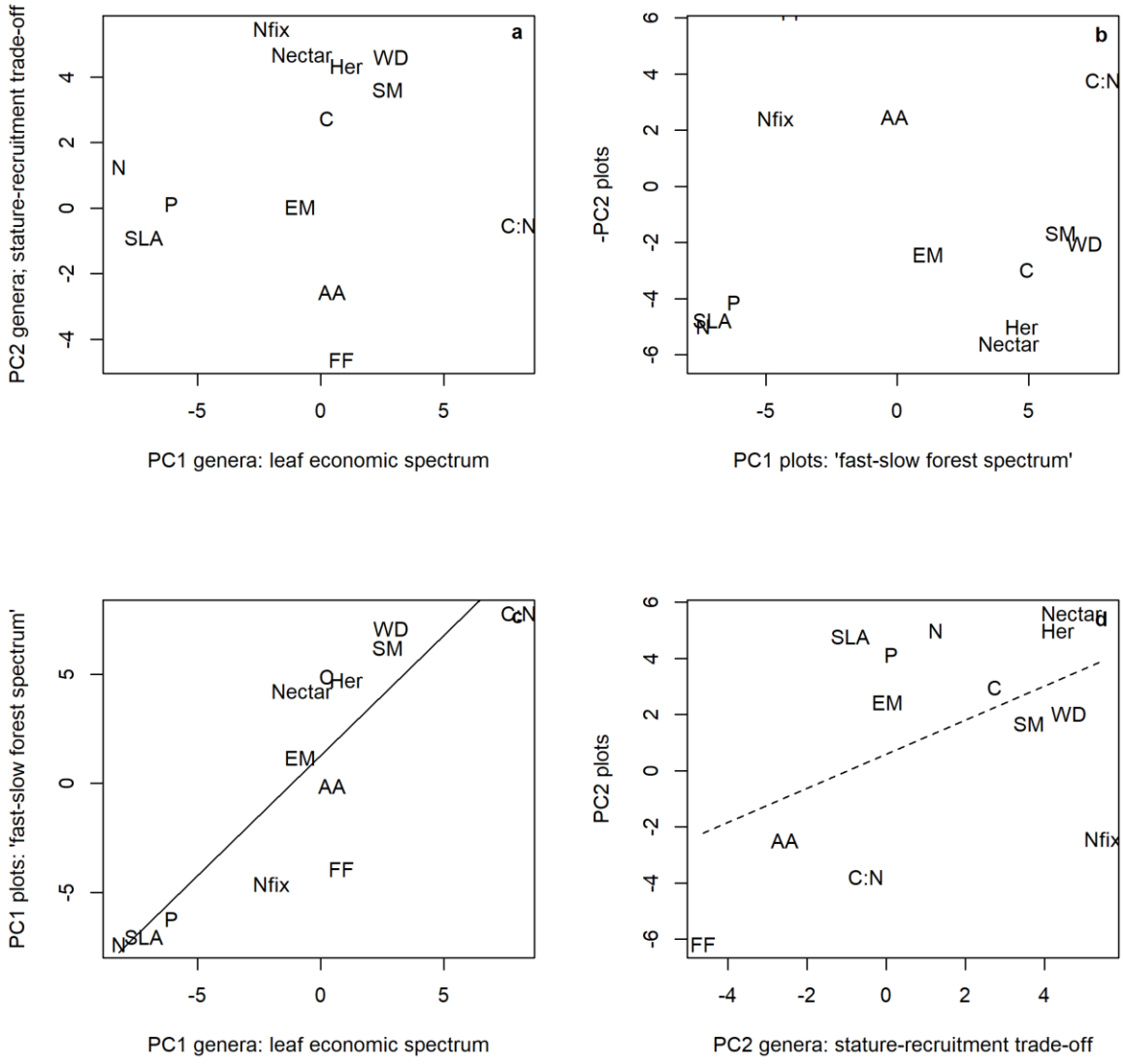
	PC1	PC2	PC3	PC4	PC5
Standard deviation	2.096	1.506	1.166	1.038	0.942
Eigenvalue	4.391	2.267	1.359	1.076	0.888
Proportion of Variance	0.338	0.174	0.105	0.083	0.068
Cumulative Proportion	0.338	0.512	0.617	0.700	0.768

Supplementary Table 2b (= Table 2). Variance of the PC axes explained by the community weighted means of 13 traits of 2054 plots in Amazonia. Traits are ordered to the variance of the axes they explain. N, leaf Nitrogen content; C:N, ration leaf carbon to leaf Nitrogen; SLA, specific leaf area; WD, wood density; P, leaf phosphorous content; Her, Hermaphroditism; FF, Fleshy fruit; Nectar, nectar producing; SM, seed mass; C, leaf Carbon content; Nfix, Atmospheric N-fixation by Fabaceae; EM, Ectomycorrhiza. LES, leaf economic spectrum; WES, wood economic spectrum; SES, dispersal, trait important for dispersal; roots, root trait. For units see Supplementary Box 1. PC1, the relative contribution of the environmental variable for PCA axis 1; PCA2 same for PCA 2. R^2 proportion of variance explained by environmental variable; p: significance level.

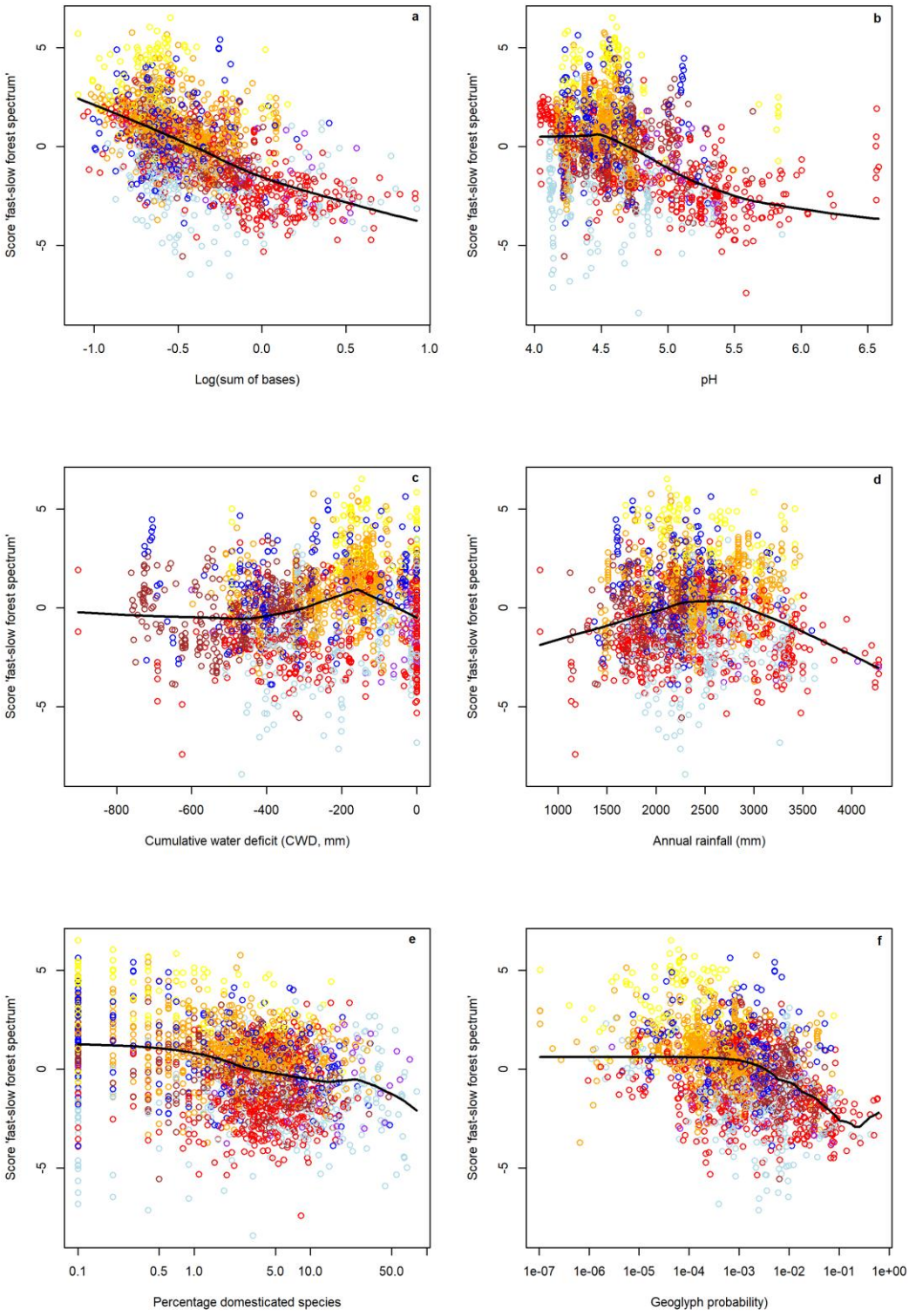
Trait	PC1	PC2	R^2	p	spectrum
N	57.98	28.91	0.869	0.001	LES
C:N	65.26	16.90	0.822	0.001	LES
SLA	52.27	26.53	0.788	0.001	LES
WD	57.03	4.59	0.616	0.001	WES
P	41.83	18.90	0.607	0.001	LES
Her	32.87	26.34	0.592	0.001	BR
FF	17.91	40.90	0.588	0.001	BR
Nectar	20.73	34.06	0.548	0.001	BR
SM	41.63	2.29	0.439	0.001	SES
C	26.95	9.54	0.365	0.001	LES
Nfix	22.95	5.29	0.282	0.001	R
EM	1.69	6.54	0.082	0.001	R
AA	0.00	5.90	0.059	0.001	R

Supplementary Table 2c. **Axis loadings and variance explained by environmental data.** (PCA of community weighted means of 13 traits of 2054 plots in Amazonia). SB, sum of bases[63]; pH, soil acidity; Flooded, forest types Várzea, Igapó, Swamp; Annual, Annual precipitation (Bioclim12)[64]; CWD, cumulative water deficit; CAPE, Convective atmospheric potential energy[65], WTC, Windthrow count[65]; GeoGl.prop, Geoglyph probability[66]; Dspp, abundance domesticated species[67]; SLP, short lived pioneers; LLP , long lived pioneers; OGS, old growth species; S.ha, species richness/ha. PC1, the relative contribution of the environmental variable for PCA axis 1; PCA2 same for PCA 2. R^2 proportion of variance explained by environmental variable; p, significance level.

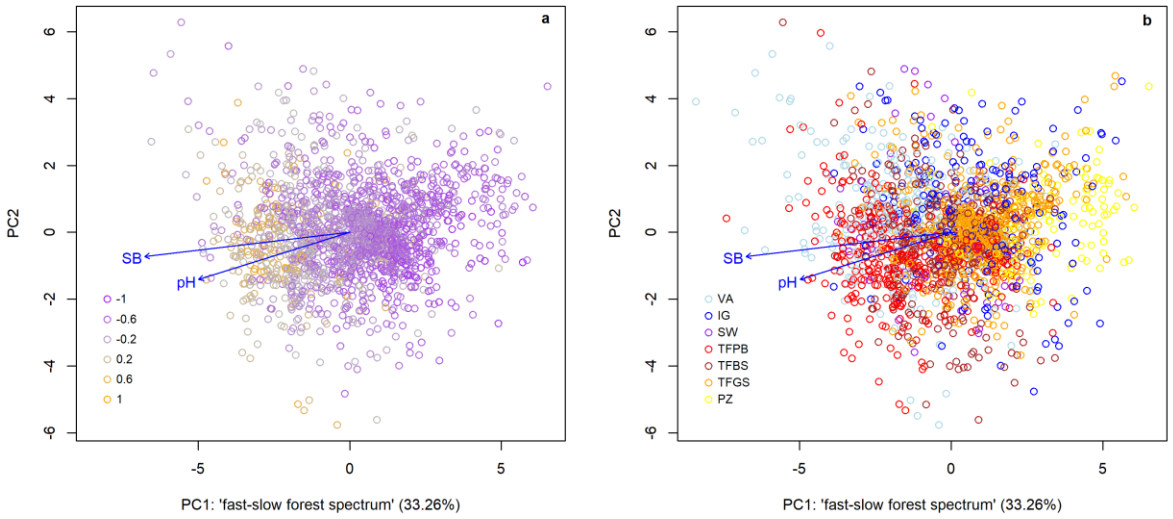
EnvFact	PC1	PC2	R^2	p
SB	**-0.999**	-0.035	**0.325**	0.001
pH	**-0.991**	-0.132	**0.214**	0.001
Flooded	-0.486	0.874	0.075	0.001
Podzol	0.996	0.089	0.156	0.001
Annual	-0.712	0.702	0.002	0.317
CWD	0.722	0.692	0.020	0.001
CAPE	-0.442	-0.897	0.066	0.001
WTC	0.586	-0.810	0.029	0.001
GeoGl.prop	-0.979	-0.206	0.056	0.001
DSpp	-0.969	-0.246	0.050	0.001
SLP	**-0.916**	**-0.400**	**0.264**	0.001
LLP	**-0.972**	**-0.236**	**0.332**	0.001
OGS	**0.946**	**0.323**	**0.666**	0.001
S.ha	**-0.035**	**-0.999**	**0.022**	0.001



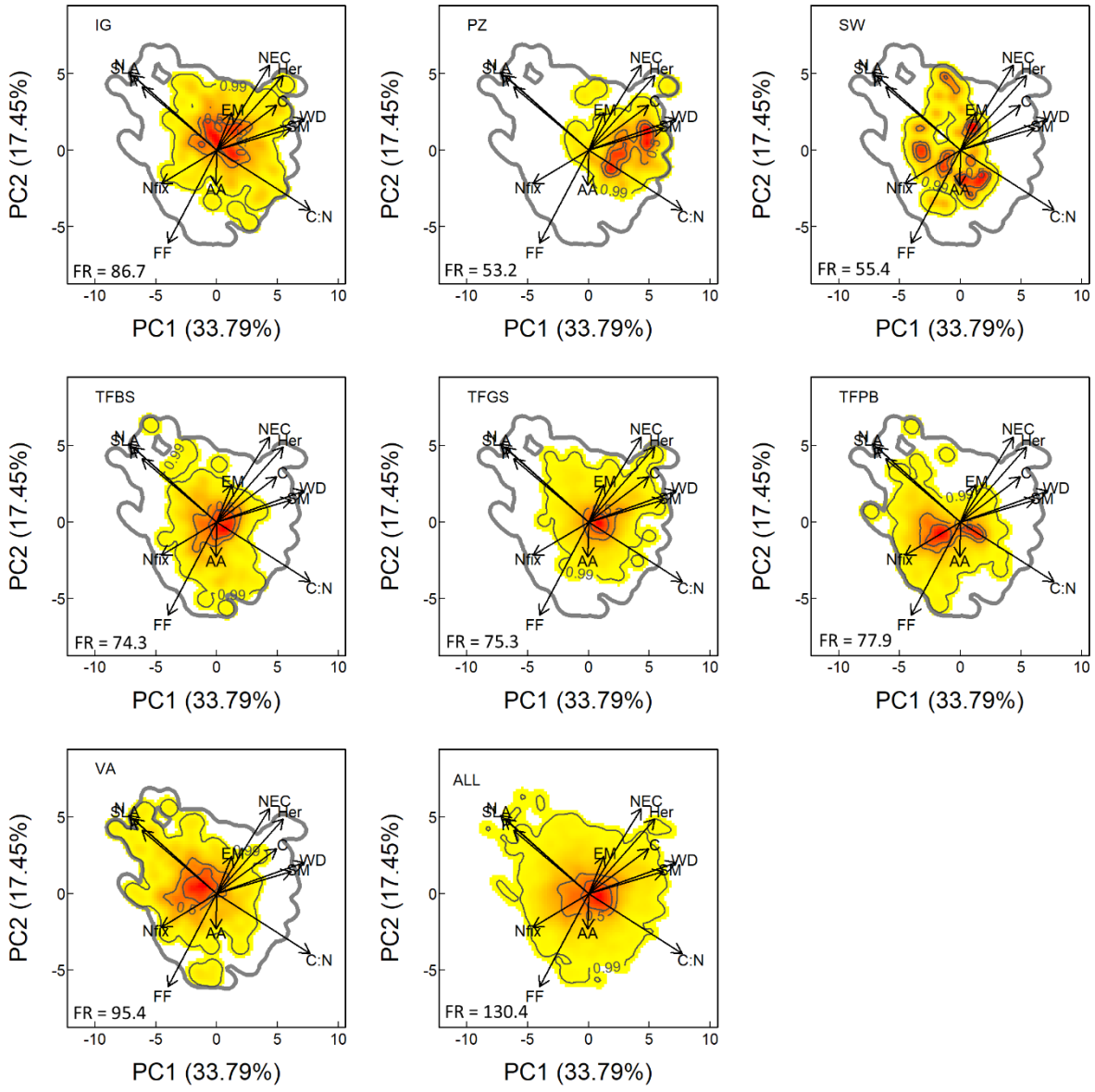
Supplementary Fig. 3 Comparing two PCA bi-plots. a. PCA with genus data (as Figure 1). **b**. PCA with plot data (as Figure 2, axes inverted – note that the direction of the axis is arbitrary). **c**. Scores of PC1 for genera and plots (reverse) are very similar (R^2 = 74%, p << 0.001). **d**. Scores of PC2 for genera and plots (reverse) are not similar (R^2 = 9%, n.s). A Mantel using the distances between the traits in both PCA plots (a, b) gives a Mantel correlation of 0.75 (P = 0.001). Thus, relationships between the traits in the PCA's are somewhat retained and this is mostly because of the very similar scores on PC1.



