Supplementary Material for 'Searching for keystone plant resources in fruit-frugivore interaction networks across the Neotropics' - Messeder JVS, Guerra TJ, Dáttilo W, Silveira FAO 2020 Biotropica

Appendix S1 - List of studies included in the network analysis

1 - Andrade PC et al (2011) Interações mutualísticas entre aves frugívoras e plantas em um fragmento urbano de Mata Atlântica, Salvador, BA. Rev. Bras. Ornitol. 19: 63-73.

2 - Athiê S, Dias MM (2012) Frugivoria por aves em um mosaico de Floresta Estacional Semidecidual e reflorestamento misto em Rio Claro, São Paulo, Brasil. Acta Bot. Brasil. 26: 84-93.

3 - Blake JG, Loiselle BA (1992) Fruits in the Diets of Neotropical Migrant Birds in Costa Rica. Biotropica 24: 200-210.

4 - Blendinger PG et al (2012) Fine-tuning the fruit-tracking hypothesis: spatiotemporal links between fruit availability and fruit consumption by birds in Andean mountain forests. J. Anim. Ecol. 81: 1298–1310.

5 - Carlo TA et al (2003) Avian fruit preferences across a Puerto Rican forested landscape: pattern consistency and implications for seed removal. Oecol. 134: 119-131.

6 - da Silva F et al (2015) The restoration of tropical seed dispersal networks. Restor. Ecol. 23: 852-860.

7 - Darosci AAB et al (2017) Seasonality, diaspore traits and the structure of plant-frugivore networks in Neotropical savanna forest. Acta Oecol. 84: 15-22.

8 - Dáttilo W et al (2016) Unravelling Darwin's entangled bank: architecture and robustness of mutualistic networks with multiple interaction types. Proc. R. Soc. B. 283: 20161564.

9 - Donatti CI et al (2011) Analysis of a hyper-diverse seed dispersal network: modularity and underlying mechanisms. Ecol. Lett. 14: 773-781.

10 - Fadini RF (2004) Interações entre aves frugívoras e plantas em um fragmento de mata atlântica de Minas Gerais. Ararajuba 12: 97-103.

11 - Faustino TC, Machado CG (2006) Frugivoria por aves em uma área de campo rupestre na Chapada Diamantina, BA. Rev. Bras. Ornitol. 14: 137-143.

12 - Galletti M, Pizo MA (1996) Fruit cating birds in a forest fragment in southcastern Brazil. Ararajuba 4: 71-79.

13 - Gorchov DL et al (1995) Dietary overlap between frugivorous birds and bats in the Peruvian Amazon. Oikos 74: 235-250.

14 - Guerra TJ, Pizo MA (2014) Asymmetrical dependence between a Neotropical mistletoe and its avian seed disperser. Biotropica 46: 285-293.

15 - Hawes JE, Peres CA (2014) Fruit–frugivore interactions in Amazonian seasonally flooded and unflooded forests. J. Trop. Ecol. 30: 381-399.

16 - Heleno RH et al (2013) Seed dispersal networks in the Galápagos and the consequences of alien plant invasions. Proc. R. Soc. B 280: 20122112.

17 - Malacco da Silva GB, Pedroni F (2014) Frugivoria por aves em área de cerrado no município de Uberlândia, Minas Gerais. Rev. Árvore 38: 433-442.

18 - Manhães MA et al (2010) Diet of understorey birds in two Atlantic Forest areas of southeast Brazil. J. Nat. Hist. 44: 469-489.

19 - Nogales M et al (2016) Seed-dispersal networks on the Canaries and the Galápagos archipelagos: interaction modules as biogeographical entities. Glob. Ecol. Biogeogr. 25: 912-922.

20 - Ortiz-Pulido R et al (2000) Frugivoría por Aves en un Paisaje Fragmentado: Consecuencias en la Dispersión de Semillas. Biotropica 32: 473-488.

21 - Pizo MA (2004) Frugivory and habitat use by fruit-eating birds in a fragmented landscape of southeast Brazil. Ornitol. Neotrop. 15: 117–126.

22 - Purificação KN et al (2014) Interactions between frugivorous birds and plants in savanna and forest formations of the Cerrado. Biota Neotrop. 14: e20140068.

