Biodiversity components mediate the response to forest loss and the effect on ecological processes of plant-frugivore assemblages

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Supporting Information

Appendix S1. Relationships between plant and bird species richness and phylogenetic diversity (MPD), trait-based functional diversity (FDis), functional complementarity (<d´> and forest cover.

Table S1. Values and degrees of significance of Pearson's coefficient of correlation between plant and bird species richness (SR) in the local assemblages of fourteen study plots, and the corresponding plant/bird phylogenetic diversity (MPD), trait-based functional diversity (FDis) and functional complementarity (<d´>): all three metrics estimated as standardized effect size values. Code for statistical significance: *$P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

Trophic level	MPD	FDis	<d´>
Plant SR	0.71**	0.17	-0.05
Bird SR	0.69**	0.59*	0.72**

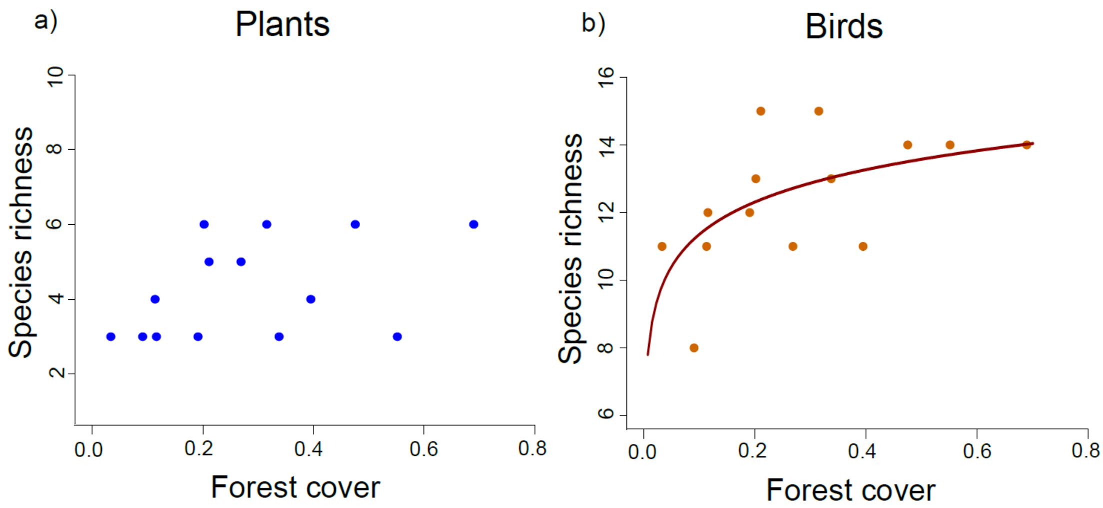

Figure S1. Relationship between species richness and forest cover (log-transformed) for a) plants and b) birds across fourteen study plots. Logarithmic trend line based on a linear model: Forest cover has a significant positive effect on bird species richness (t= 2.53, P = 0.03, N =14), but not on plant richness (t =1.88, P = 0.08, N = 14). Note that different y-axis scales are used for plants and birds.

Appendix S2. Phylogenetic relationships of fleshy-fruited plants and frugivorous birds.