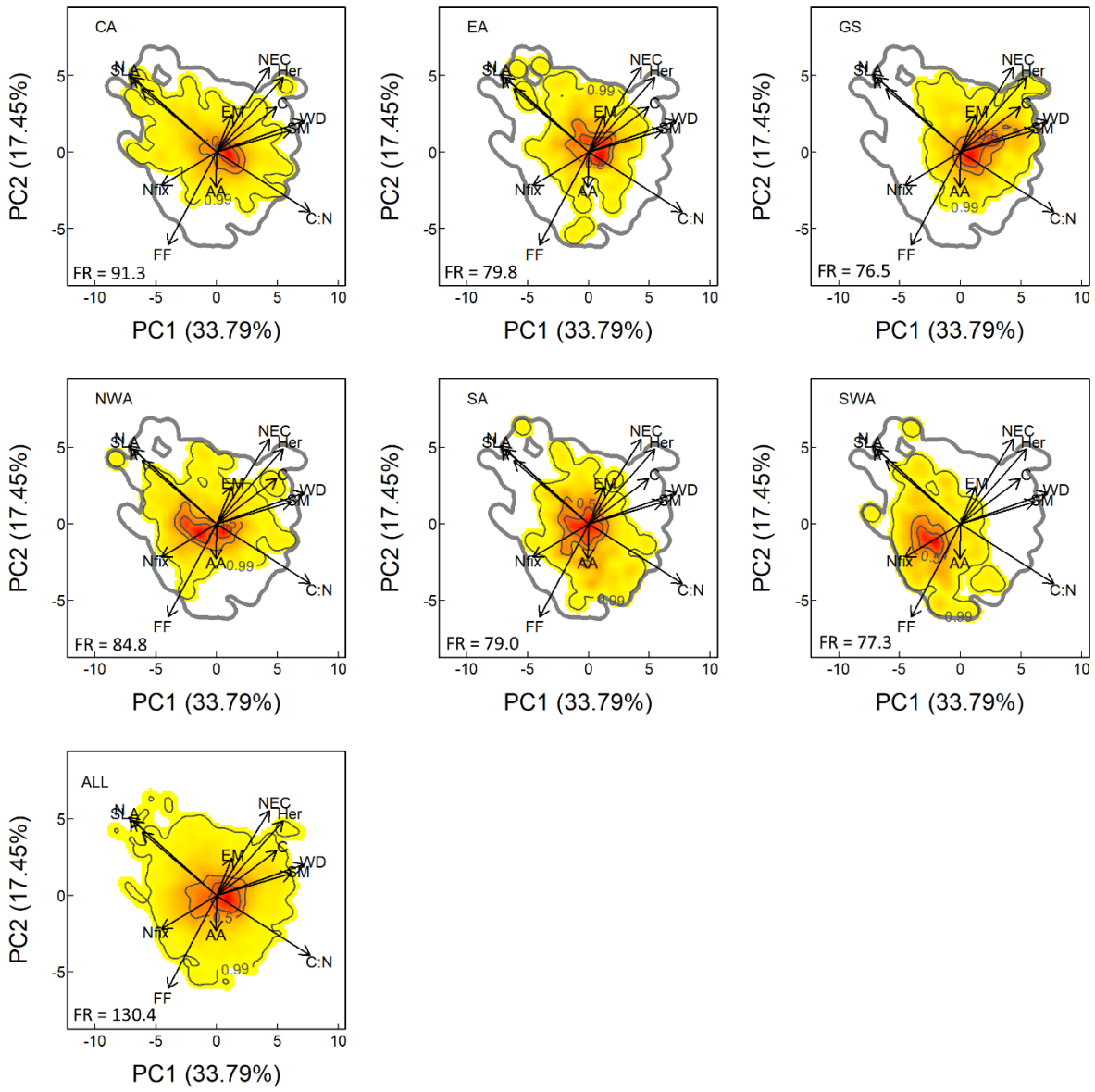
Supplementary Fig. 4. Potential drivers of the first axis of the PCA based on community weighted means. **a** PC1 as predicted by soil fertility (log(sum of bases)). **b** as predicted by soil acidity (pH). **c.** as predicted by cumulative water deficit (CWD, mm) **d** as predicted by annual rainfall (mm). **e** as predicted by domesticated species (% of individuals). **f** as predicted by geoglyph probability. Note that **e** and **f** have a logarithmic x-axis. Colours: Red = terra firme Pebas formation, brown = terra firme Brazilian Shield, orange = terra firme Guiana Shield, yellow = white sand forest, purple = swamp forest, dark blue = igapó, light blue = várzea.



Supplementary Fig. 5 Functional trait space of Amazonia, using community weighted means of 13 tree traits of 2054 Amazonian forest communities. a PC1 scores of 2054 forest communities. Colours from purple-grey-orange indicate increasing log(sum of bases) of the forest communities. Added are the vectors for proxies of soil fertility - log(sum of bases) and pH as calculated with EnvFit[68]. **b** same Amazonian forest communities but by forest type/soil combination: VA, várzea forest; IG, igapo forest; SW, swamp forest; TFPB terra firme Pebas formation; TFBS, terra firme Brazilian shield; TFGS, terra firme Guiana Shield; PZ, white sand forest. Forest communities are ordered from very poor soils (PZ), through terra firme's of the Guiana Shield, Brazilian Shield to the richer soils of the Pebas formation (TFPB). Flooded forests are also ordered from poor soils (IG) to rich soils (VA). Note that panel a has a few less plots than panel b as the original map of sum of bases[63] does not have 100% plot coverage.



Supplementary Fig. 6 Functional trait space of Amazonian forest types, using community weighted means of 12 tree traits on 2054 Amazonian forest plots. See figure 1 for full legend. IG, igapo forest; PZ, white sand forest; SW, swamp forest; TFBS, terra firme Brazilian shield; TFGS, terra firme Guiana Shield; TFPB terra firme Pebas formation; VA, várzea forest; ALL, all plots combined.



Supplementary Fig. 7 Functional trait space of Amazonian regions, using community weighted means of 13 tree traits on 2054 Amazonian forest plots. See figure 1 for full legend. FR, functional richness**;** CA, central Amazonia; EA, eastern Amazonia; GS, Guiana Shield; NWA, north-western Amazonia; SA, southern Amazonia; SWA, south-western Amazonia; ALL, all regions combined.

Supplementary results by trait

Wood density (WD: g/cm^3) (Supplementary Fig. 8). Mean wood density at genus level and community weighted mean wood density are both 0.64 g cm^{-3}. The distribution is more skewed, however, with the mode shifted towards 0.70 g/cm^3. Wood density is highest in forest-soil combination that are relatively nutrient poor (IG, PZ, TFGS) and lower in soil-forest combinations that are considered to have higher fertility (TFPB, VA). Swamp forests have a very low wood density, primarily caused by dominance of low-density species (e.g. from Arecaceae). Regionally, wood density increases from west (0.55 g/cm^3) to east, having the highest values in the upper Rio Negro white sand areas (0.72 g/cm^3), central Amazonia and the Guianas. Forest type explains 33% of the variation in CWM wood density, soil type and location together 55%.

Specific leaf area (SLA – cm^2/g) (Supplementary Fig. 9). The mean SLA at genus level is 14.46 cm^2/g, slightly skewed to the right. At community level the data is more normally distributed with a mean of 12.35 cm^2/g. Lowest SLA is found in forests associated with nutrient poorness (variation explained by forest type: 16%), as is also shown by the map of SLA (explained variation 41%), with SLA of 11 cm^2/g in the nutrient poor regions and 14 cm^2/g in the more fertile areas.

Carbon by leaf mass (C mg/g) (Supplementary Fig. 10). Mean C is 469 mg/g for all genera and 477 mg/g at community level. Variation in leaf carbon is relatively low. Forests with higher-than-average C are IG, TFGS and PZ but the spatial pattern is very consistent. Especially upper Rio Negro and the Guianas are dominated by genera with somewhat higher leaf carbon (495 mg/g). Forest type explains 17% of the variation in leaf carbon, the regional model 60%.

Nitrogen by leaf mass (N mg/g) (Supplementary Fig. 11). Mean N is 22.4 mg/g for all genera and 21.0 mg/g at community level. Generally, strongly related to SLA (Supplementary Fig. 9) it shows similar patterns with very low N in leaves of forest communities on white sands (PZ). Especially upper Rio Negro and Guianan forests are dominated by genera with very low N (19 mg/g). Forest type explains 16% of the variation in N, the regional model 46%.

Phosphorus by leaf mass (P mg/g) (Supplementary Fig. 12). Mean P is 0.89 mg/g for all genera and 0.88 at community level. Generally, also strongly related to SLA and N, it shows similar patterns with very low P in leaves of forest communities on white sands (PZ). Especially upper Rio Negro and central Amazonian forests are dominated by genera with very low leaf P (0.6 mg/g). Forest type explains 27% of the variation in P, the regional model 48%.

Carbon Nitrogen Ratio (C:N mg C/mg N) (Supplementary Fig. 13). Mean C:N ratio for genera and forest communities is 24 (mg C / mg N). There is moderate variation among forest types but várzea forests have relatively low CN ratio, whereas white sand forests have quite high CN ratios. Forest type explains 21% of the variation in N, the regional model 51%.

Breeding systems (Supplementary Fig. 14-16). Most Amazonian species are hermaphroditic (67%), followed by dioecious (23%) and finally monoecious (10%). At plot level, the numbers are slightly different (57%, 17%, and 26% respectively). Highest proportions of hermaphroditic individuals are found in PZ and IG, and TFGS. South western Amazonia has values as low as 30%. Dioecy is very rare in PZ and IG, and regionally in the Guiana Shield. Monoecy is common (up to 32%) in southwestern Amazonia.

Nectar production (Supplementary Fig. 17). Seventy five percent of all Amazonian species are estimated to produce nectar. Accounting for abundances this amounts to 72% of all individuals. High values are found in the poor soil areas of eastern Amazonia (PZ, 82% of al individuals) and the Guyana Shield. Much lower values are found in north-western Amazonia (TFBS, 64%) and south-western Amazonia (TFBS, 65%). The latter is related to the high abundance of Moraceae in that area, a family whose species generally do not produce nectar[25].

Fleshy fruits (Supplementary Fig. 18). Fifty-seven percent of all genera in our data have fleshy fruit. In the forest communities this is somewhat higher (67%). Igapó and white sand forest have the lowest percentage of individuals with fleshy fruit. Thus, in the Guiana Shield area values are as low as 46%, while in Western Amazonia communities may consist of over 90% of individuals with fleshy fruits. Forest type explains 16% of the variation in N, the regional model 47%.

Seed mass (SM) (Supplementary Fig. 19). Mean SM (log) by genus is 4.37 (equivalent to a seed mass of 0.25 gr.). Community weighted SM is slightly higher (4.96). The highest mean seed mass is found in forests on poor soils (PZ, IG) and swamp forests, the latter dominated by Arecaceae. Várzea forests and forests of the Brazilian shield and Pebas formation have generally lower community weighted means. Forest type explains 16% of the variation in seed mass class at community level. Regionally SMC is lowest in the more fertile western Amazonia and towards the Cerrado, and highest in the areas with poor soils. The regional model explains 54% of the variation in SMC.

Nitrogen fixation (Supplementary Fig. 20). N-fixation is mainly found in Fabaceae and eight other eurosid families[44], and nodulating genera make up just 9% of all genera. About 68% of all Fabaceae in the Amazonian tree communities belong to N-fixing genera. Variation within forest types is large and among forest types is small (variation explained is 11%). Swamp forests and, especially, white sand forests have much lower percentages of individuals of N-fixing genera. The regional model explains 36% of the variation at community level.

Ectomycorrhiza (EM) (Supplementary Fig. 21). Only five genera are known to have EM association in Amazonia (*Dicymbe*, *Aldina, Guapira, Neea, Coccoloba*) and they make up only a very small part of the forest trees in our plots (1%). White sand forests and forest in the Guiana Shield are sometimes dominated by EM species (*Dicymbe, Aldina*), while Nyctaginaceae are the reason for relatively high fraction in western Amazonia. Forest type and the regional model explain only low levels of variation (4% and 31%, respectively).

Alluminium accumulation (Supplementary Fig. 22). Alluminium accumulation is also quite rare among Amazonian tree genera (~5%) and in the forest communities (~5%). Forest type explains only 4% of the variation in Aluminium accumulators in the communities but high percentages are found in a few igapó forests in southern Amazonia dominated by *Ruizterania* (Vochysiaceae). Regionally, the highest percentages are found in southern Amazonia, close to the cerrado, where such species may be very prominent[56]. The regional model explains 32% of the variation at community level. Regionally the highest percentages are found in south western Amazonia, the lowest on the white sands of the upper Rio Negro and Guianas.

Short lived pioneers (SLP, Supplementary Fig. 23). Approximately 31% of all genera are classified as SLP. On average they make up 23% of all stems in the plot data. PZ, SW, IG and TFGS have less than average but forest type explains only 10% of the variation in percentage of SLP in the forest

communities. The pattern is similar to that of WD and SMC. Forests on relatively infertile areas tend to have a low percentage of SLP. The regional model explains 45% of the community variation of short lived pioneers.

Long lived pioneers (LLP, Supplementary Fig. 24). LLP make up 26% of all genera in our data. At the community level, however, they make up 41% of all stems. They are most abundant in the terra firme forests of the Pebas formation, Várzea forests and swamps (palms have light wood and big seeds – so this may be an artefact). LLP are very uncommon in central Amazonia and the infertile Amazonian areas (PZ of upper Rio Negro and Guianas and central Amazonia). Forest type explains 23% of the variation in mean climax species abundance, the regional model explains 51% of the spatial variation.

Old growth species (OGS) (Supplementary Fig. 25. OGS make up 37% of all genera in our data. At the community level they make up 36% of all stems. They are most abundant in the terra firme forests Guiana Shield and central Amazonia. Forest type explains 26% of the variation in mean climax species abundance, the regional model explains 56% of the spatial variation.

Standard legend for Figs. S8 – S25.

a. Histogram of trait values by **genus** – this can be seen as the available trait pool. Red markers indicate mean, mean ± 1 sd, mean ± 2sd.

b. Histogram of **community** weighted trait value. Red markers as above.

c. Compound map of **community** weighted mean (CWM) of the trait value. The legend is truncated at mean plus and minus 2 standard deviations to avoid outliers influencing the legend division too much. Red polygon: Amazonian Biome limit [60]. Maps created with a custom R[61] script. Base map source (country.shp, rivers.shp): ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company).

d. Boxplot of **community** weighted trait value by forest type (VA, IG, SW, PZ, TFGS (terra firme of the Guiana Shield), TFBS (same of Brazilian Shield), TFPB (same of Pebas formation), ordered from the type with the lowest median to the type with the highest median value. A red line indicates then overall mean. The r^2 (left top) indicates the explained variation by a linear model (Anova).

e. Fit of the predicted and observed CWM (red line). This is considered the goodnes of fit for the entire map. The r^2 (left top) indicates the explained variation by a linear model.

f. Histogram of the residuals of the linear model. Red markers as A.

Supplementary Fig. 8. Wood density (WD: g/cm^3).

Supplementary Fig. 9. Specific Leaf Area (SLA: cm^3/g).

Supplementary Fig. 10. Leaf carbon concentration (C: mg/g).

Supplementary Fig. 11. Leaf nitrogen concentration (N: mg/g).

Supplementary Fig. 12 Leaf phosphorus concentration (P: mg/g).

Supplementary Fig. 13. C:N ratio (C/N)

Supplementary Fig. 14. Hermaphroditism (% of individuals).

Supplementary Fig. 15. Dioecy (% of individuals).

Supplementary Fig. 16. Monoecy (% of individuals).

Supplementary Fig. 17. Nectar production (Nectar: % of individuals).

Supplementary Fig. 18. Fruit type (fleshy: % of individuals).

