Supplementary information for:

Covariation among reproductive traits in flowering plants determine interactions with floral visitors

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Supplementary text

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Supplementary Information Text

Description of the traits compiled in this study

Here we describe the different traits of the database used in this study to explore the reproductive spectrum of trait variation and plant-pollinator associations. Note that all species have references or links providing the original source of the information.

Reproductive traits

- Breeding system: The different plant species were classified in hermaphrodite, dioecious and monoecious species. Intermediate breeding systems or more complex ones were also annotated but all the species were divided into these three main categories for simplicity of the analysis.

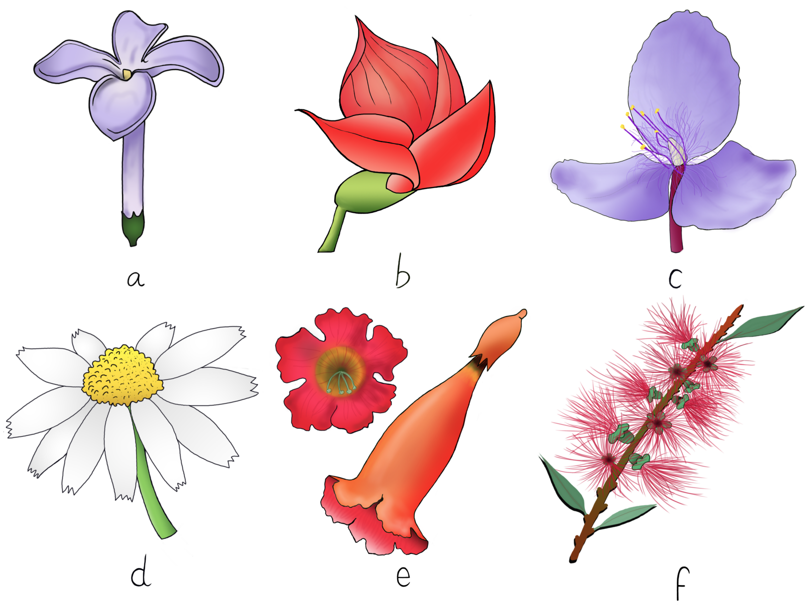
- Selfing level: We recorded the selfing level of the different species with both quantitative and qualitative data. The qualitative data was divided in four main categories, high selfers, medium selfers, low selfers and none which was for the species that were unable to self-pollinate. In addition, quantitative data was also divided into these four categories with the following criteria: from 0% to lower than 1% 'none', from 1% to 25% 'low', from 26% to 75% 'medium' and from 76% to 100% 'high'. Because quantitative selfing had a high percentage of missing values (68%), we were able to solve this by converting these four categories to representative percentages of each category 0%, 13%, 50.5% and 88%. This reduced the percentage of missing values for this quantitative trait from 68% to 35% and allowed the imputation of this variable.

- Compatibility system: The different species were divided in three main categories in order to know their ability to self-pollinate. These categories were self-compatible, partially self-compatible and self-incompatible species. The field of selfing level is partly complementary to the compatibility system but is important to note that not all the self-compatible species or partially self-compatible species will self-pollinate.

Floral traits

- Flower symmetry: We also recorded if the flowers were bilaterally symmetrical "zygomorphic" or were radially symmetrical "actinomorphic".
- Flower and inflorescence size: We searched for flower length and flower and inflorescence width (mm) for all species. When possible, we calculated the not found measurements with the help of online images and the software ImageJ. Note that for species with compound flowers (e.g., Asteraceae) or similar floral structures with flower heads with many small flowers we considered the inflorescence as the floral unit. For each species this is indicated in the dataset with the field of "info_level" where the measurement level is specified as capitulum or flower level. Note that for some Asteraceae species information about the disc and ray floret is also provided in the database but these were not included in our analyses.
- Flower number per plant: We compiled information about the number of flowers per plant for all species. However, this field was rare to find and we also used online images of the different species in order to calculate rough numbers of flowers per plant. We referenced all the filled fields in order to be able to follow the images that were used for these counts. It is important to note, that these numbers are not pretended to be the exact number of flowers per species but an approximate indicator of the reproductive investment for the different species that allow the macroecological analysis of this field.
- Ovule number: We searched for the number of ovules per flower for all the different species. The number of ovules of Asteraceae species are considered as the total number of ovules per capitulum. Many species were filled by genus or family level because the number of ovules in this taxonomic groups is considered to be mostly constant (e.g., Lamiaceae Boraginaceae or Apiaceae).
- Flower morphology: We looked for images and illustrations of the flowers from the different species on the floras and available resources in order to categorize the flower

shape. We divided the flowers in 8 main different categories: open, bowl, tube, campanulate, funnelform, papilionaceous, brush and capitulum. However, we ended up groupping all flowers on the following 6 morphological groups for analyses: tube, papilonaceous, open, capitulum, campanulate and brush (Supplementary Information Text Fig. 1).