23 - Ramos-Robles M et al (2016) Temporal changes in the structure of a plant-frugivore network are influenced by bird migration and fruit availability. PeerJ 4: e2048.

24 - Saavedra F et al (2014) Functional importance of avian seed dispersers changes in response to human-induced forest edges in tropical seed-dispersal networks. Oecol. 176: 837-848.

25 - Sarmento R et al (2014) Partitioning of seed dispersal services between birds and bats in a fragment of the Brazilian Atlantic Forest. Zool. 31: 245-255.

26 - Silva WR et al (2002) Patterns of fruit-frugivores interactions in two Atlantic Forest bird communities of South-eastern Brazil: implications for conservation. In: Levey DJ et al (eds.) Seed dispersal and frugivory: ecology, evolution and conservation. Wallinford: CAB International, pp. 423-435.

27 - Snow BK, Snow DW (1971) The feeding ecology of tanagers and honeycreepers in Trinidad. The Auk 88: 291-322.

28 - Stevenson PR et al (2015) Frugivory in canopy plants in a western Amazonian forest: dispersal systems, phylogenetic ensembles and keystone plants. PLOS ONE 10: e0140751.

29 - Wheelwright NT et al (1984) Tropical fruit-eating birds and their food plants: a survey of a Costa Rican lower montane forest. Biotropica 16: 173-192.

Appendix S2 - Supplementary tables

Table S1 - Details about the structure of the Neotropical fruit-frugivore networks sampled. The *p*-value columns show whether nestedness and modularity were significant or not according to comparisons to null models ($p < 0.05$). F = Forest; NF = Non-Forest; Ref column shows the respective paper number on appendix S1.