Supplementary Fig. 19. Seed mass (Seed mass class (Hammond & Brown 1995; ter Steege & Hammond 2001))

Supplementary Fig. 20. Atmospheric N-fixation (Nfix: % of individuals of Fabaceae)

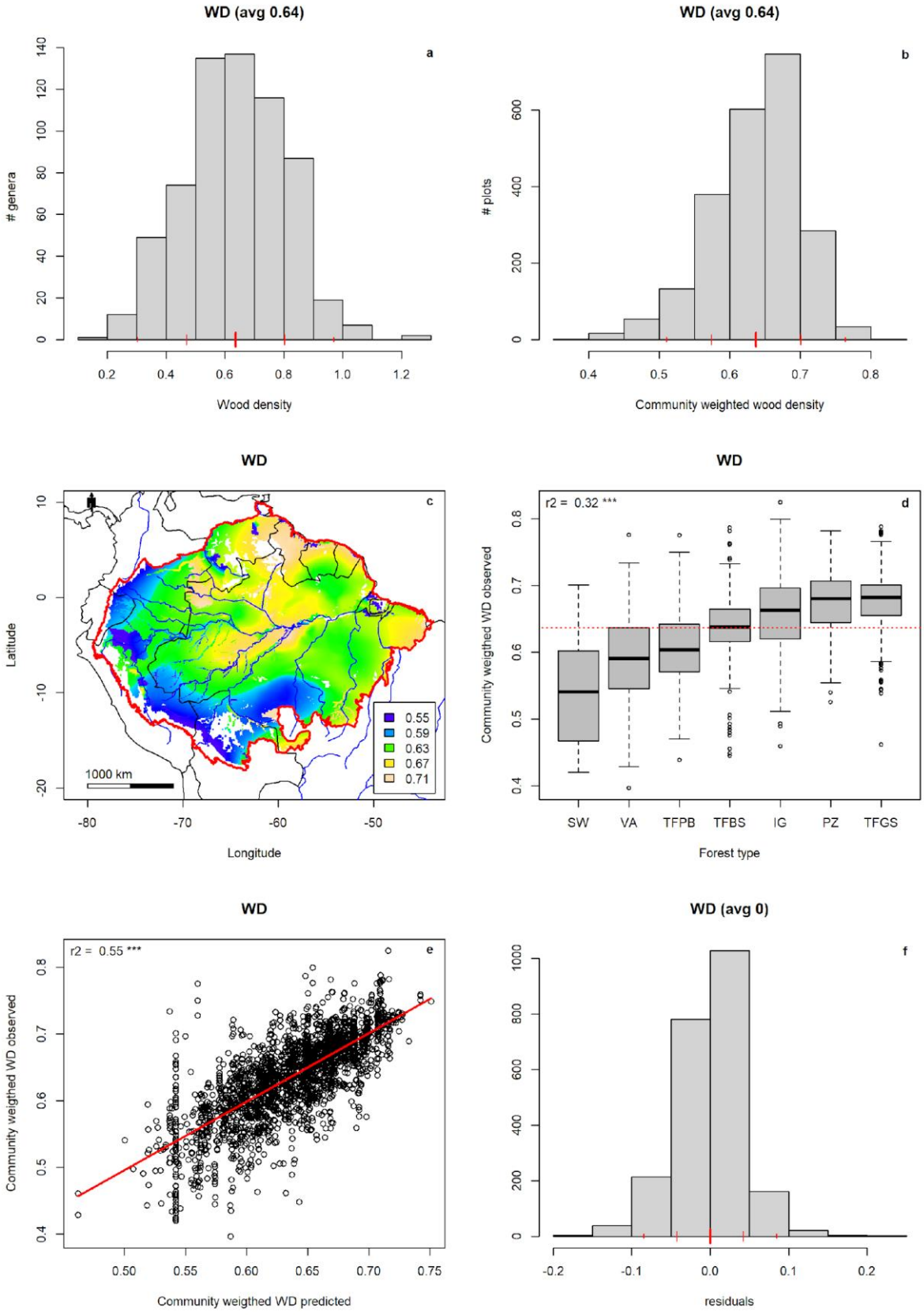
Supplementary Fig. 21. Ectomycorrhiza (EM: % of individuals).

Supplementary Fig. 22. Aluminium accumulation (Al: % of individuals).

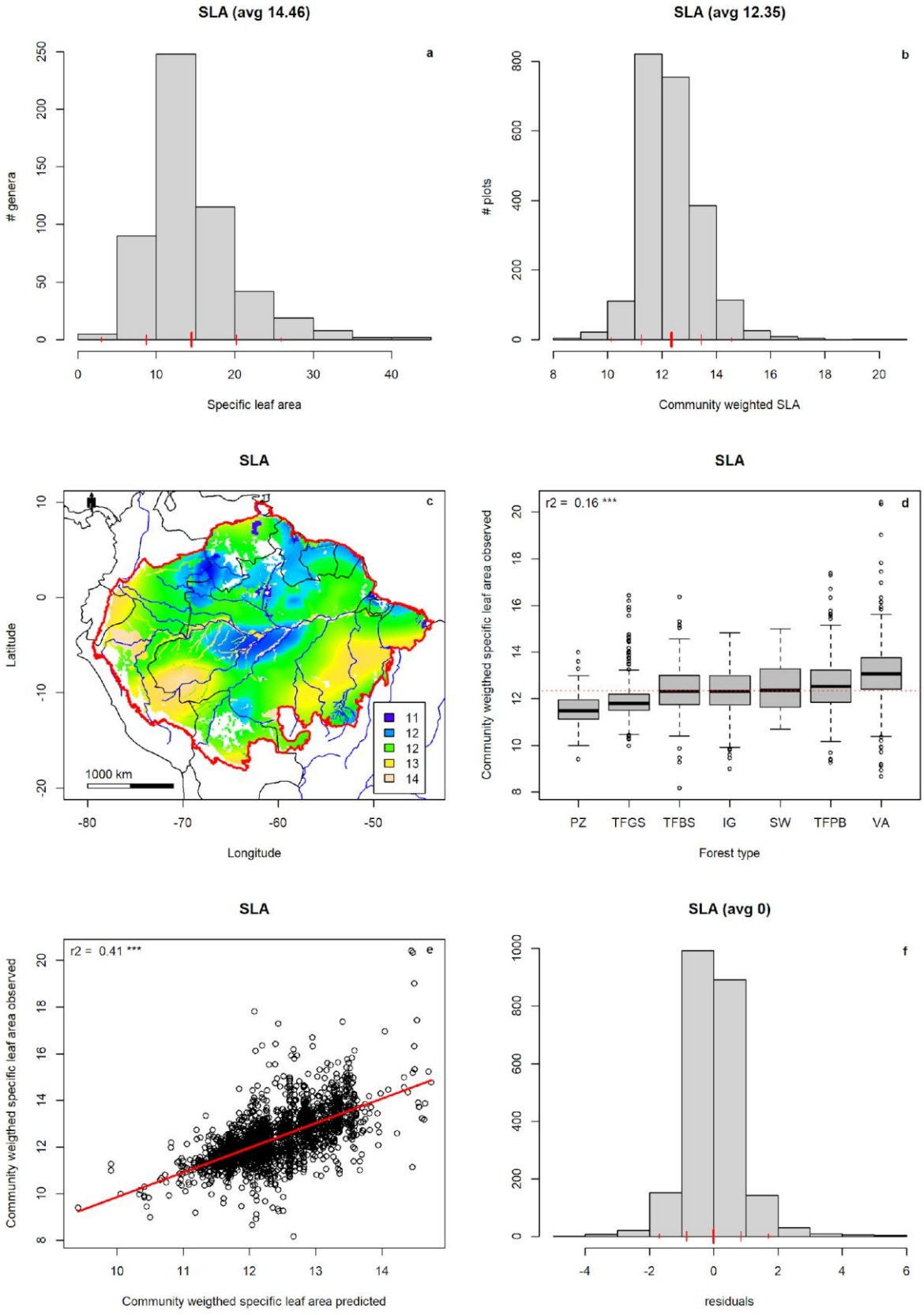
Supplementary Fig. 23. Short lived pioneers (SLP: % of individuals).

Supplementary Fig. 24. Long lived pioneers (LLP: % of individuals).

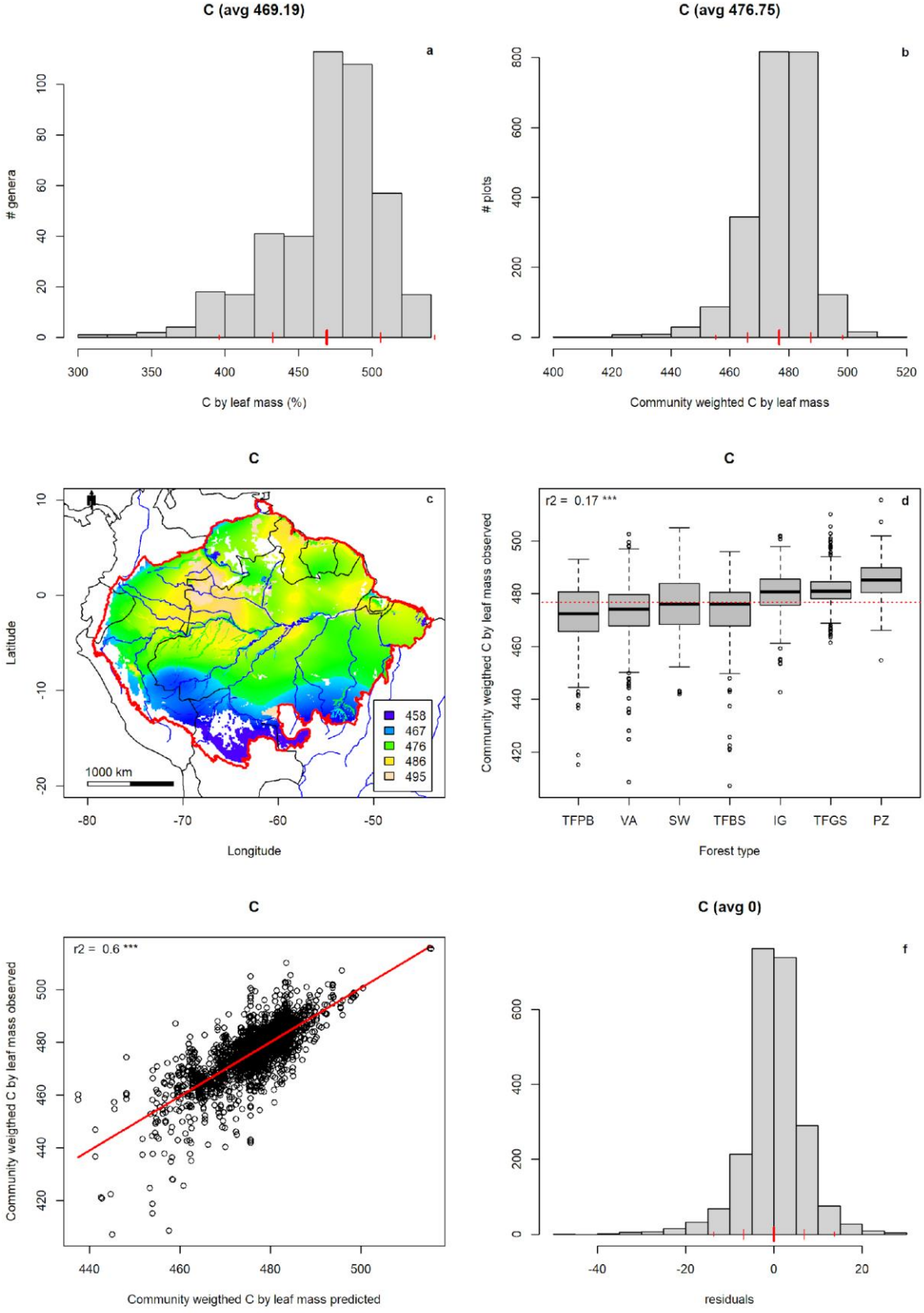
Supplementary Fig. 25. Old growth species (OGS: % of individuals).



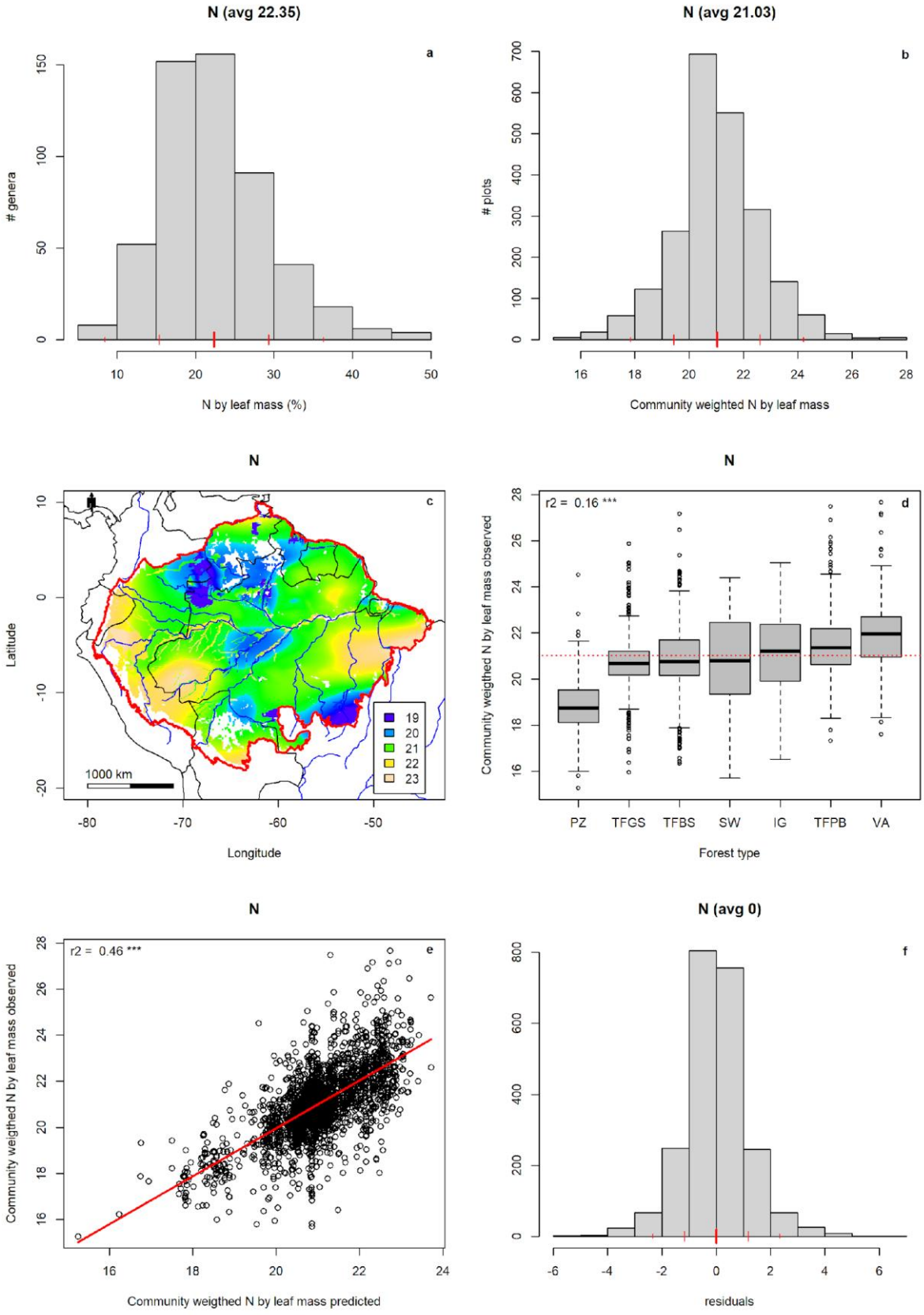
Supplementary Fig. 8 Wood density (WD – g/cm³).