Supplementary Information Text Fig. 1. Main floral morphologies considered in this study. All species were groupped within these categories for analysis: (a) tube, (b) papilonaceous, (c) open, (d) capitulum, (e) campanulate and (f) brush.

- Style length: The length of the style (mm) of the different species was also included. When possible, we calculated style length from images and illustrations on the online floras.

- Nectar provision: We recorded the presence and absence of nectar for all species. In addition, we also searched for microlitres and milligrams of nectar per flower and nectar concentration. For species that did not have nectar information but belonged to a family that is considered as 'nectarless', this trait was recorded at family level and the species was recorded with 'absence' of nectar. This was done exclusively for well documented nectarless taxonomical groups. For the field of microlitres of nectar, we considered single measurements of nectar standing crop. In general terms, the timming of the measurement and methodology differed across studies. For instance, some studies measured nectar in freshly opened flowers while others in flowers that were bagged for 24 hours. Despite the different methodologies to measure nectar provision, we believe that this is an appropriate way to collate measurements of nectar to explore trait associations at a macroecological scale.

- Pollen grains per flower: We recorded pollen grains per flower for all species but this field was rarely described in the literature. When just the pollen:ovule ratio was found we converted it back to pollen grains by multiplying it by the average ovule number found for each species.

Vegetative traits

- Life form, life span and plant height: We divided the different plant species in 4 main categories: herbs, vines, shrubs and trees. Moreover, we also divided the species between short-lived species (annual, biennial and short-lived perennials) and perennial species (long-lived). Finally, we also searched for the average height (m) of the different species and annotated the maximum and minimum height when possible. We conducted the average between the maximum and minimum height to get an approximate average height of the species when the average was not indicated.

Table S1. List of the 28 plant-pollinator studies used to build the plant trait database. Each study is shown with the first author that conducted the study, number of networks or metawebs that contains, type of information that contains (weighted or unweighted), the structure (web or metaweb), year of publication and digital object identifier or permanent link for each study.

First author	Year	Web N.	Network type	DOI
Arroyo-Correa	2019	3	Weighted web	https://doi.org/10.1111/1365-2745.13332
Bartomeus	2008	6	Weighted web	https://doi.org/10.1007/s00442-007-0946-1
Bartomeus	2008	16	Weighted web	https://github.com/ibartomeus/BeeFunData
Bek	2006	1	Unweighted web	Unpublished, Master thesis
Bundgaard	2003	1	Weighted web	Unpublished, Master thesis
Burkle	2013	1	Weighted web	https://doi.org/10.1126/science.1232728
Dicks	2002	2	Weighted web	https://doi.org/10.1046/j.0021-8790.2001.00572.x
Dupont	2003	3	Weighted web	https://doi.org/10.1111/j.1365-2656.2008.01501.x
Elberling	1999	1	Weighted web	https://doi.org/10.1111/j.1600-0587.1999.tb00507.x
Fang	2008	1	Weighted web	https://doi.org/10.1111/1749-4877.12190
Inouye	1988	1	Weighted web	https://doi.org/10.1111/j.1442-9993.1988.tb00968.x
Inouye	1990	1	Weighted metaweb	http://hdl.handle.net/2433/156099

(continued)