Country	Lat	Lon	Elevation	Habitat	Plants	Birds	Interactions	Nestedness ($NODF_{zscore}$)	*p*	Modularity (Q_{zscore})	*p*	Niche Overlap	Ref
Argentina	-26.8	-65.3	1000	F	29	27	122	8.228	<0.001	-6.236	<0.001	0.364	4
Bolivia	-16.4	-63.51	2500	F	36	41	127	5.695	<0.001	-2.044	<0.001	0.135	24
Bolivia	-16.4	-63.51	2500	F	20	23	52	3.801	<0.001	-3.878	<0.001	0.220	24
Brazil	-5.43	-67.28	NA	F	71	16	250	7.711	<0.001	-0.772	0.4	0.288	15
Brazil	-5.43	-67.28	NA	F	69	17	316	9.801	<0.001	-1.948	<0.001	0.305	15
Brazil	-8.96	-36.05	500-600	F	28	8	41	0.934	0.183	-0.003	0.2	0.238	25
Brazil	-12.86	-51.26	650	NF	19	31	60	2.408	0.017	-5.190	<0.001	0.075	22
Brazil	-12.86	-51.26	650	F	33	45	128	5.252	<0.001	-3.781	<0.001	0.110	22
Brazil	-12.93	-38.4	30	F	27	18	87	6.244	<0.001	-11.206	<0.001	0.245	1
Brazil	-12.98	-41.33	950	NF	10	9	22	1.665	0.057	-1.928	<0.001	0.207	11
Brazil	-15.95	-47.93	1097	F	13	66	240	9.044	<0.001	-4.609	<0.001	0.431	7
Brazil	-18.95	-48.2	NA	NF	21	33	90	4.771	<0.001	-1.246	<0.001	0.241	17
Brazil	-19.25	-43.55	1100-1400	NF	17	13	57	2.689	0.007	-2.073	<0.001	0.358	14
Brazil	-19.56	-56.23	NA	NF	20	30	105	4.414	<0.001	-1.988	<0.001	0.228	9
Brazil	-20.75	-42.86	550-750	F	25	29	92	6.765	<0.001	-2.489	<0.001	0.168	10
Brazil	-21.61	-43.35	670-800	F	20	11	35	1.701	0.049	-0.913	0.2	0.196	18
Brazil	-21.7	-43.88	1050–1784	F	14	15	41	3.109	0.006	-3.099	<0.001	0.243	18
Brazil	-22.48	-47.6	NA	F	13	37	125	5.776	<0.001	-4.395	<0.001	0.326	2
Brazil	-22.56	-47.5	NA	F	32	31	159	8.804	<0.001	-1.900	<0.001	0.256	6
Brazil	-22.66	-47.2	NA	F	18	15	40	2.516	0.01	-1.348	<0.001	0.256	6
Brazil	-22.81	-47.1	640	F	35	29	146	6.430	<0.001	-3.061	<0.001	0.192	12
Brazil	-22.81	-47.41	NA	F	15	17	36	3.252	0.001	-3.428	<0.001	0.186	6
Brazil	-22.95	-46.73	800	F	13	48	124	8.304	<0.001	-2.081	<0.001	0.211	21
Brazil	-24.43	-48.66	800-1000	F	178	86	985	11.175	<0.001	-4.254	<0.001	0.102	26
Colombia	2.66	-70.16	350-400	F	60	120	590	12.830	<0.001	-2.096	<0.001	0.148	28
Costa Rica	10.41	-84.01	NA	F	100	21	201	8.137	<0.001	-6.187	<0.001	0.404	29
Costa Rica	10.3	-84.8	1350-1550	F	169	40	666	11.358	<0.001	0.938	0.2	0.182	3
Ecuador	-0.66	-90.55	0-1707	NF	25	18	91	5.746	<0.001	-2.423	<0.001	0.303	16
Ecuador	-0.75	-89.43	400-864	NF	43	15	97	4.357	<0.001	-2.803	<0.001	0.230	19
Mexico	19.6	-96.36	100	F	27	46	128	5.983	<0.001	-2.437	<0.001	0.101	8
Mexico	19.6	-96.36	50	F	44	42	221	8.156	<0.001	-2.664	<0.001	0.146	23
Mexico	19.6	-96.36	100	F	26	47	132	6.233	<0.001	-1.097	0.2	0.100	20
Peru	-4.91	-73.75	130	F	42	7	77	3.948	<0.001	-0.180	0.2	0.331	13
Puerto Rico	18.31	-66.73	430	F	25	16	68	5.486	<0.001	-3.466	<0.001	0.280	5
Puerto Rico	18.31	-66.55	300	F	21	15	51	3.608	<0.001	-1.822	<0.001	0.241	5
Puerto Rico	18.25	-66.53	650	F	34	20	95	5.887	<0.001	-5.494	<0.001	0.307	5
Puerto Rico	18.16	-66.58	250	F	25	13	49	3.199	0.002	-1.989	<0.001	0.216	5
Trinidad	10.98	-61.05	NA	F	50	14	234	6.868	<0.001	-3.018	<0.001	0.333	27

Table S2 - Global Moran's I analysis of spatial autocorrelation of keystone plant resources removal simulations effects on network descriptors. Results revealed no strong evidence of significant spatial autocorrelation. Shown are the observed Global Moran's I values (MI) and associated *p*-values, with numbers in bold showing significant correlations ($p < 0.05$).

KPR Genera	Network metrics		
	Nestedness	**Modularity**	**Niche overlap**
Miconia	MI = 0.062, p = 0.26	MI = 0.085, p = 0.15	MI = -0.004, p = 0.66
Cecropia	MI = 0.047, p = 0.31	MI = -0.048, p = 0.94	MI = 0.009, p = 0.72
Ficus	MI = -0.005, p = 0.64	MI = 0.010, p = 0.57	MI = -0.011, p = 0.73
Psychotria	MI = 0.084, p = 0.19	MI = 0.000, p = 0.53	**MI = 0.198, p = 0.01**
Clusia	MI = -0.140, p = 0.61	MI = -0.065, p = 0.90	MI = -0.059, p = 0.74
Byrsonima	MI = -0.071 p = 0.42	MI = -0.032, p = 0.16	MI = -0.168, p = 0.51

Table S3 - Plant families recorded in all the 38 fruit-frugivore networks and number of species per family recorded.