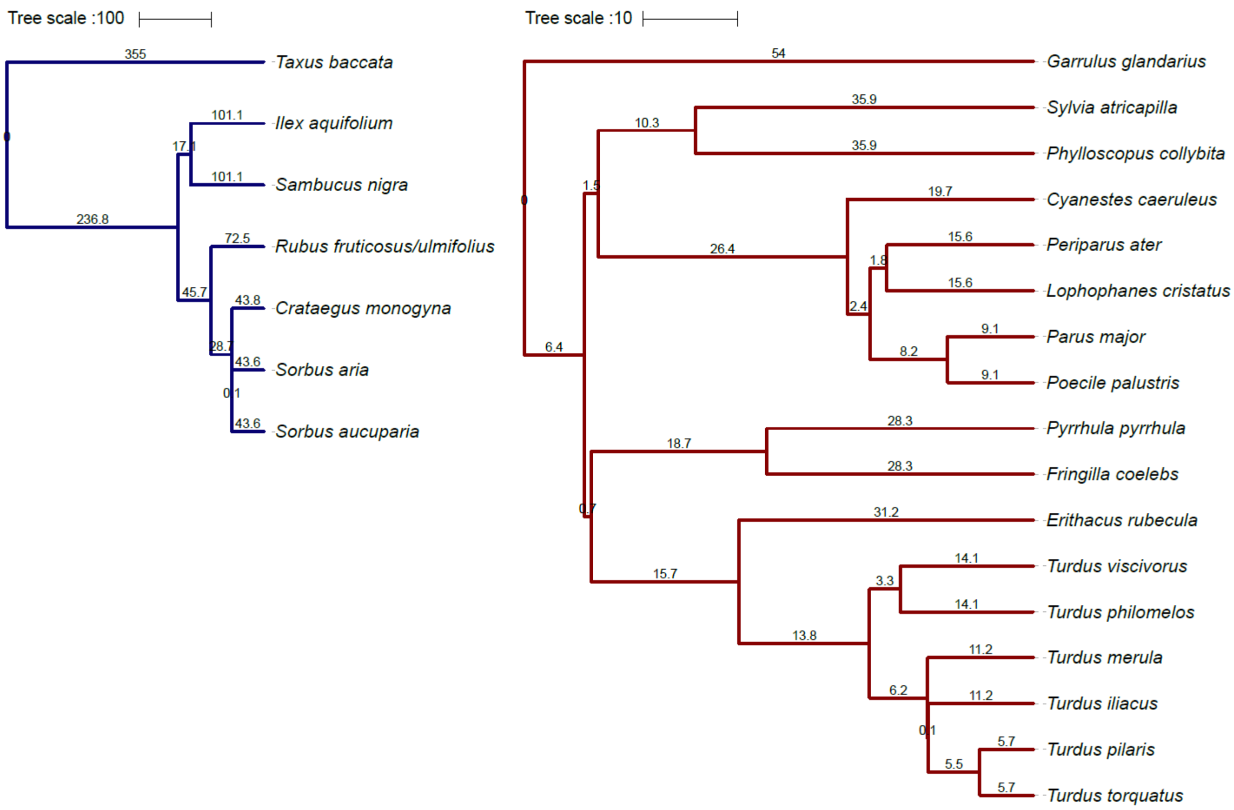

Figure S2. Phylogenetic relationships for fleshy-fruited plants (left) and frugivorous birds (right) in the Cantabrian Range (N Iberian Peninsula). Plant and bird trees are based on published phylogenies (Durka & Michalski, 2012; and Jetz, Thomas, Joy, Hartmann, &Mooers, 2012, respectively). Branch length is shown for both taxa (note the different tree scale for each taxa). Plants belonged to four families (Rosaceae, Aquifoliaceae, Adoxaceae and Taxaceae), with *T. baccata,* the only gymnosperm, being the most distant species (355 Myr). Birds belonged to five passerine families (Silviidae, Turdidae, Corvidae, Paridae and Fringillidae).

References

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Appendix S3. Multidimensional trait spaces of fleshy-fruited plants and frugivorous birds.

Morphological trait measurements

In order to estimate the trait-based functional diversity in a number of assemblages along a gradient of forest cover, we considered morphological traits for all plant and bird species recorded in the plant-frugivore network of the Cantabrian Range (N Iberian Peninsula) under study. We selected four morphological traits at each trophic level that are functionally relevant for frugivory (Dehling, Fritz, et al., 2014; Dehling, Töpfer, et al., 2014; Jordano, 2014). For plants these measurements were: fruit length, fruit diameter, plant height and crop mass and all data was from individuals in the field. From 25 ripe fruit samples (five fruits from five different individuals), fruit length was measured as the distance from the peduncle insertion to the most distal point; fruit width as the maximum diameter at 90º to the length; plant height as the maximum height of each plant species; and crop mass was estimated by multiplying fruit mass by fruit crop (the latter calculated as the mean number of fruits per individual per species within the fourteen plots). Fruit measurements of *R. fruticosus/ulmifolius* refer to single drupes, whereas crop mass was estimated based on the number and weight of the infrutescence (Table S3.1). For all bird species, we measured the Kipp's index, bill length and width from museum specimens (two adult females and two adult males of each species). Bill length was calculated as the distance from the bill tip to the commissural points of the upper and lower bill; bill width as the external distance between the two commissural points; Kipp's index was calculated from the Kipp's distance (distance from the tip of the first secondary to the tip of the longest primary feather measured on the folded wing) divided by wing length (Dehling, Töpfer, et al., 2014). Wing length was taken as the distance from the carpal joint to the tip of the wing (maximum chord method). Body mass was extracted from Dunning (2008). For all traits, we used the species trait mean from sampled individuals, as well as the log-transformed crop mass and body size to perform the analyses.