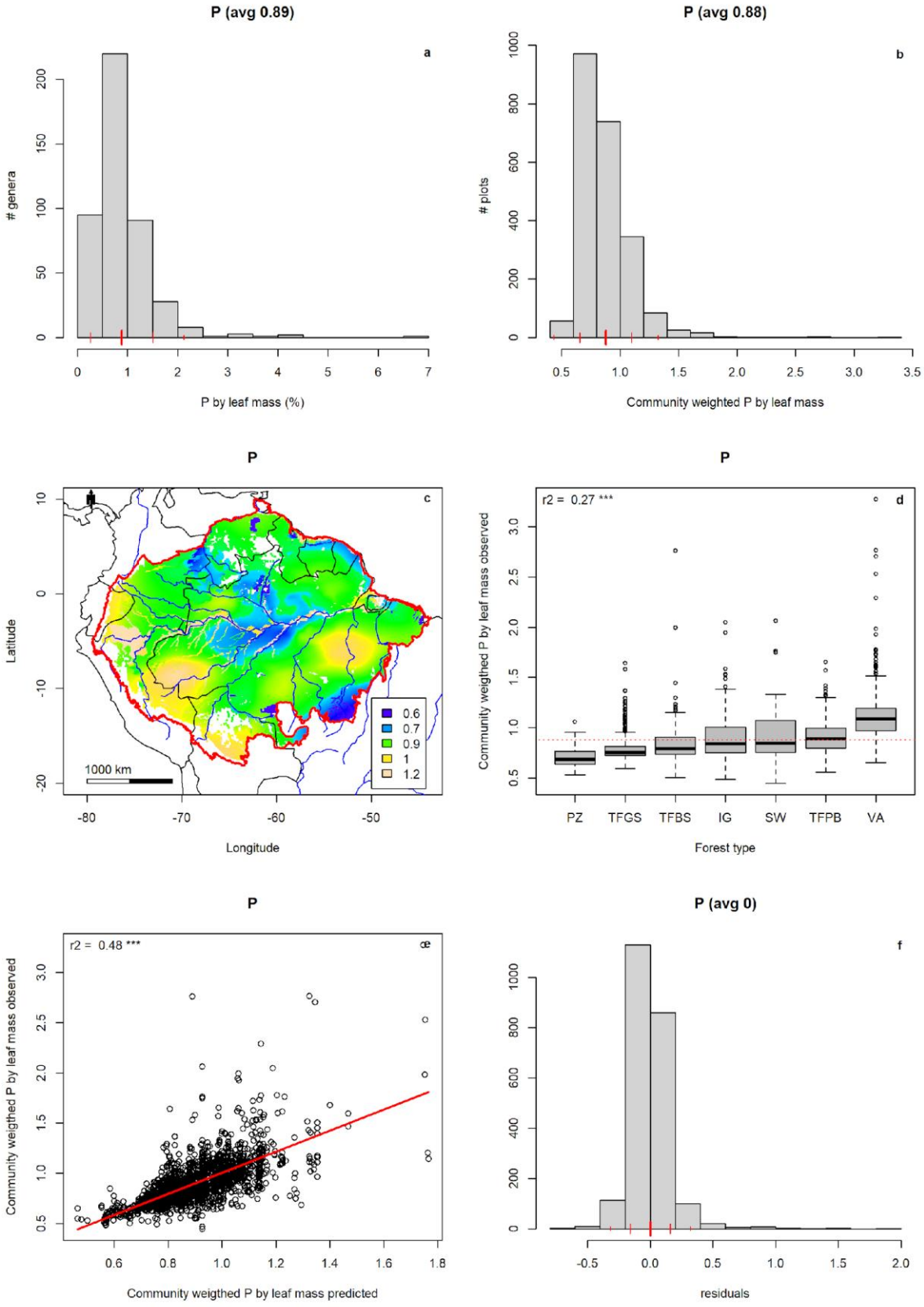
Supplementary Fig. 9 Specific Leaf Area (SLA: cm²/g).



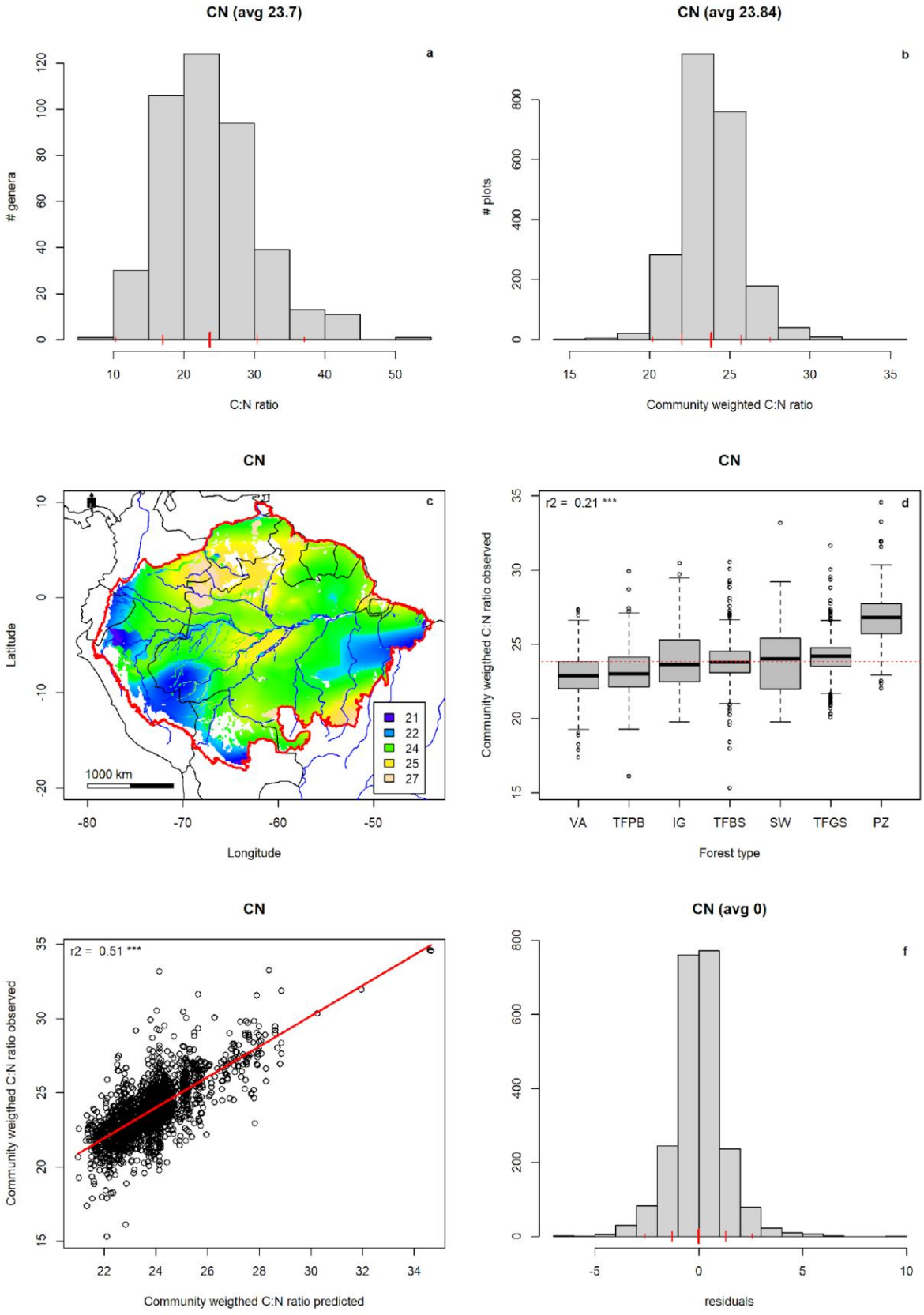
Supplementary Fig. 10. Leaf carbon concentration (C: mg/g).



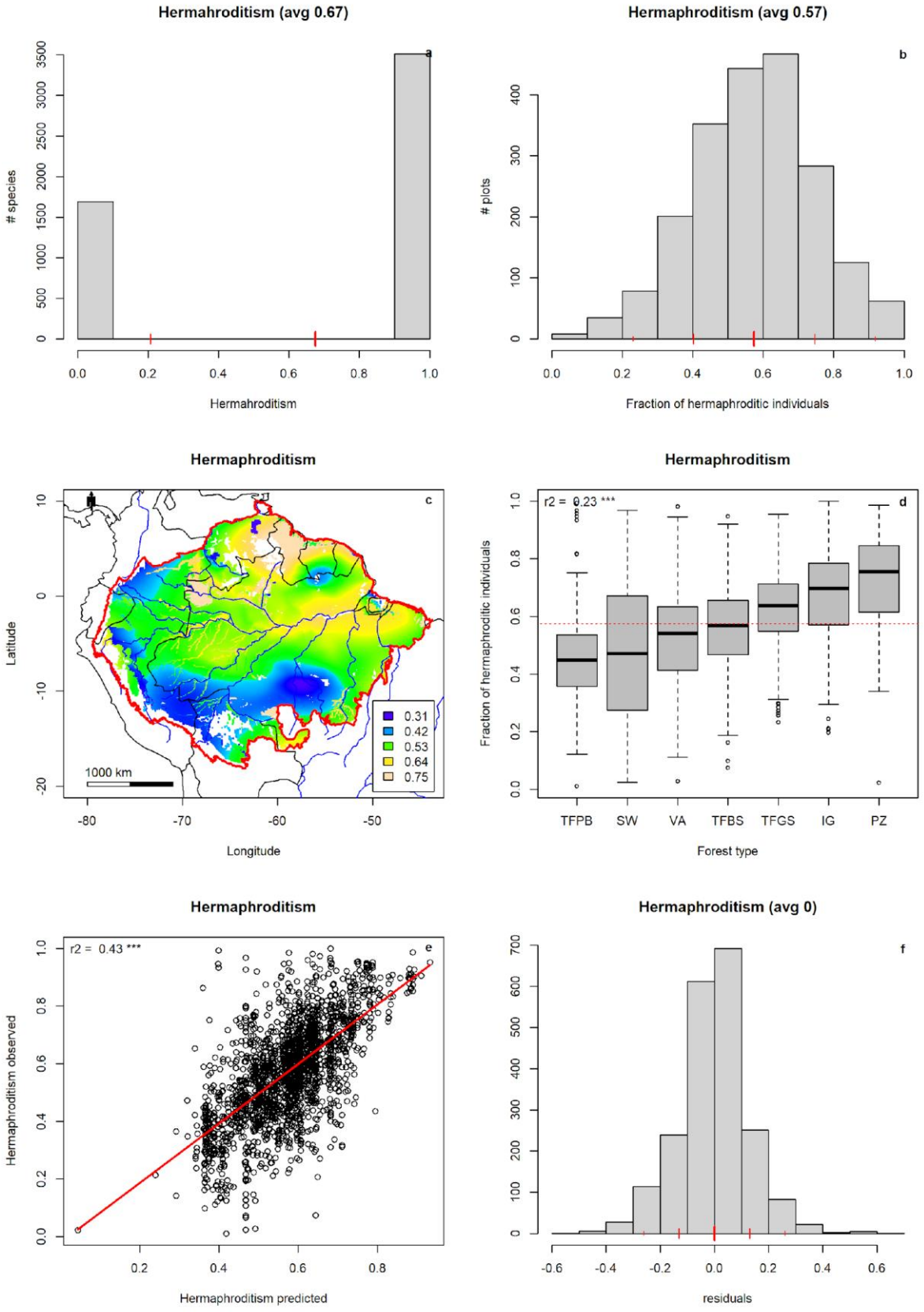
Supplementary Fig. 11. Leaf nitrogen concentration (N: mg/g).



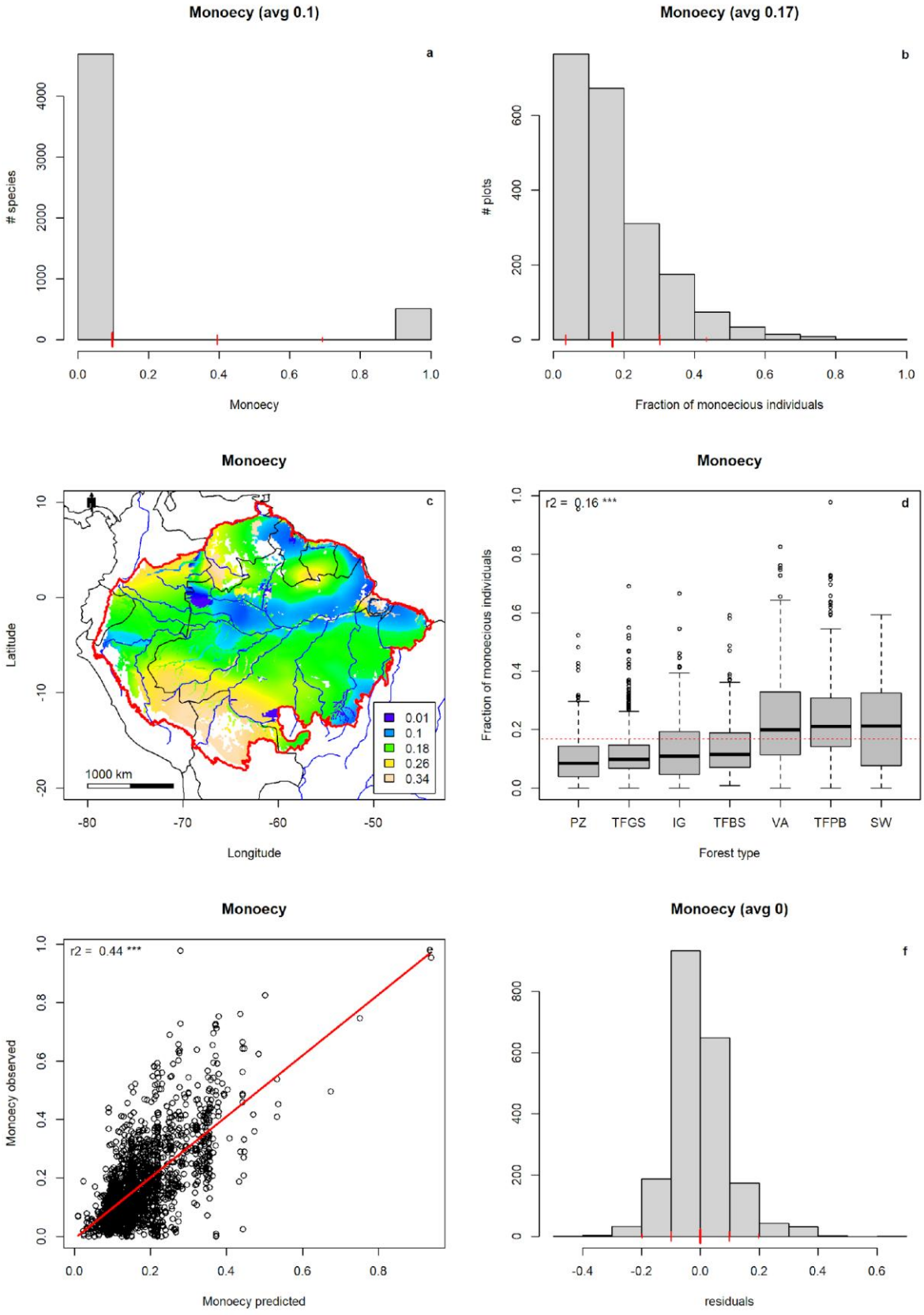
Supplementary Fig. 12. Leaf phosphorus concentration (P: mg/g).