Family	Species recorded	Family	Species recorded	Family	Species recorded	Family	Species recorded
Melastomataceae	142	Myristicaceae	11	Erythroxylaceae	4	Amaranthaceae	1
Rubiaceae	86	Myrsinaceae	11	Monimiaceae	4	Asparagaceae	1
Lauraceae	63	Rosaceae	11	Ochnaceae	4	Calophyllaceae	1
Myrtaceae	62	Viscaceae	11	Passifloraceae	4	Campanulaceae	1
Moraceae	47	Anacardiaceae	10	Phytolaccaceae	4	Capparaceae	1
Fabaceae	41	Bromeliaceae	10	Bignoniaceae	3	Cyperaceae	1
Solanaceae	39	Gesneriaceae	10	Chloranthaceae	3	Goupiaceae	1
Urticaceae	29	Apocynaceae	9	Commelinaceae	3	Haemodoraceae	1
Arecaceae	27	Symplocaceae	9	Cucurbitaceae	3	Heliconiaceae	1
Euphorbiaceae	21	Ericaceae	8	Menispermaceae	3	Hypericaceae	1
Sapindaceae	21	Nyctaginaceae	8	Pentaphylacaceae	3	Hypoxiaceae	1
Boraginaceae	20	Sapotaceae	8	Simaroubaceae	3	Lacistemataceae	1
Clusiaceae	20	Verbenaceae	8	Sterculiaceae	3	Loasaceae	1
Loranthaceae	20	Asteraceae	7	Adoxaceae	2	Magnoliaceae	1
Araliaceae	19	Dilleniaceae	7	Caryocaraceae	2	Metteniusaceae	1
Meliaceae	19	Lecythidaceae	7	Chrysobalanaceae	2	Musaceae	1
Annonaceae	17	Marcgraviaceae	7	Connaraceae	2	Oleaceae	1
Rutaceae	16	Phyllanthaceae	7	Ebenaceae	2	Papaveraceae	1
Cactaceae	15	Aquifoliaceae	6	Elaeocarpaceae	2	Peraceae	1
Poaceae	15	Primulaceae	6	Humiriaceae	2	Podocarpaceae	1
Malpighiaceae	14	Smilacaceae	6	Icacinaceae	2	Putranjivaceae	1
Malvaceae	14	Vitaceae	6	Loganiaceae	2	Sabiaceae	1
Salicaceae	13	Cannabaceae	5	Onagraceae	2	Strelitziaceae	1
Araceae	12	Combretaceae	5	Portulacaceae	2	Styracaceae	1
Piperaceae	12	Lamiaceae	5	Siparunaceae	2	Thymelaeaceae	1
Burseraceae	11	Polygonaceae	5	Winteraceae	2	Zingiberaceae	1
Celastraceae	11	Rhamnaceae	5	Achatocarpaceae	1	Santalaceae	1

Table S4 - Table showing the mean, range and standard error (SE) of the relative change caused by each keystone resource genera removal simulation on each network descriptor evaluated. All values are expressed in percentages. N represents the number of networks that each plant genus were sampled.

KPR	**Network metrics**		
	Nestedness	**Modularity**	**Niche overlap**
Miconia (n = 28)			
Mean	-9.32	4.44	-5.04
Range	7.18 to -55.86	37.66 to -6.83	3.13 to -19.28
SE	1.56	1.02	0.83
Cecropia (n = 24)			
Mean	-4.39	2.95	-1.92
Range	4.30 to -25.54	23.35 to -10.60	2.21 to -10.67
SE	0.88	0.57	0.53
Ficus (n = 24)			
Mean	-2.48	1.88	0.11
Range	8.83 to -30.01	11.47 to -3.07	10.37 to -6.86
SE	0.90	0.58	0.53
Psychotria (n = 15)			
Mean	-1.02	-0.12	-1.64
Range	5.45 to -10.57	8.97 to -5.07	8.88 to -22.07
SE	1.40	0.89	0.69
Clusia (n = 13)			
Mean	1.62	2.29	2.29
Range	25.49 to -17.83	11.75 to -5.93	30.11 to -6.74
SE	1.03	0.68	0.70
Byrsonima (n = 9)			
Mean	-1.35	1.09	-2.37
Range	4.23 to -4.27	4.36 to -0.80	-0.03 to -5.39
SE	1.74	1.21	0.45

Table S5 - Results of generalized linear models of the relative change caused by keystone plant resource genus removal simulations and ecological gradients (latitude and elevation) on each network metric evaluated (GLM Gaussian distribution/identity link function **-** $p < 0.05$).