Multidimensional trait-spaces

Traits were combined to calculate trait-based functional metrics. For this, species were projected into a multidimensional trait-space using Principle Coordinate Analysis (PCoA; Villéger, Mason, & Mouillot, 2008), according to the Euclidean distances between species, where traits represent dimensions and species are plotted as coordinates (Fig. S3). Plant species did not show clear clustering patterns across the trait-space (Fig. S3a). Elder *Sambucus nigra* and blackberry *Rubus fruticosus/ulmifolius* contributed considerably to the variability within the trait-space, representing the shortest plants with the smallest fruits (drupes), and being placed far from the remaining species which had larger crop size and were taller. As regards birds, species were irregularly distributed across the trait-space, with some species in clusters and others (e.g. Eurasian jay *Garrulus glandarius*) being isolated. Thrushes (*Turdus* spp.) created a cluster characterized by a high Kipp's index (> 0.30), with the exception of blackbird *T. merula*, which had a central position, closer to bullfinch *Pyrrhula pyrrhula*. Another principal cluster was composed of tits (Paridae) and certain other species, all of which shared the characteristics of small body size, and small bill width and height. Eurasian jay exhibited some trait distinctiveness due to its having the largest beak and greatest body mass but a low Kipp's index (Fig. S3b).

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Table S3.1. Average values of morphological traits and fruit ripening peaks of fleshy-fruited plant species.

Species	Acronym	Fruit width (mm)	Fruit length (mm)	Cropmass (g)	Height (m)	Ripening peak
Crataegus monogyna	Cramon	9.54	9.97	939.78	9.00	Sept./Oct.
Ilex aquifolium	Ileaqu	8.96	9.02	1156.67	12.00	October
Rubus fruticosus/ulmifolius	Rubfru	3.57	4.31	678.34	1.50	Aug./Sept.
Sambucus nigra	Samnig	5.01	5.95	163.55	4.00	Aug./Sept.
Sorbus aria	Sorari	11.34	11.76	2085.96	18.00	Sept./Oct.
Sorbus aucuparia	Sorauc	10.35	8.66	2986.75	20.00	Aug./Sept.
Taxus baccata	Taxbac	9.37	8.04	1301.37	25.00	September

Table S3.2. Average values of morphological traits of frugivorous birds.

Species	Acronym	Bill width (mm)	Bill height (mm)	Body mass (g)	Kipp's index
Cyanistes caeruleus	Cyacae	5.01	4.71	13.30	0.22
Erithacus rubecula	Erirub	7.28	4.19	17.70	0.22
Fringilla coelebs	Fricoe	7.51	7.33	23.81	0.28
Garrulus glandarius	Gargla	17.60	13.96	159.46	0.19
Lophaphanes cristatus	Lopcri	5.01	4.43	11.04	0.22
Parus major	Parmaj	6.30	5.21	16.25	0.19
Periparus ater	Perate	5.51	4.32	9.20	0.21
Phylloscopus collybita	Phycol	4.93	3.16	8.30	0.20
Poecile palustris	Poepal	4.83	4.18	11.14	0.18
Pyrrhula pyrrhula	Pyrpyr	11.55	9.36	24.26	0.25
Sylvia atricapilla	Sylatr	7.48	4.53	16.70	0.27
Turdus iliacus	Turili	10.78	6.66	61.20	0.32
Turdus merula	Turmer	12.39	7.90	102.73	0.23
Turdus phillomelos	Turphi	12.20	6.85	67.74	0.32
Turdus pilaris	Turpil	12.90	7.57	106.00	0.33
Turdus torquatus	Turtor	13.37	7.59	109.00	0.31
Turdus viscivorus	Turvis	13.05	8.42	117.37	0.35