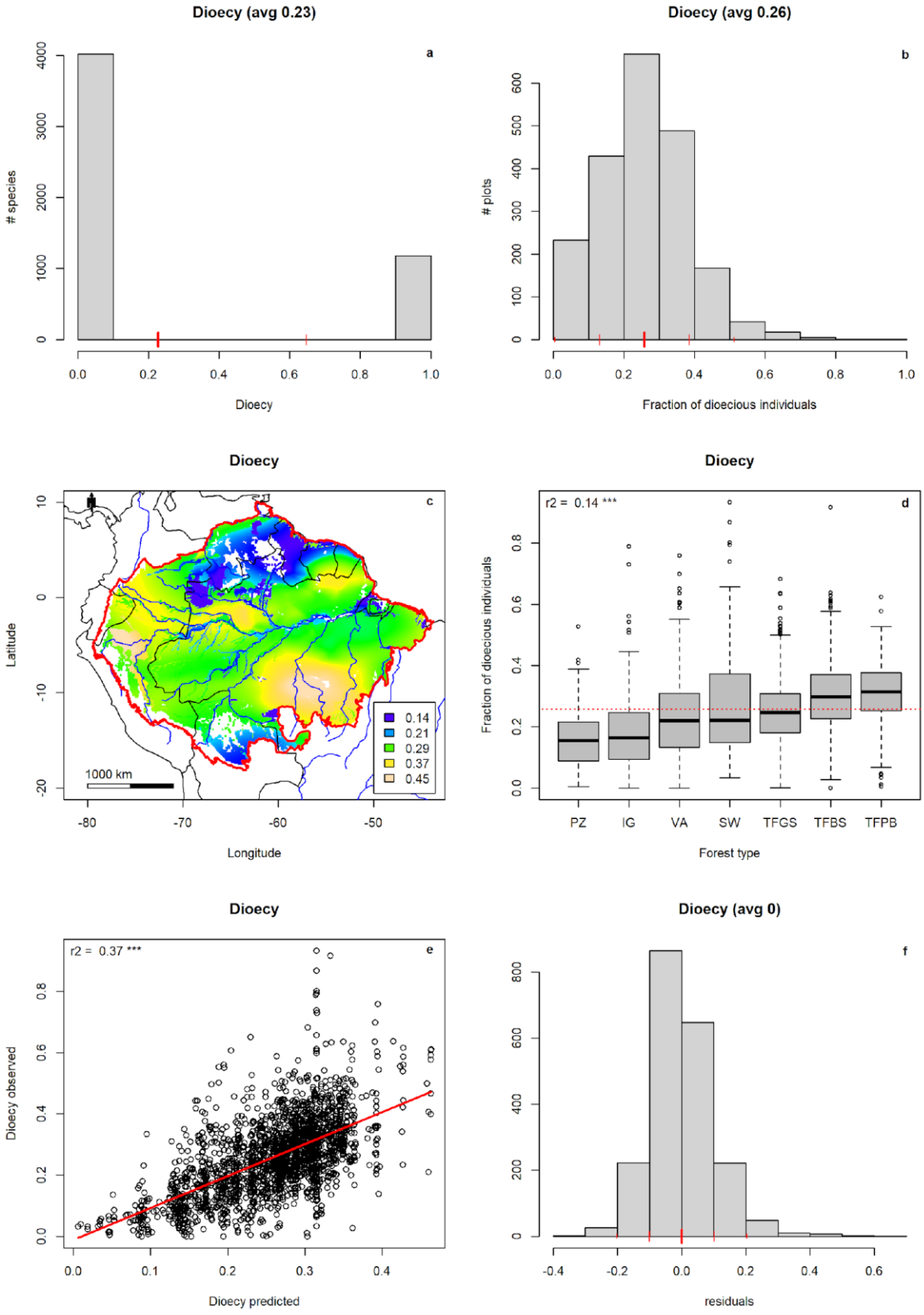
Supplementary Fig. 13. C:N ratio



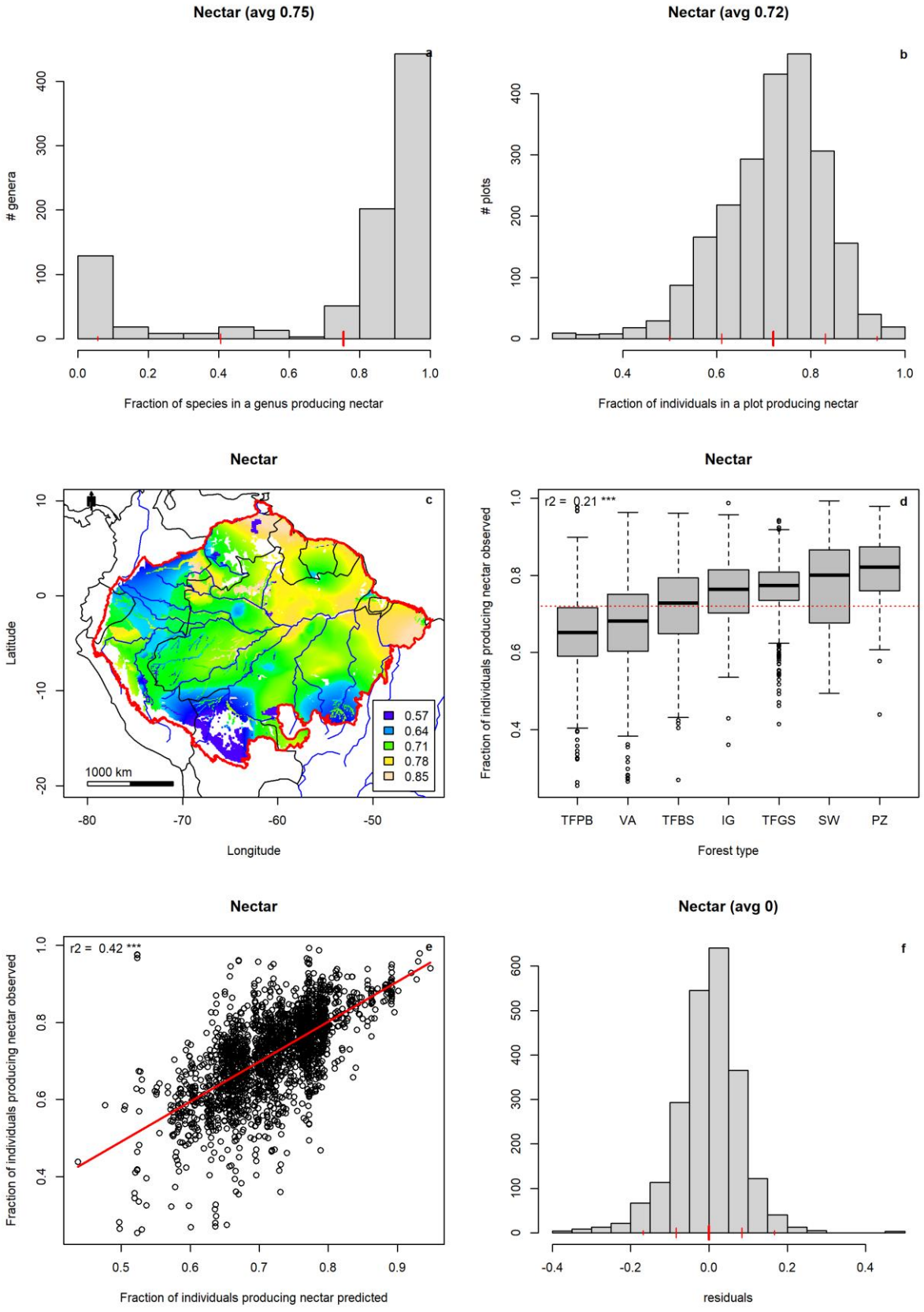
Supplementary Fig. 14 Hermaphroditism (% of individuals).



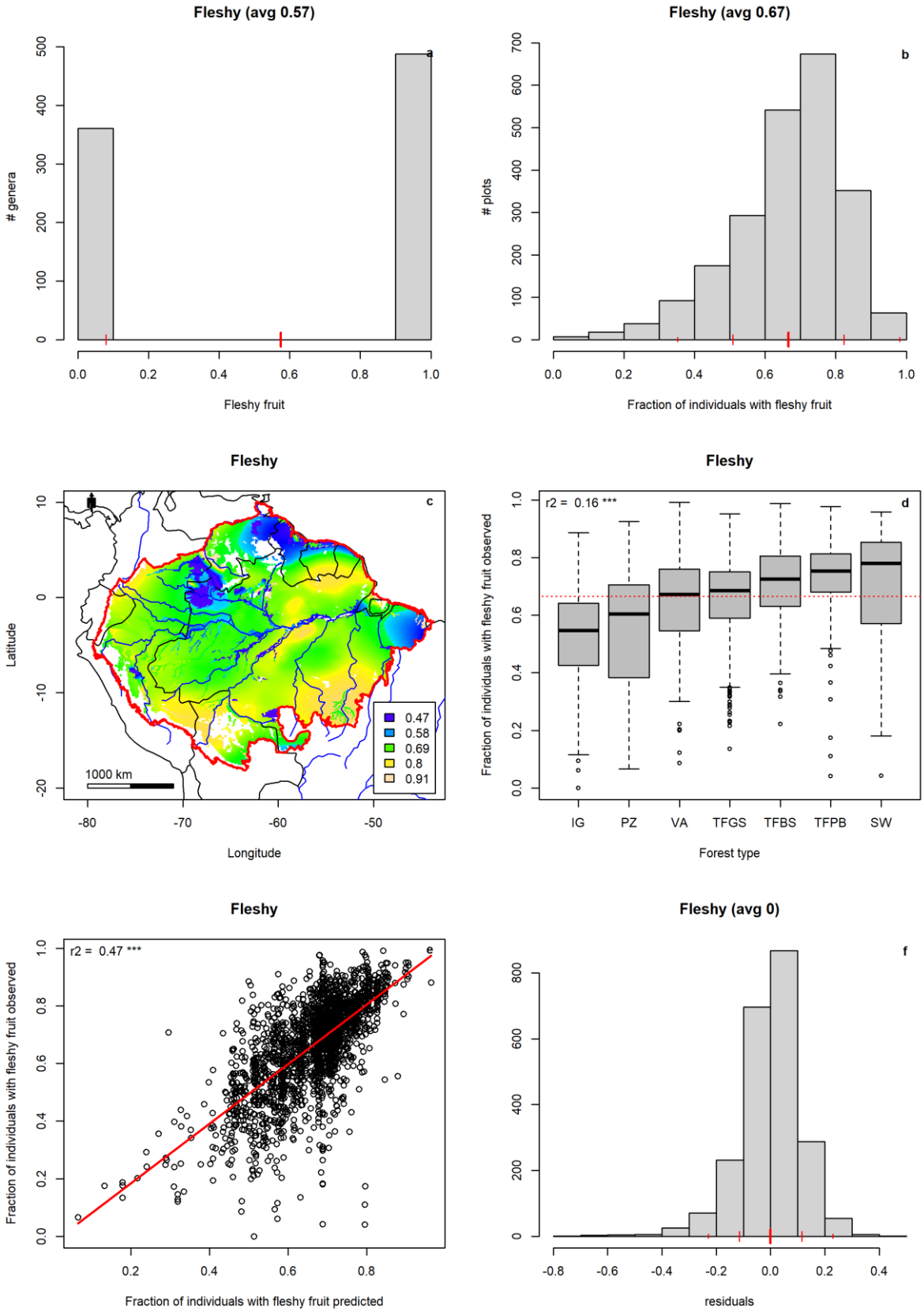
Supplementary Fig. 15 Monoecy (% of individuals).



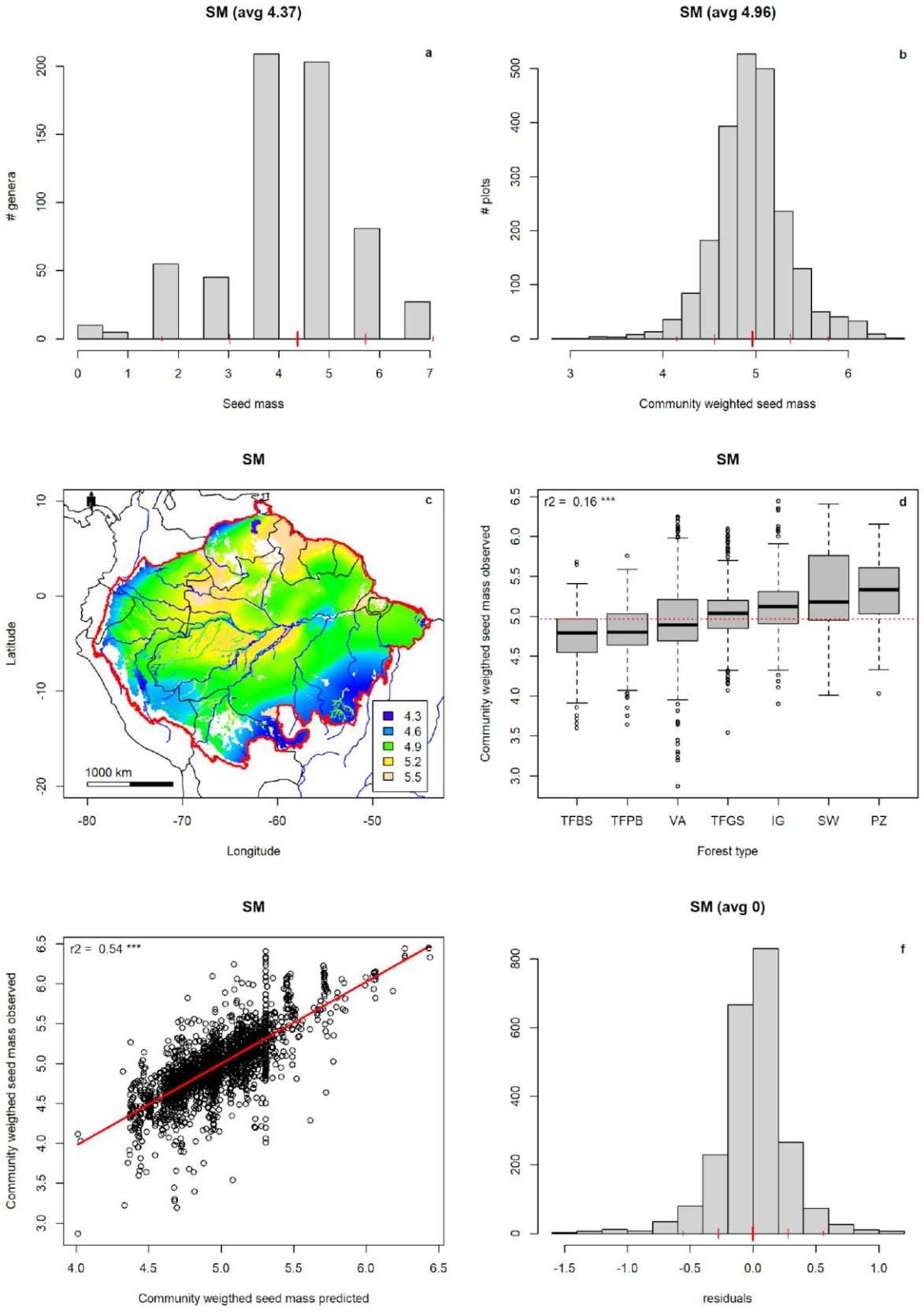
Supplementary Fig. 16 Dioecy (% of individuals).



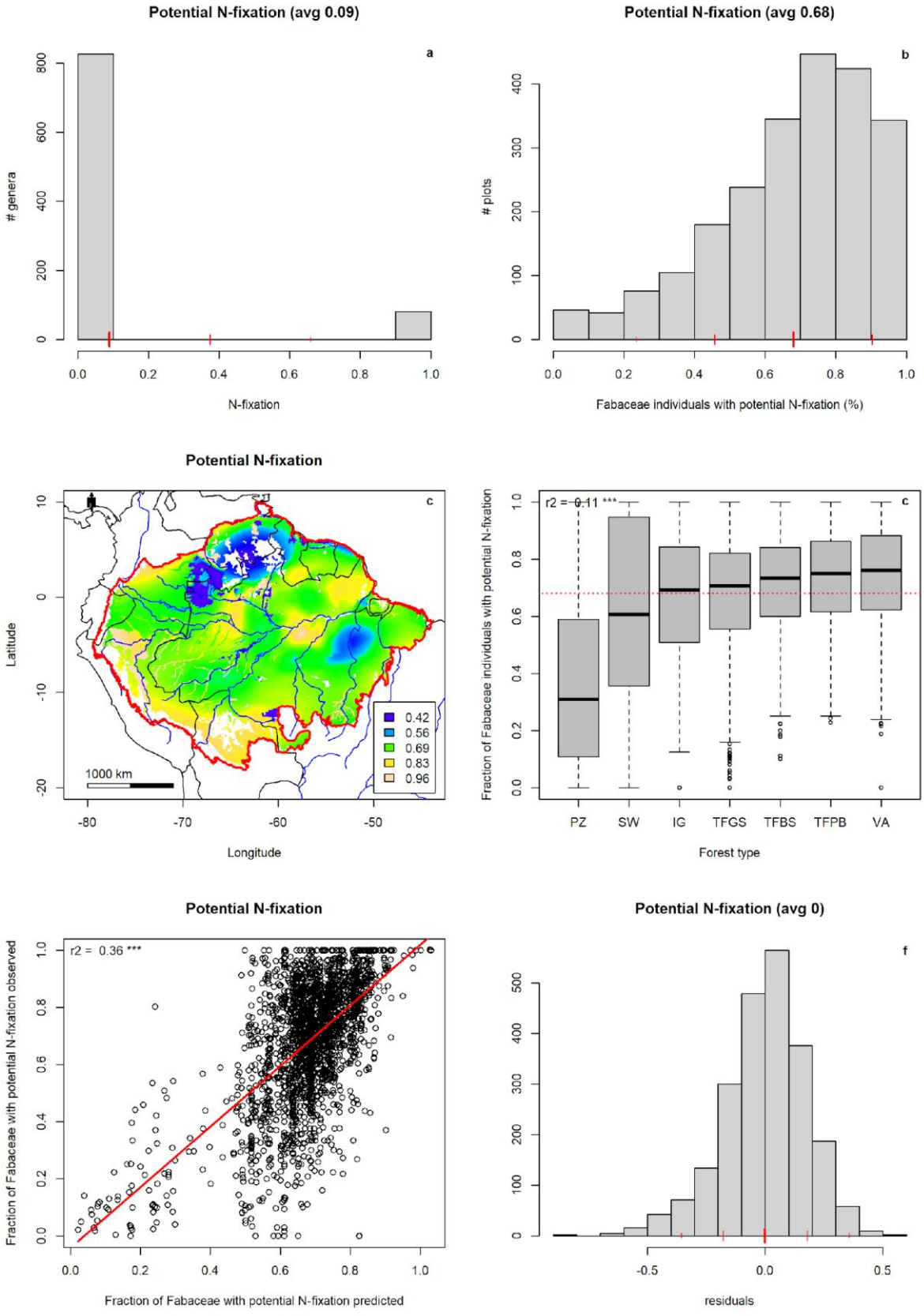
Supplementary Fig. 17 Nectar production (% of individuals).