Models and variables	*F*	*p*-value
Nestedness		
KPR:Latitude	0.1669	0.974
KPR:Elevation	1.0725	0.410
Modularity		
KPR:Latitude	0.1899	0.9658
KPR:Elevation	1.0390	0.451
Niche overlap		
KPR:Latitude	0.4270	0.828
KPR:Elevation	0.6144	0.945

Appendix S3 - Supplementary figures

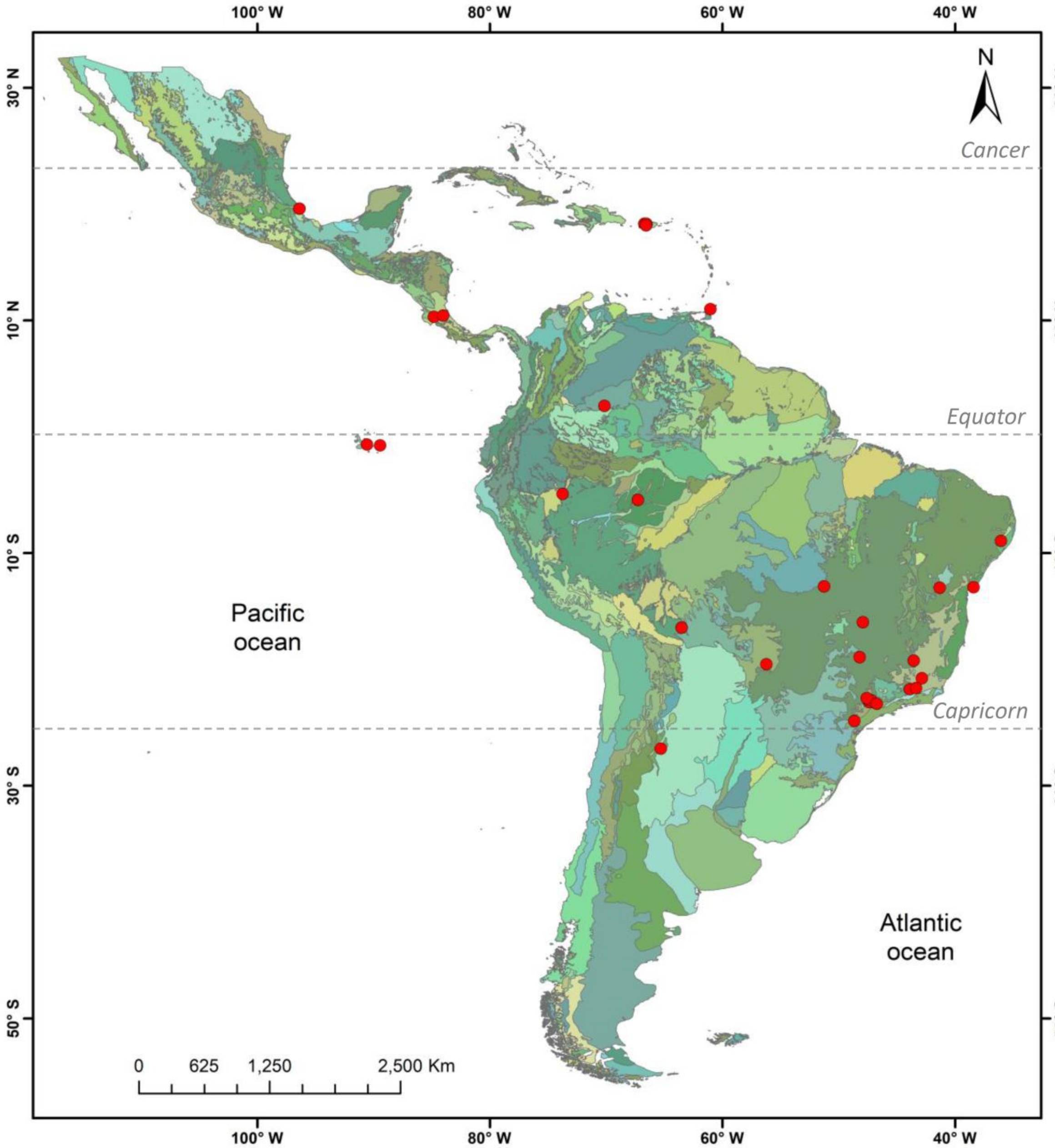

Fig. S1 - Geographical location of the Neotropical region with the red dots representing