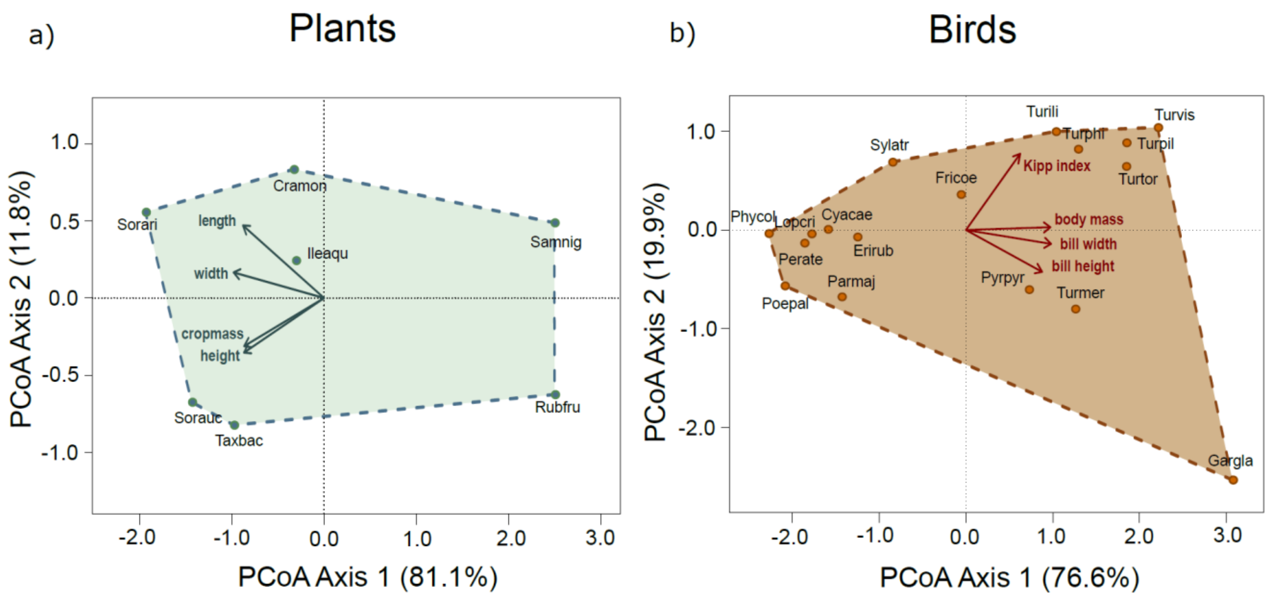

Figure S3. Multidimensional trait-spaces considering four phenotipic traits relevant for frugivory with respect to a) plants (fruit length, fruit diameter, crop mass and plant height) and b) birds (bill height, bill length, Kipp's index and body mass). Note the different scales for the y-axis in the different graphics. Dots represent individual species, which are also indicated by their acronyms (see Tables S3.1- S3.2).

Appendix S4. Interaction network and degree of specialization per species (d´)

Table S4. Frugivory regional network in the Cantabrian Range (N Iberian Peninsula). Cell values are the total number of fruits consumed (two years pooled) per bird (rows) and plant species (columns). Species names are indicated by their acronyms (see Tables S3.1- S3.2).

Species	Cramon	Ileaqu	Rubfru	Samnig	Sorari	Sorauc	Taxbac
Cyacae	1	0	1	0	0	0	0
Erirub	29	1	15	3	0	1	2
Fricoe	2	0	0	0	1	0	0
Gargla	0	0	7	0	0	0	1
Lopcri	0	0	0	0	0	0	1
Parmaj	3	0	3	0	0	0	4
Perate	4	0	0	0	0	0	1
Phycol	0	0	0	2	0	0	0
Poepal	2	0	0	0	0	0	6
Pyrpyr	6	5	151	0	0	53	0
Sylatr	4	7	75	77	1	5	7
Turili	241	254	0	0	0	0	5
Turmer	1049	467	28	7	13	104	47
Turphi	131	40	12	0	8	5	69
Turpil	59	0	0	0	0	0	5
Turtor	0	0	0	0	8	0	0
Turvis	15	6	0	0	78	1	25