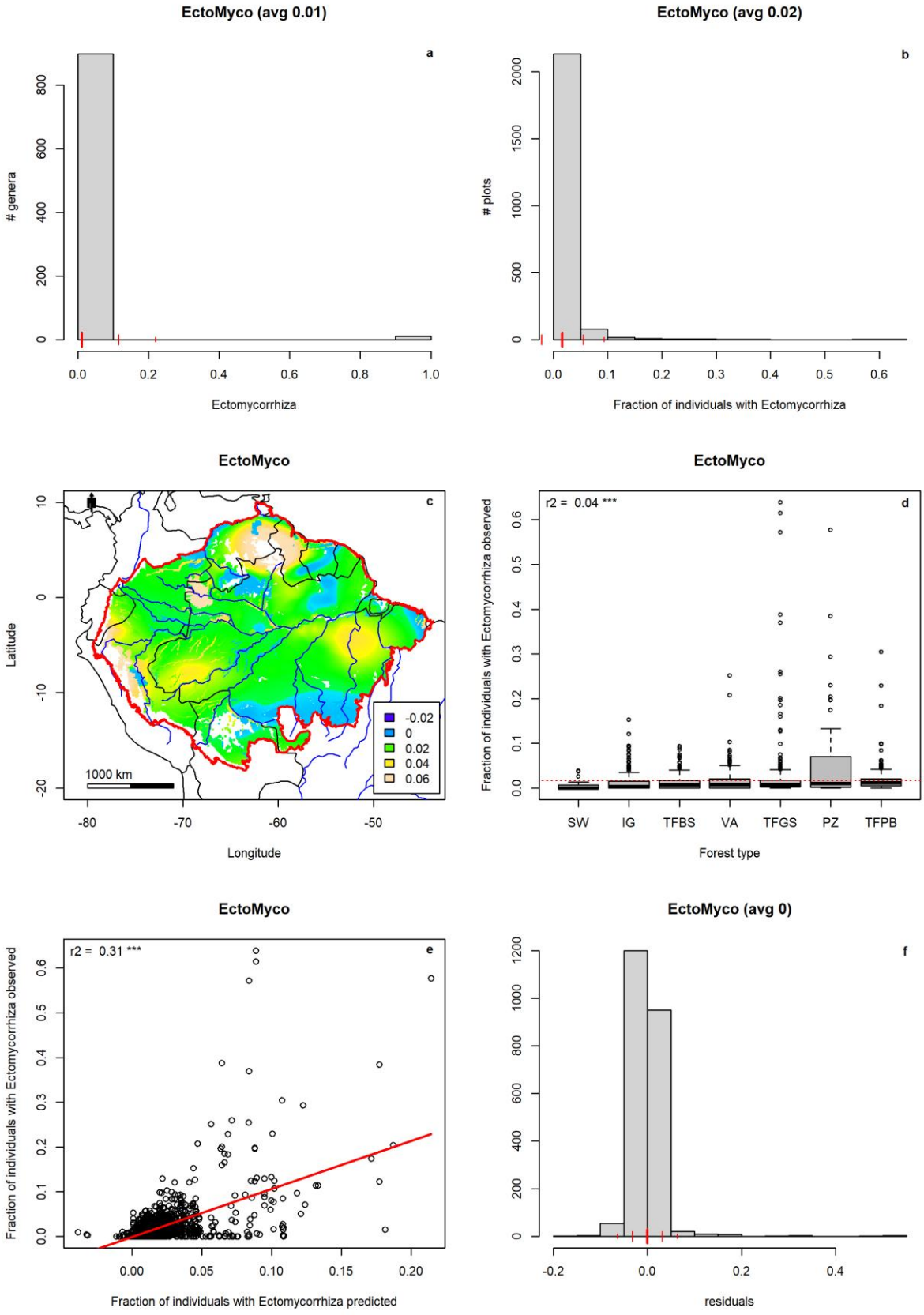
Supplementary Fig. 18 Fruit type (fleshy: % of individuals).



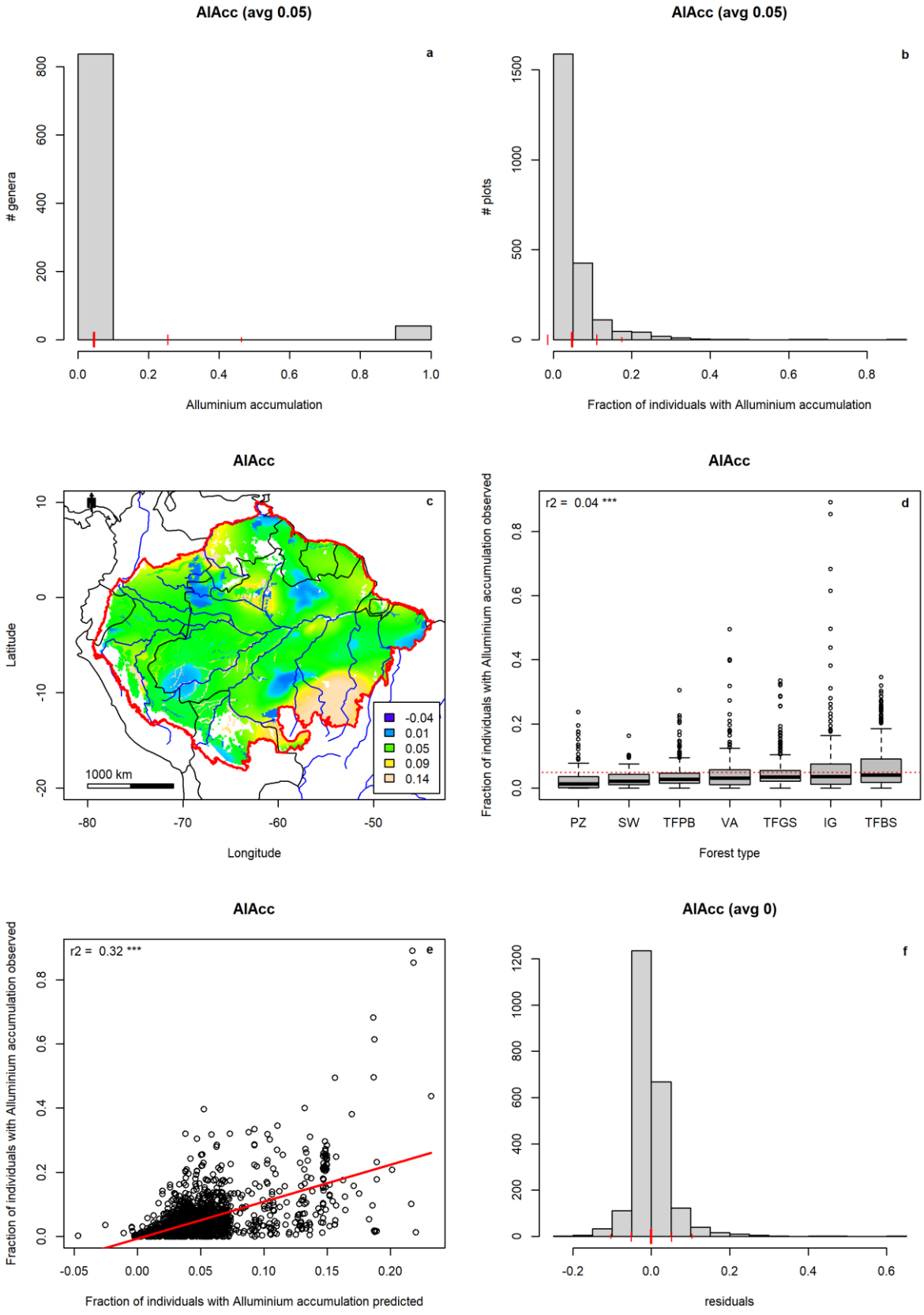
Supplementary Fig. 19 Seed mass (Seed mass class)



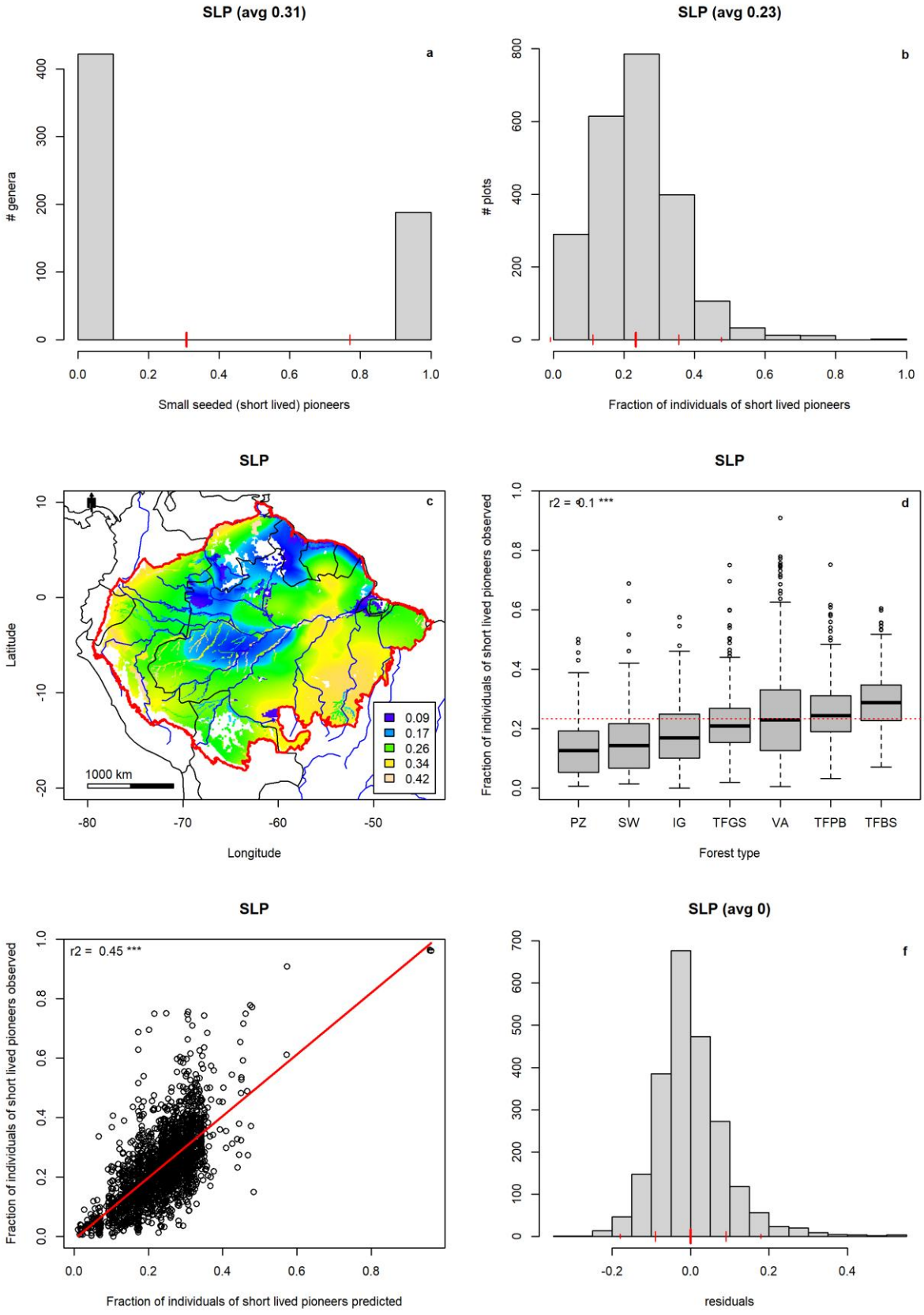
Supplementary Fig. 20 Atmospheric N-fixation (% of individuals of N-fixing Fabaceae)



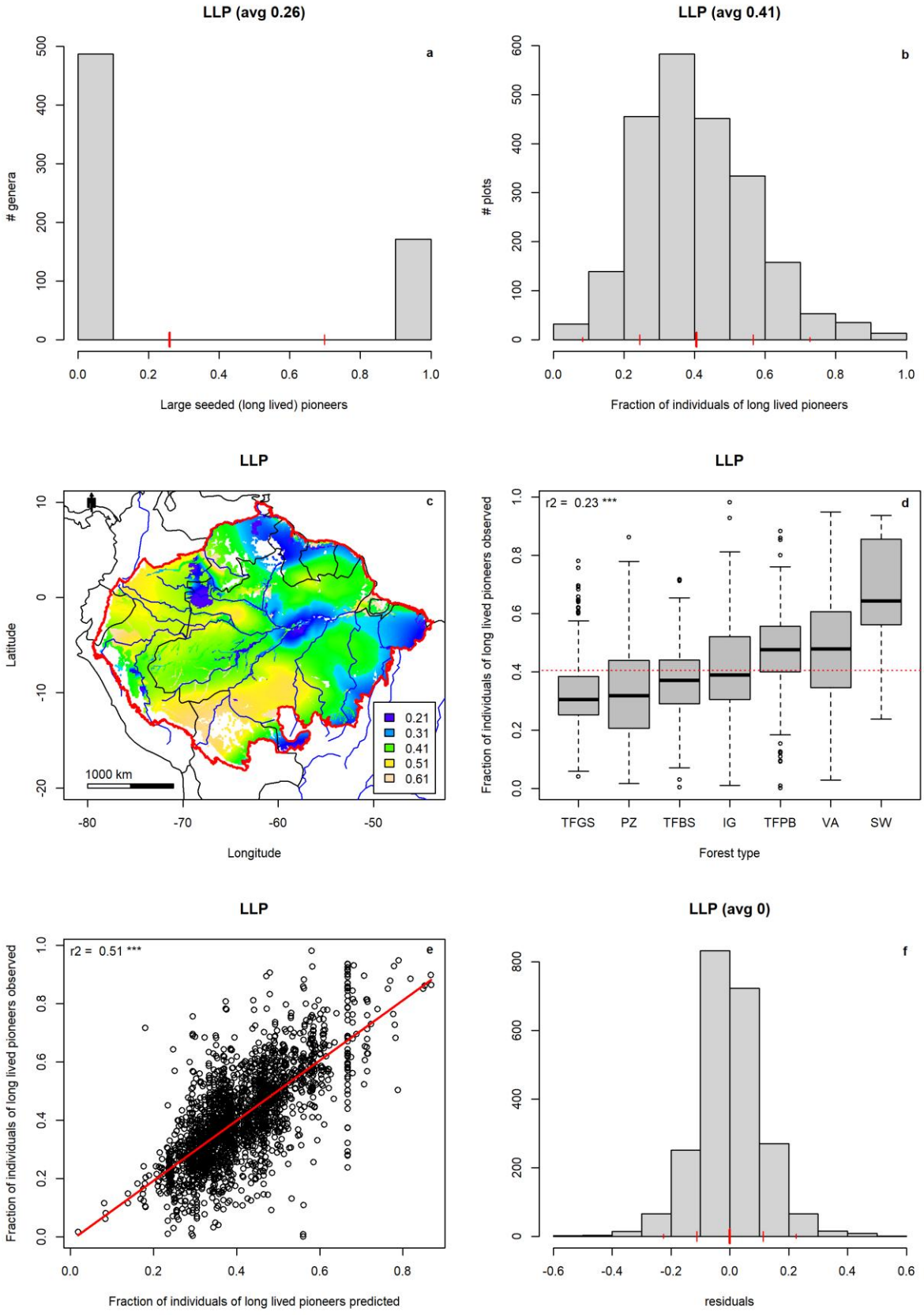
Supplementary Fig. 21 Ectomycorrhiza (% of individuals).