the sites where fruit-frugivore networks were sampled (some dots are overlapped due to sampling on very close locations). Background colors represent the diversity of ecoregions throughout the Neotropics following Olson et al., 2001.

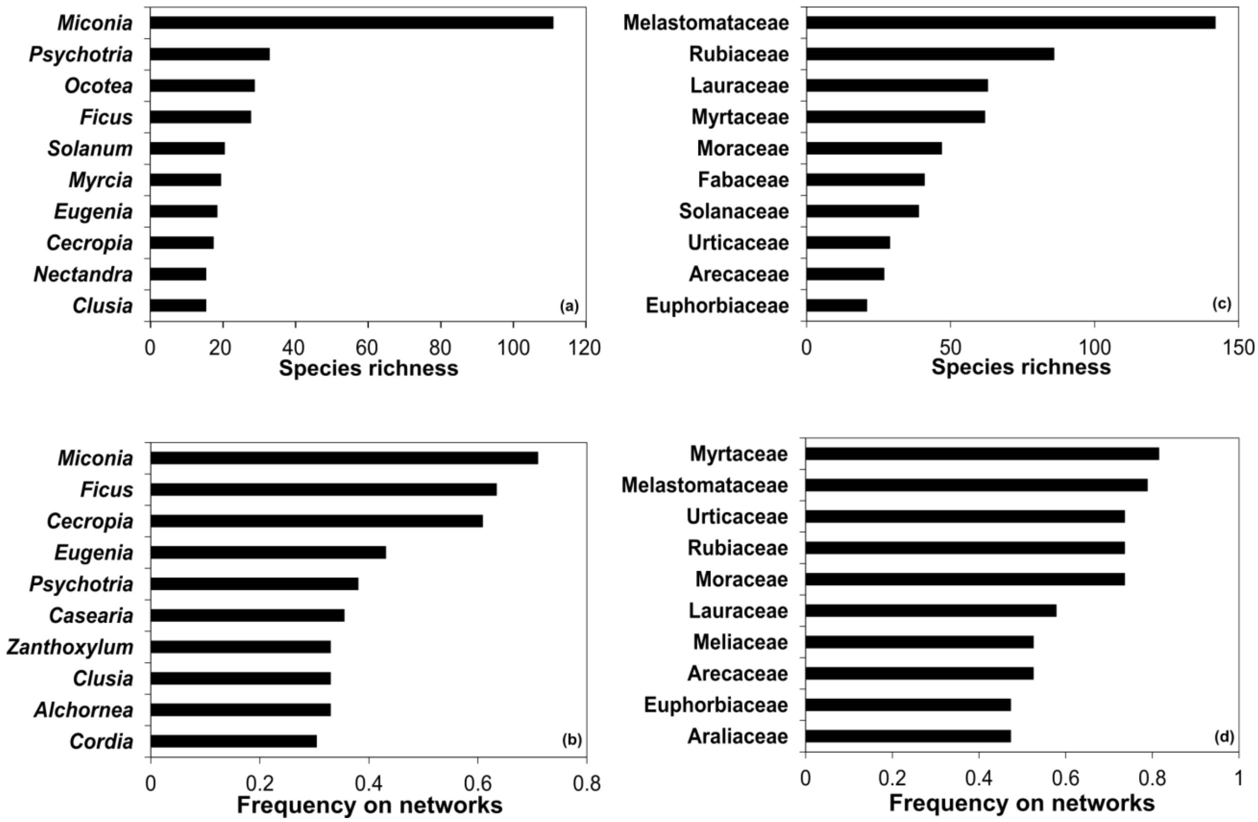

Fig. S2 - Bar charts showing the species richness and frequency on networks for plant genera (a, b) and families (c, d).