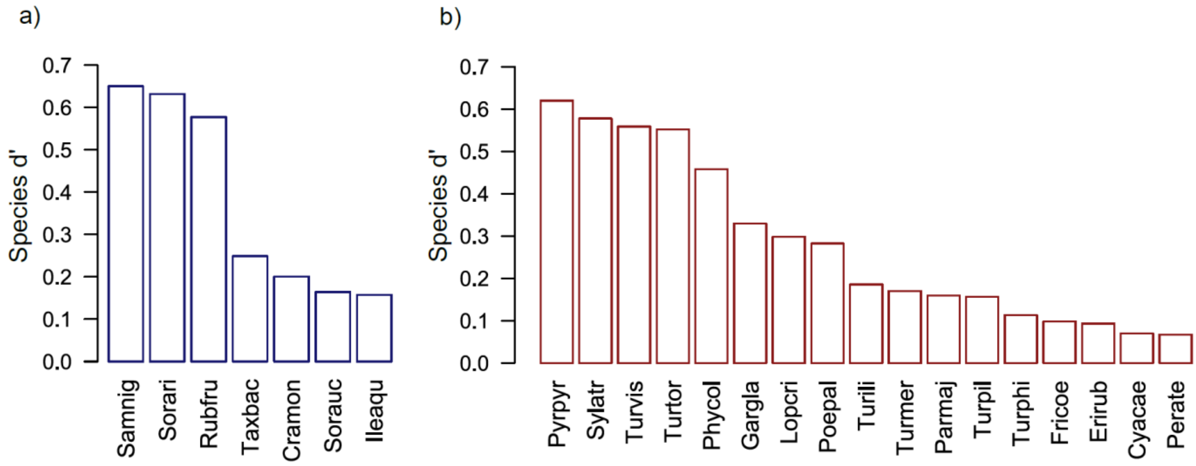

Figure S4. Bar plots indicating the values of the degree of specialization (d´ of each a) plant and b) bird species, estimated from the plant-bird regional network (Table S4). Species are ranked in decreasing order of d´, and named using their acronyms (see Tables S3.1 - S3.2).

Appendix S5. Relationship between the degree of functional complementarity (standardized effect size; <d´>) and forest cover.

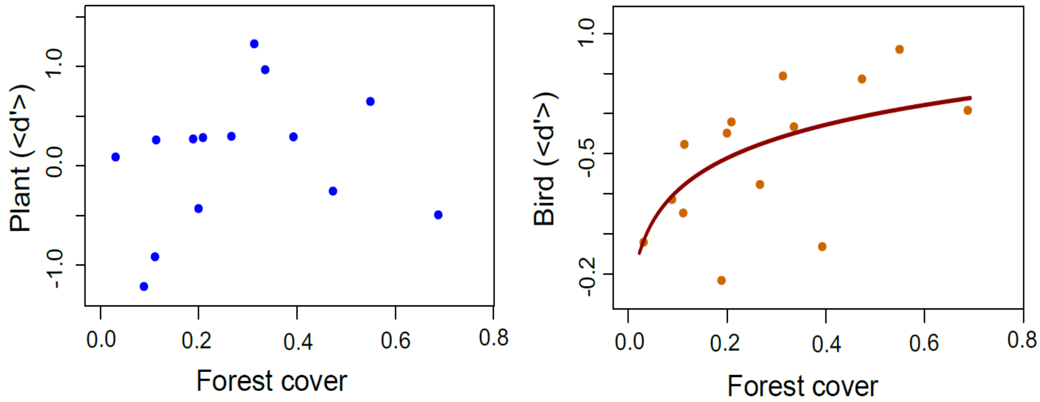

Figure S5. Relationship between the degree of functional complementarity (<d´>) and proportion of forest cover (log-transformed) for plants (blue) and birds (orange) in the fourteen study plots (dots). Bird functional complementarity significantly increased with increasing forest cover (logarithmic trend line, fitted based on linear model: t= 2.47, p = 0.03, n =14).

Appendix S6. Abundance of fleshy-fruited plants and frugivorous bird across study plots.