First author	Year	Web N.	Network type	DOI
Kaiser-Bunbury	2017	8	Weighted web	https://doi.org/10.1038/nature21071
Kaiser-Bunbury	2011	6	Weighted web	https://doi.org/10.1111/j.1365-2745.2010.01732.x
Kaiser-Bunbury	2010	2	Weighted web	https://doi.org/10.1016/j.ppees.2009.04.001
Kato	2000	1	Unweighted web	http://hdl.handle.net/2433/156116
Kevan	1970	1	Unweighted web	https://doi.org/10.2307/2258569
Lundgren	2005	1	Weighted web	https://doi.org/10.1657/1523-0430(2005)037[0514:TDAHCW]2.0.CO;2
McMullen	1993	1	Unweighted metaweb	https://biostor.org/reference/244737
Olesen	2002	2	Weighted web	https://doi.org/10.1046/j.1472-4642.2002.00148.x
Peralta	2006	4	Weighted web	https://doi.org/10.1111/ele.13510
Primack	1983	3	Unweighted metaweb	https://doi.org/10.1080/0028825X.1983.10428561
Ramirez	1989	1	Unweighted web	https://doi.org/10.2307/2388282
Ramirez	1992	1	Unweighted metaweb	https://doi.org/10.1111/j.1095-8339.1992.tb00294.x
Robertson	1929	1	Unweighted metaweb	https://doi.org/10.5962/bhl.title.11538
Small	1976	1	Weighted web	/13960/t4km08d21

(continued)

First author	Year	Web N.	Network type	DOI
Souza	2017	1	Weighted web	https://doi.org/10.1111/1365-2745.12978
Traveset	2013	1	Weighted metaweb	https://doi.org/10.1098/rspb.2012.3040

Table S2. Statistical association between the different categorical variables and the first three main axes of trait variation with the full set of species.

Functional traits	Sum Sq	F value	Pr(>F)	PC
Breeding system	304.59	119.50	0.00	PC1
Compatibility system	89.12	23.31	0.00	PC1
Lifespan	35.65	27.97	0.00	PC1
Life form	565.87	222.00	0.00	PC1
Flower shape	132.24	20.75	0.00	PC1
Flower symmetry	0.37	0.29	0.59	PC1
Nectar provision	0.38	0.29	0.59	PC1
Breeding system	304.59	119.50	0.00	PC2
Compatibility system	89.12	23.31	0.00	PC2
Lifespan	35.65	27.97	0.00	PC2
Life form	565.87	222.00	0.00	PC2
Flower shape	132.24	20.75	0.00	PC2
Flower symmetry	0.37	0.29	0.59	PC2
Nectar provision	0.38	0.29	0.59	PC2

Table S3. Loadings of the first three axes of trait variation of the phylogenetic informed principal component analysis with the full set of species.

	PC1	PC2	PC3
Autonomous selfing	0.03	0.85	-0.51
Flowers per plant	0.75	-0.27	-0.24
Flower width	-0.67	-0.38	-0.30
Style length	-0.34	-0.37	-0.66
Ovule number	-0.53	0.00	-0.02
Plant height	0.56	-0.40	-0.46
Explained variation	26.72	25.08	19.17

Table S4. Loadings of the first three axes of trait variation of the phylogenetic informed principal component analysis with the subset of species with data of nectar and pollen quantity.

	PC1	PC2	PC3
Autonomous selfing	-0.24	0.45	0.76
Flowers per plant	0.75	-0.32	0.03
Flower width	-0.72	-0.36	-0.04
Style length	-0.43	-0.37	0.07
Ovule number	-0.71	-0.03	0.00
Plant height	0.33	-0.75	0.35
Microlitres of Nectar per flower	-0.34	-0.40	0.35
Pollen per flower	-0.42	-0.29	-0.45
Explained variation	26.82	18.70	13.53

Table S5. Phylogenetic signal of the different quantitative traits.

Functional traits	Lambda	P-value
Autonomous selfing	0.34	0.00
Flower number	0.69	0.00
Inflorescence width	0.57	0.00
Flower width	0.73	0.00
Flower length	0.75	0.00
Style length	0.49	0.00
Ovule number	1.00	0.00
Plant height	0.96	0.00
Nectar per flower (μl)	0.14	0.00
Nectar concentration (%)	0.65	0.00
Pollen grains per flower	1.00	0.00