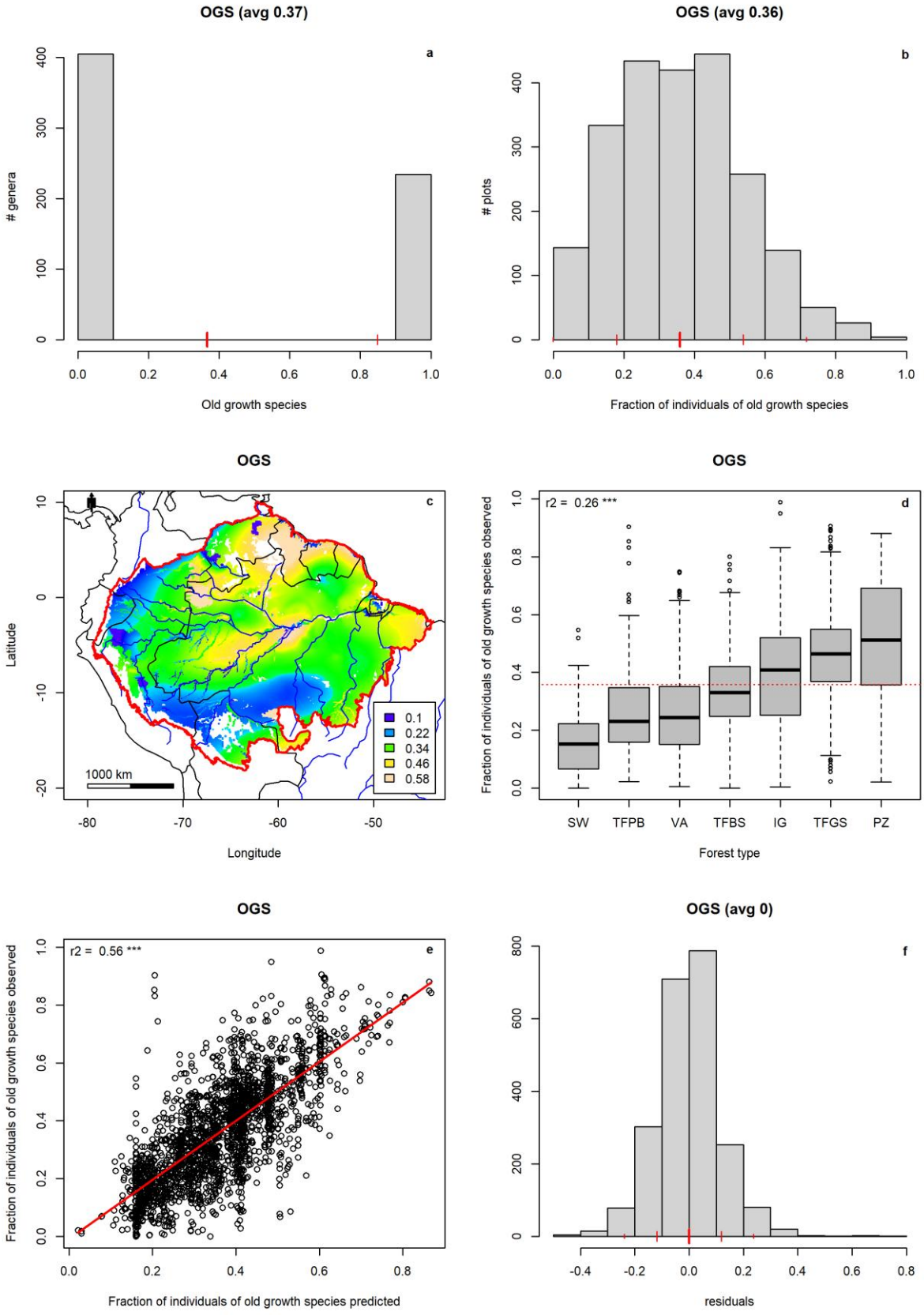
Supplementary Fig. 22 Aluminium accumulation (% of individuals).



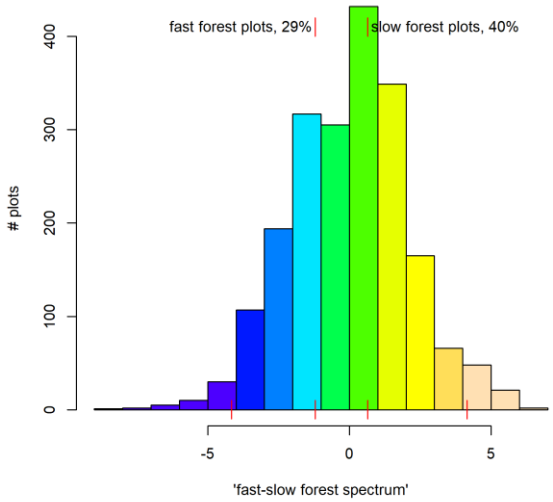
Supplementary Fig. 23 Short lived pioneers (SLP: % of individuals).



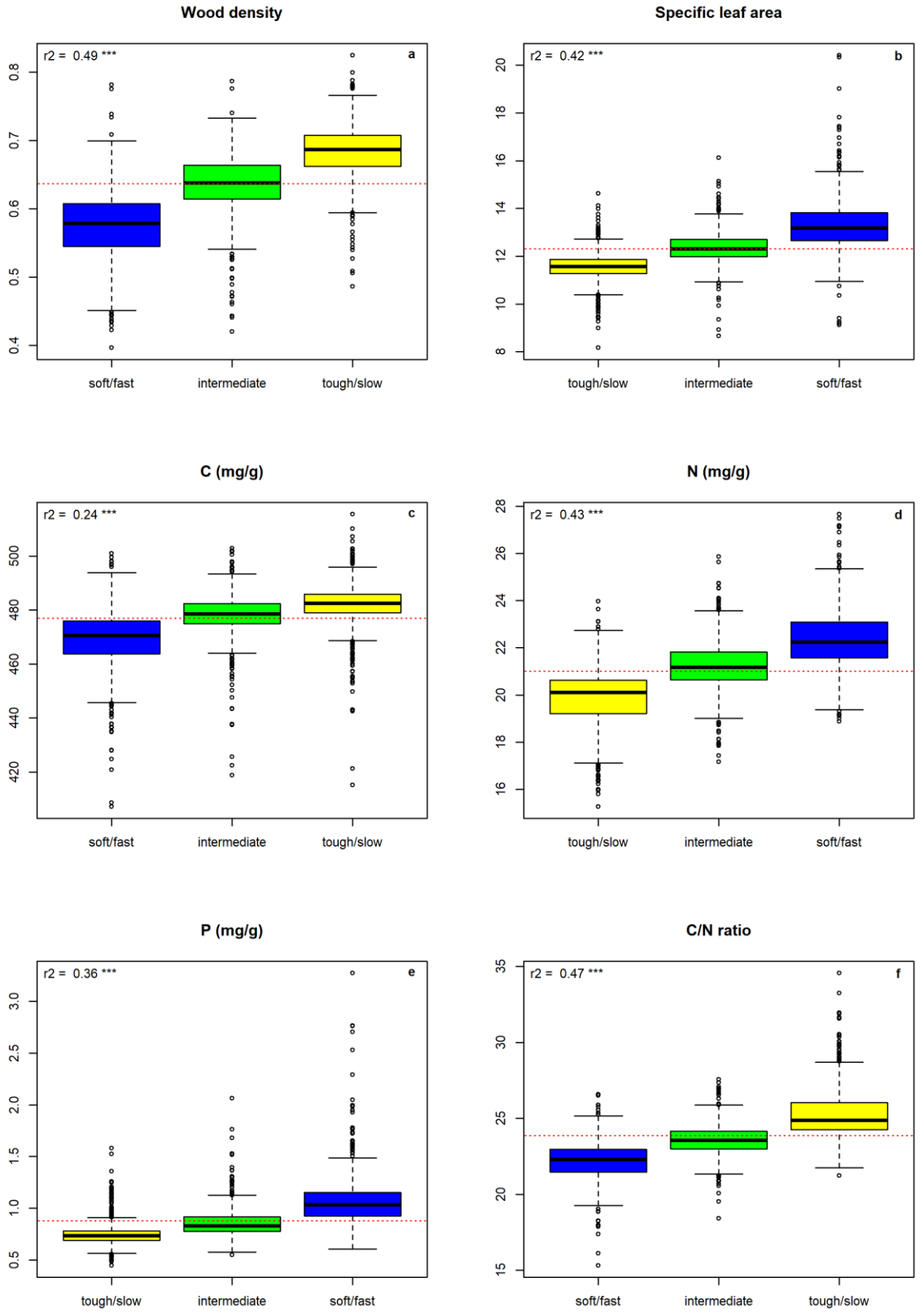
Supplementary Fig. 24 Long lived pioneers (LLP: % of individuals).



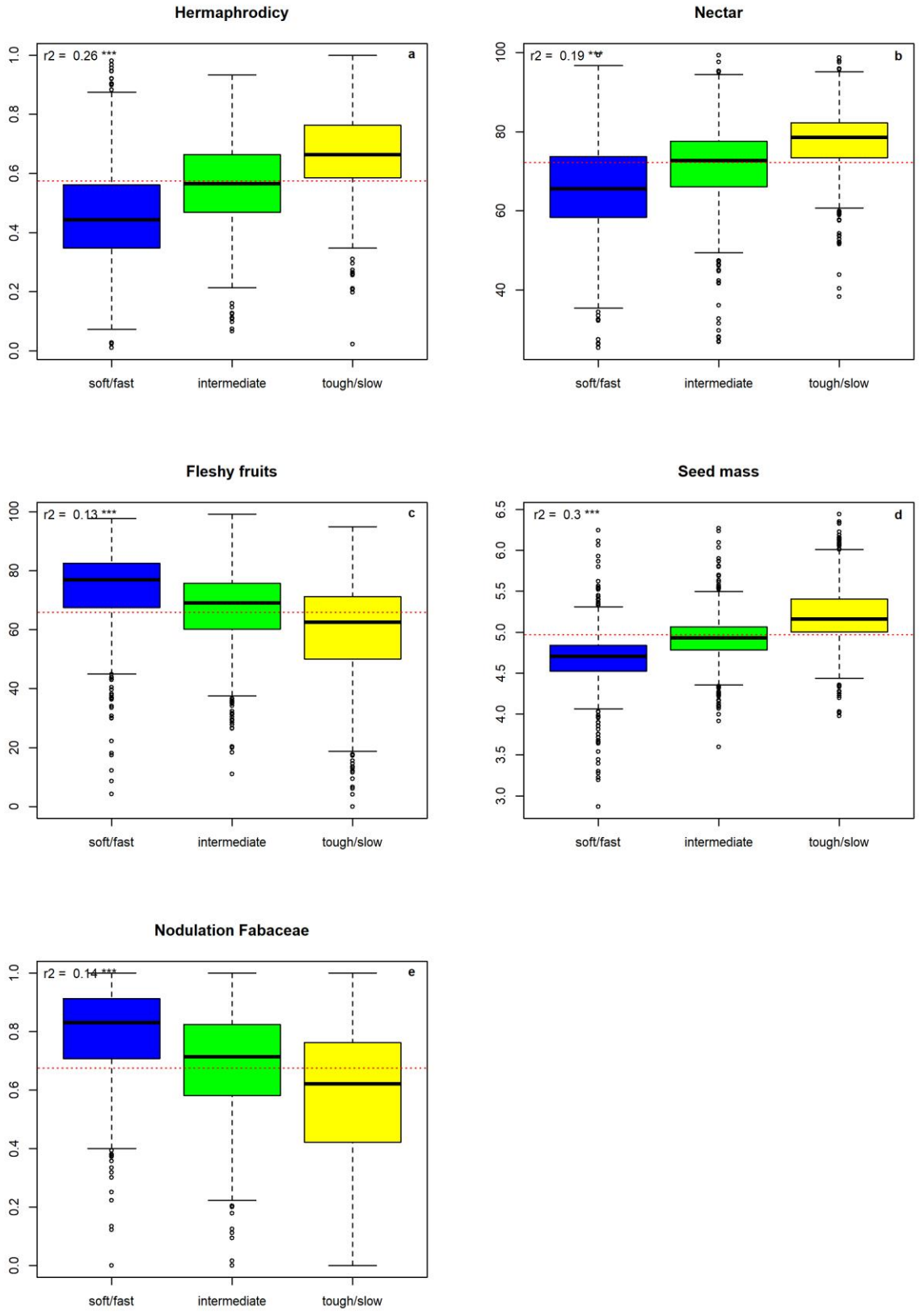
Supplementary Fig. 25 Old growth species (OGS: % of individuals).



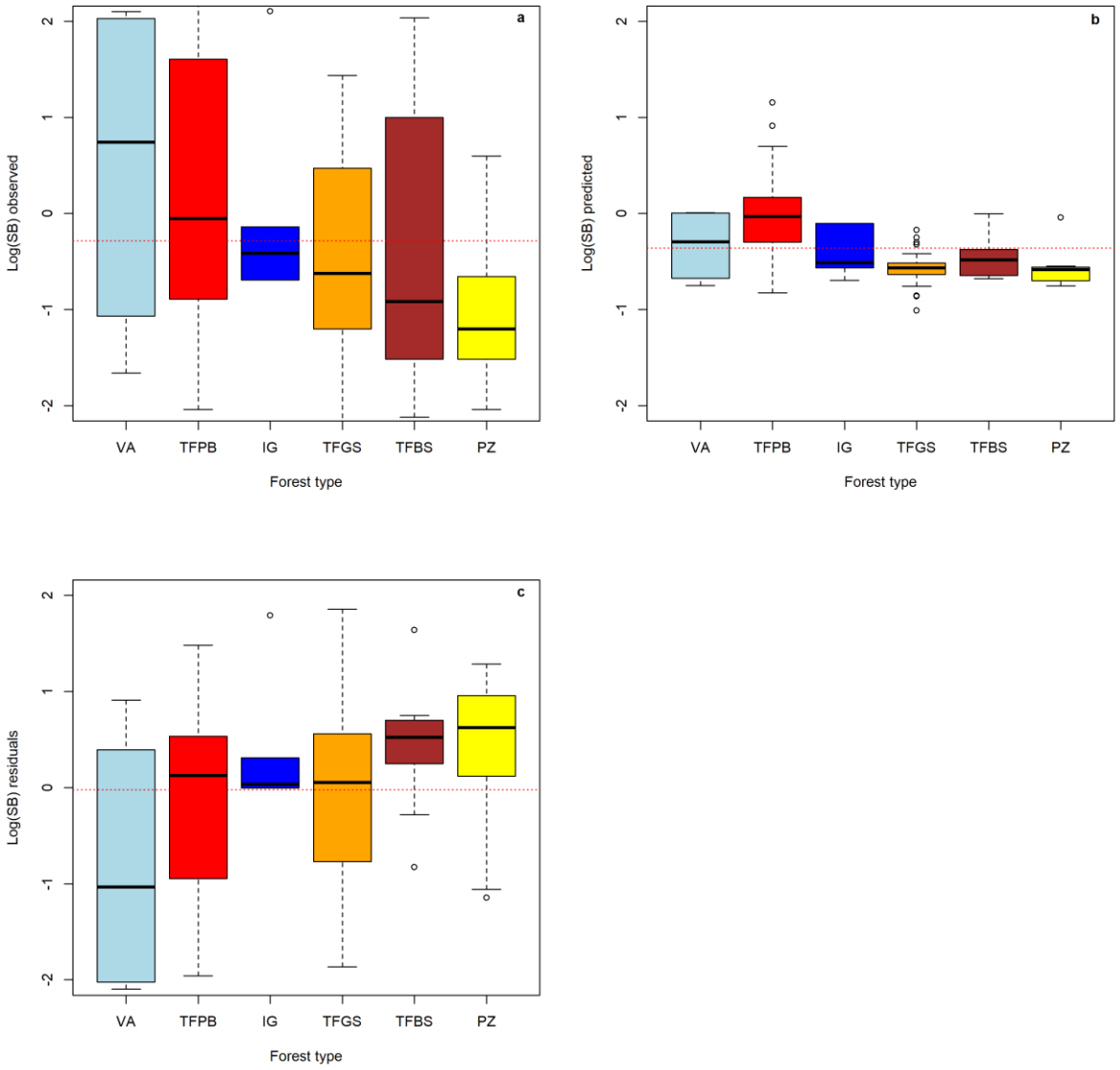
Supplementary Fig. 26. Histogram of the plot score on the 'fast-slow forest spectrum'. Colours are identical to those in Fig. 4. Off all plots 2054, 29% are 'fast forest plots' (value < 1.2); 40% are 'slow forest' plots (score > 0.65), and 31 are intermediate. Outer red lines indicate the 95% confidence interval (2 times the standard away from the mean). Areas left of mean – 2sd are aal given the minimum legend colour, those right of the mean + 2sd are given the maximum legend colour. This is to avoid that in the map (Fig. 4), these strongly influence the visible pattern.