Table S6.1. Relative abundance of fleshy-fruited plant species (columns) at the fourteen study plots (rows), estimated as the proportion of fruits of a given species within the total number of fruits of all species across plots (two years pooled). The percentage of forest cover in each plot is also shown in brackets.

PLOT (% forest cover)	Cramon	Ileaqu	Rubfru	Samnig	Sorari	Sorauc	Taxbac
B1 (3.11)	0.44	0.34	0.224	0.000	0.000	0.000	0.000
B2 (26.6)	0.50	0.28	0.093	0.000	0.011	0.116	0.000
B3 (47.32)	0.24	0.70	0.028	0.002	0.000	0.022	0.000
B4 (20.88)	0.49	0.43	0.056	0.000	0.005	0.015	0.000
M1 (33.54)	0.10	0.72	0.177	0.000	0.000	0.000	0.000
M2 (11.36)	0.18	0.67	0.147	0.000	0.000	0.000	0.000
M3 (54.93)	0.04	0.85	0.109	0.000	0.000	0.000	0.000
G1 (11.36)	0.92	0.07	0.003	0.000	0.000	0.000	0.000
G2 (18.88)	0.83	0.11	0.061	0.000	0.000	0.000	0.000
G3 (39.28)	0.48	0.45	0.054	0.010	0.000	0.000	0.000
P1 (19.98)	0.28	0.46	0.017	0.008	0.000	0.057	0.177
P2 (31.1)	0.36	0.37	0.093	0.019	0.024	0.000	0.127
P3 (8.87)	0.54	0.46	0.002	0.000	0.000	0.000	0.000
P4 (68.74)	0.35	0.56	0.001	0.000	0.014	0.005	0.071

Table S6.2. Relative abundance of bird species (columns) at the fourteen study plots (rows), estimated as the proportion of individual birds of a given species in terms of the total number of birds of all species across plots (two years pooled). The percentage of forest cover in each plot is also shown in brackets.

PLOT (% forest cover)	Cyacae	Erirub	Fricoe	Gargla	Lopcri	Parmaj	Perate	Phycol	Poepal	Pyrpyr	Sylatr	Turili	Turmer	Turphi	Turpil	Turtor	Turvis
B1 (3.11)	0.013	0.135	0.032	0.000	0.000	0.013	0.032	0.000	0.000	0.006	0.000	0.224	0.442	0.071	0.006	0.000	0.026
B2 (26.6)	0.000	0.199	0.078	0.011	0.000	0.028	0.053	0.000	0.000	0.050	0.018	0.117	0.372	0.064	0.011	0.000	0.000
B3 (47.32)	0.011	0.097	0.086	0.004	0.000	0.004	0.049	0.002	0.018	0.082	0.018	0.281	0.277	0.066	0.000	0.000	0.004
B4 (20.88)	0.000	0.156	0.123	0.004	0.002	0.012	0.036	0.020	0.008	0.030	0.014	0.265	0.263	0.051	0.012	0.000	0.004
M1 (33.54)	0.005	0.133	0.101	0.007	0.000	0.010	0.022	0.002	0.022	0.014	0.080	0.241	0.272	0.092	0.000	0.000	0.000
M2 (11.36)	0.022	0.237	0.094	0.022	0.000	0.065	0.036	0.007	0.000	0.065	0.022	0.094	0.309	0.029	0.000	0.000	0.000
M3 (54.93)	0.011	0.120	0.042	0.024	0.000	0.015	0.031	0.027	0.002	0.026	0.078	0.358	0.201	0.064	0.002	0.000	0.000
G1 (11.36)	0.005	0.124	0.093	0.000	0.000	0.010	0.088	0.005	0.000	0.015	0.021	0.196	0.412	0.031	0.000	0.000	0.000
G2 (18.88)	0.012	0.162	0.088	0.000	0.000	0.012	0.033	0.002	0.002	0.014	0.007	0.112	0.513	0.041	0.000	0.000	0.000
G3 (39.28)	0.024	0.166	0.169	0.000	0.000	0.010	0.014	0.003	0.000	0.020	0.017	0.088	0.424	0.064	0.000	0.000	0.000
P1 (19.98)	0.028	0.128	0.104	0.000	0.035	0.035	0.048	0.000	0.045	0.007	0.010	0.038	0.346	0.090	0.000	0.000	0.087
P2 (31.1)	0.015	0.232	0.095	0.004	0.019	0.019	0.019	0.008	0.004	0.053	0.034	0.038	0.395	0.053	0.000	0.000	0.011
P3 (8.87)	0.000	0.098	0.174	0.000	0.022	0.000	0.033	0.000	0.000	0.000	0.000	0.380	0.217	0.011	0.000	0.000	0.065
P4 (68.74)	0.017	0.054	0.168	0.002	0.025	0.037	0.119	0.000	0.037	0.010	0.000	0.124	0.166	0.089	0.000	0.002	0.149