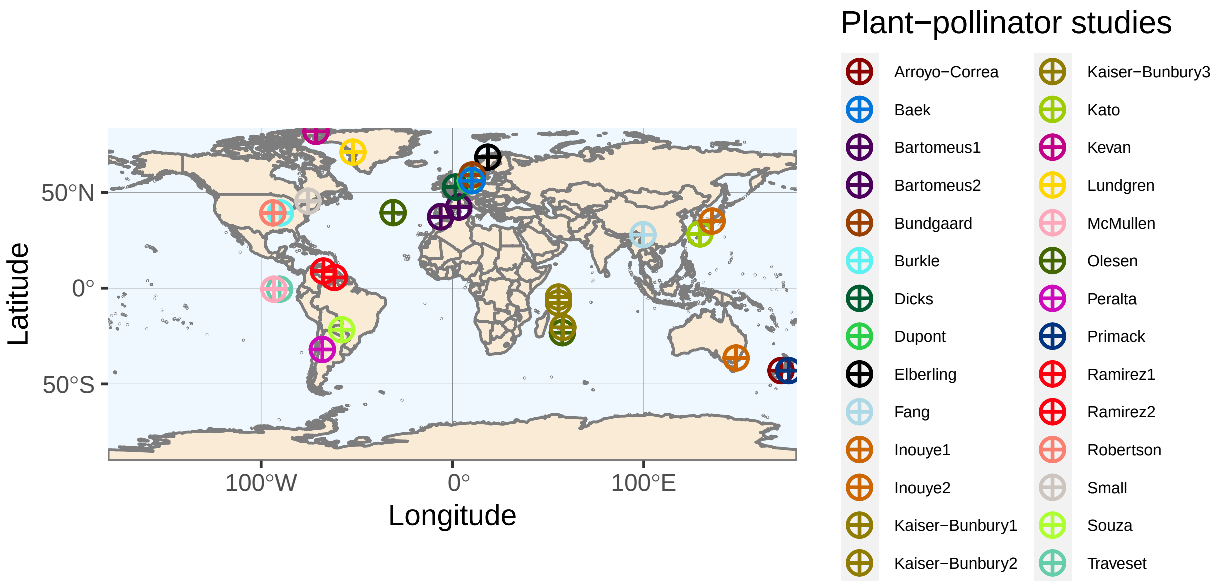


Fig. S1. Map with the different locations of the plant-pollinator studies used in this work to explore woldwide patterns at the meso-scale level. Note that for visualization purposes studies from the same authors are shown with the same colour.

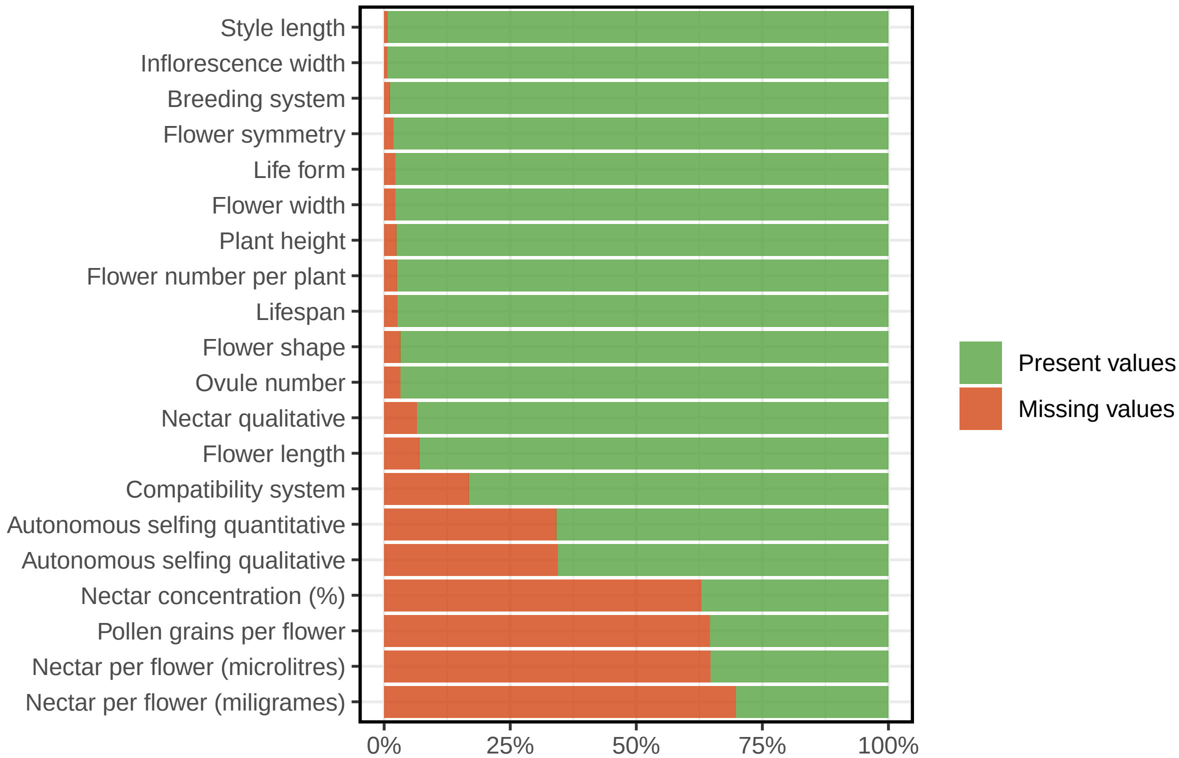


Fig. S2. Percentage of present and missing values of the different plant traits.