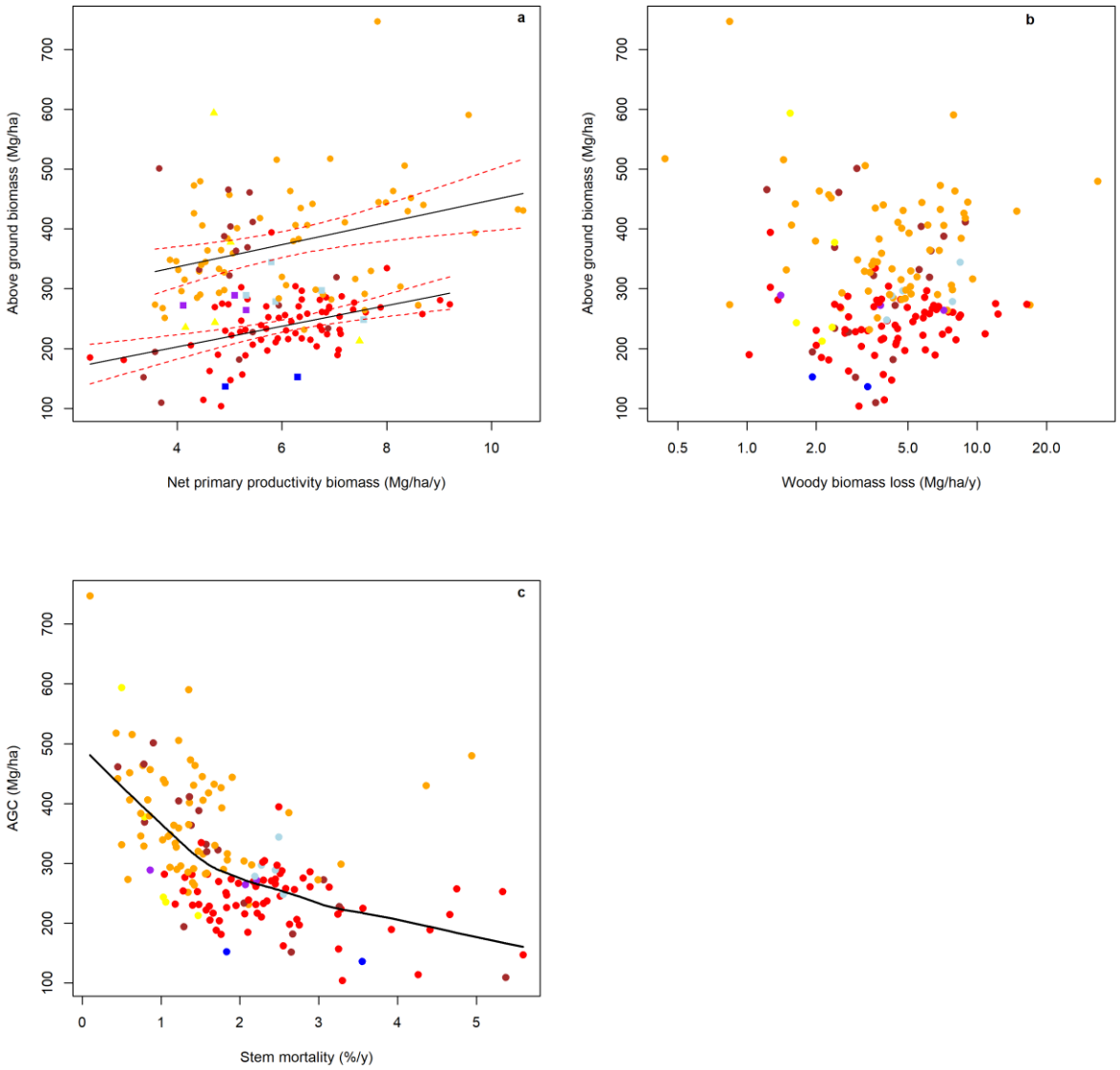
Supplementary Fig. 27. Box plots of six tree functional traits versus 3 classes of PCA 1 scores (soil fertility and productivity) of the community weighted means of plots. Each trait shows a significant cline from low to high or high to low values. Blue: soft and fast; green: intermediate; yellow: tough and slow.



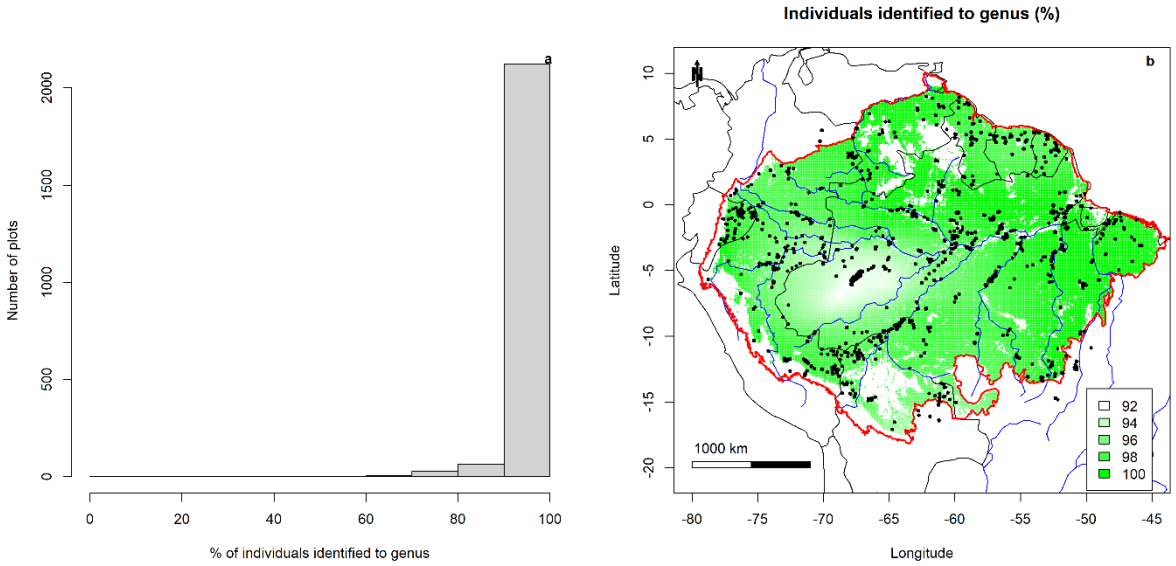
Supplementary Fig. 28. Box plots of five tree functional traits versus 3 classes of PCA 1 scores (soil fertility and productivity) of the community weighted means of plots. Each trait shows a significant cline from low to high or high to low values. Blue: soft and fast; green: intermediate; yellow: tough and slow.



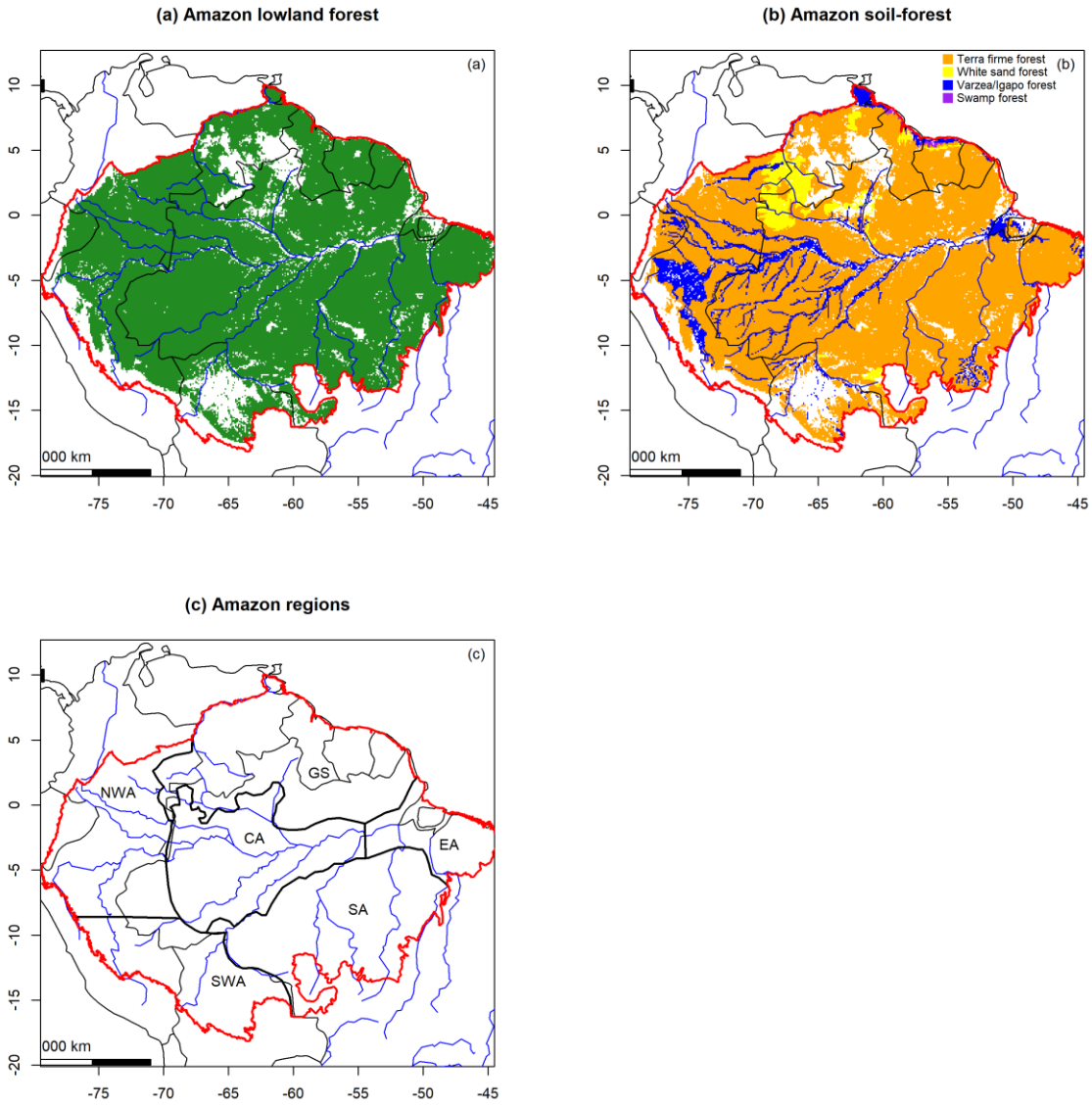
Supplementary Fig. 29 Bias in SB among forest types. **a** Actual log(sum of bases) in soil pits in Amazonia[69], Guyana[70], Suriname[71], in order of decreasing soil fertility. **b** Log(sum of bases) for the locations of A, estimated with the map of Zuquim et al[63]. Order as in a. The spread of the data is very restricted suggesting a high smoothing. **c** Residuals of the model of ref[63] (b – a), order as in a. It is clearly visible that SB of PZ and TFBS is overestimated, while that of VA is strongly underestimated. Legend from rich to poor soils: VA, várzea; TFPB, terra firme Pebas Formation; IG, igapó; TFGS, terra firme Guiana Shield; TFBS, terra firme Brazilian Shield; PZ, white sand forest. Red dashed line: mean of all data.



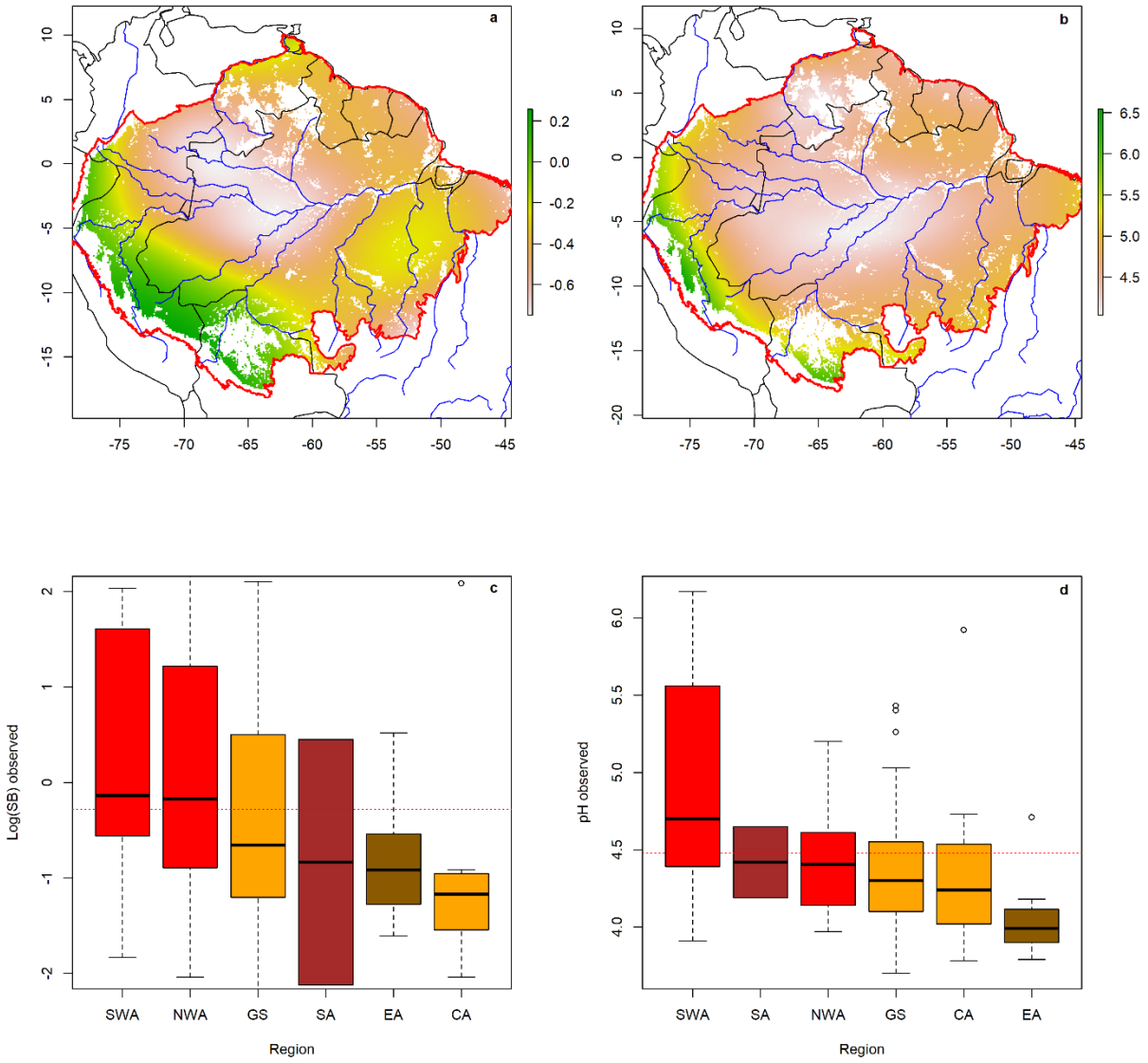
Supplementary Fig. 30 Relationships between above ground carbon (AGC). a. Net primary productivity (NPP) of carbon, **b**. woody carbon loss and **c**. stem mortality rates. The figure is identical to Fig. 4 of Johnson et al.[72], with the difference that we use our forest types here and two non-Amazonian plots were removed. Regression lines in **a** are for TFGS (R^2 = 12%***) and TFPB (R^2 = 19%***). Fitted line in **c** is a loess smoother (span = 0.75) through all data. Note that the biomass values here are twice that of Johnson et al, as we use biomass and not carbon (50% of biomass).



Supplementary Fig. 31 a. Histogram of the percentage of individuals by plot (n = 2253), identified to genus level. **b**. Interpolation of the percentage of individuals by plot, identified to genus level, with loess regression (model: percentage ~ longitude*latitude, span = 0.2, degree = 2). Red polygon: Amazonian Biome limit[60]. Maps created with a custom R[61] script. Base map source (country.shp, rivers.shp): ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company).



Supplementary Fig. 32. Amazonian base maps. A: The Amazonian lowland forest based on land area[73], minus large water bodies[73], minus areas above 500 m elevation[74], and minus areas originally without forest[75,76]. The originally forested area sums to approximately 5.79 million km^2. **B**: Major hydrology-soil-forest combinations of the Amazonian lowland forest with a major distinction in unflooded forests (terra-firme, white sand forest) and forest subject to long-term flooding (várzea, igapó) or waterlogging (swamps). Soils after[77,78]. **C**: Amazonian forest regions[58,59]: GS, Guiana Shield; CA, central Amazonia; EA, eastern Amazonia; SA, southern Amazonia; NWA north-western Amazonia; SWA, south-western Amazonia. Red polygon: Amazonian Biome limit[60]. Maps created with a custom R[61] script. Base map source (country.shp, rivers.shp): ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company)[79].



Supplementary Fig. 33 Major pattern of soil fertility in Amazonia. **a** Slightly smoothed map of sum of bases from Zuquim et al[69], **b** Map of interpolated pH values. Data from Soterlac[77], ISRIC wise[80], RAINFOR sites[69,78], and refs[70,71,81]. **c** Boxplot of Log(sum of bases) by region, based on plot data from RAINFOR sites[69,78], and refs[70,71,81]. **d**. Boxplot of soil pH by region , based on plot data from RAINFOR sites[69,78], and refs[70,71,81]. Legend in order of soil fertility (panel c): SWA, south west Amazonia; NWA, northwest Amazonia; GS, Guiana Shield; SA, southern Amazonia; EA, eastern Amazonia; CA, central Amazonia. Colours follow the major forest type (SWA, NWA: TFPB; SA: TFBS; CA, GS: TFGS; EA: mix of TFBS, TFGS). Red dashed line: mean of all data.

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