Appendix S7. Sampling completeness of plant and bird species richness.

We evaluated the completeness of our sampling effort to detect frugivorous birds and plants across plots, generating sample-based accumulation curves of species richness on sampled plots (Chao & Jost, 2012). As gradients of sampling effort we used the set of species richness detected during the whole period of the study (1-7 for plant species; and, 1-17 bird species) and the presence of those species per sampling unit (i.e. sampled plots, 1-14). The accumulation curves and the 95% confidence interval were generated by randomly re-sampling 1000 times (function specaccum in *vegan* package in R; Oksanen et al., 2018), and the expected number of plant species and frugivorous birds, were computed by means of Chao´s richness estimators (function specpool in *vegan* package in R; Oksanen et al., 2018).

Accumulation curves showed that the species richness of plant and bird species observed, reached saturating trends along the gradient of sampling effort, and overlapped the estimated asymptotic species richness (Fig. S7.a-b). This result suggests that our sampling efforts was adequate to detect the expected richness of plant and frugivorous birds.

References:

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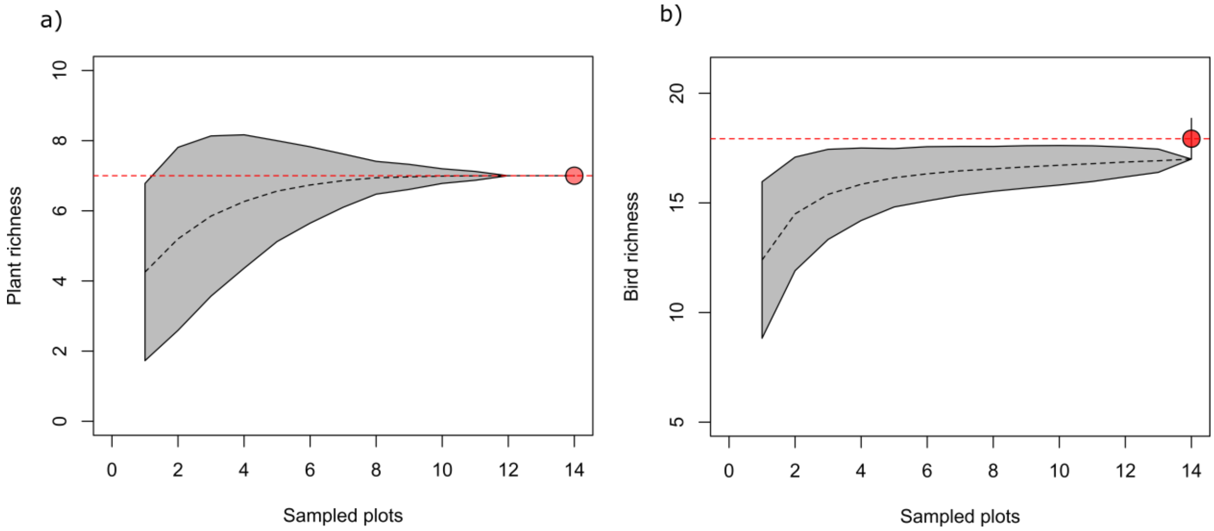

Figure S7. Accumulation curves (solid black line, with grey areas representing the 95% confidence intervals) and Chao's estimated richness (horizontal red dashed line and dot, together with the standard errors) for the richness of plants and bird species observed in the sampled plots as a function of the cumulative sampling effort of species richness sampled.