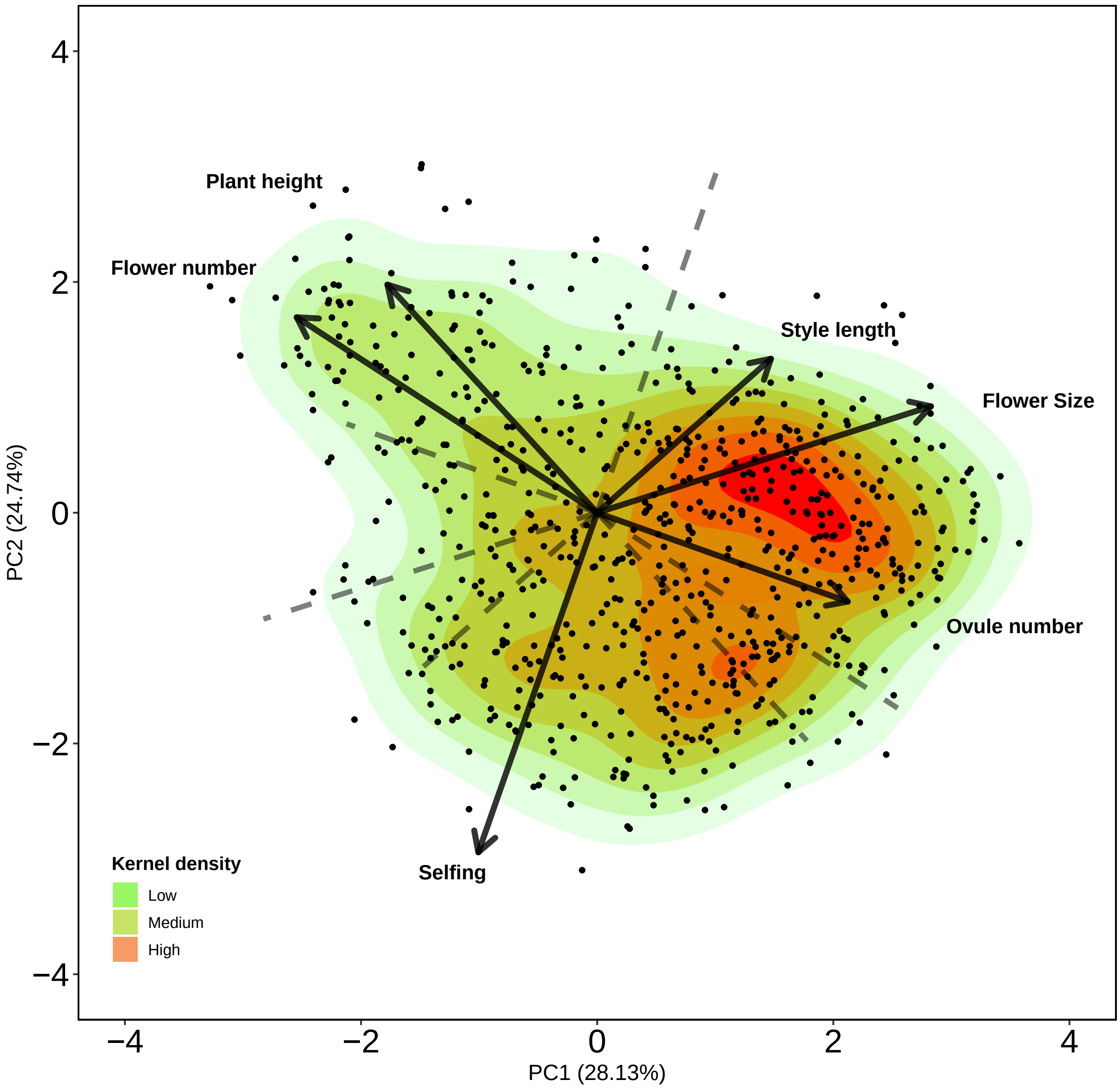


Fig. S3. Phylogenetic informed principal component analysis for the species that did not have missing values.

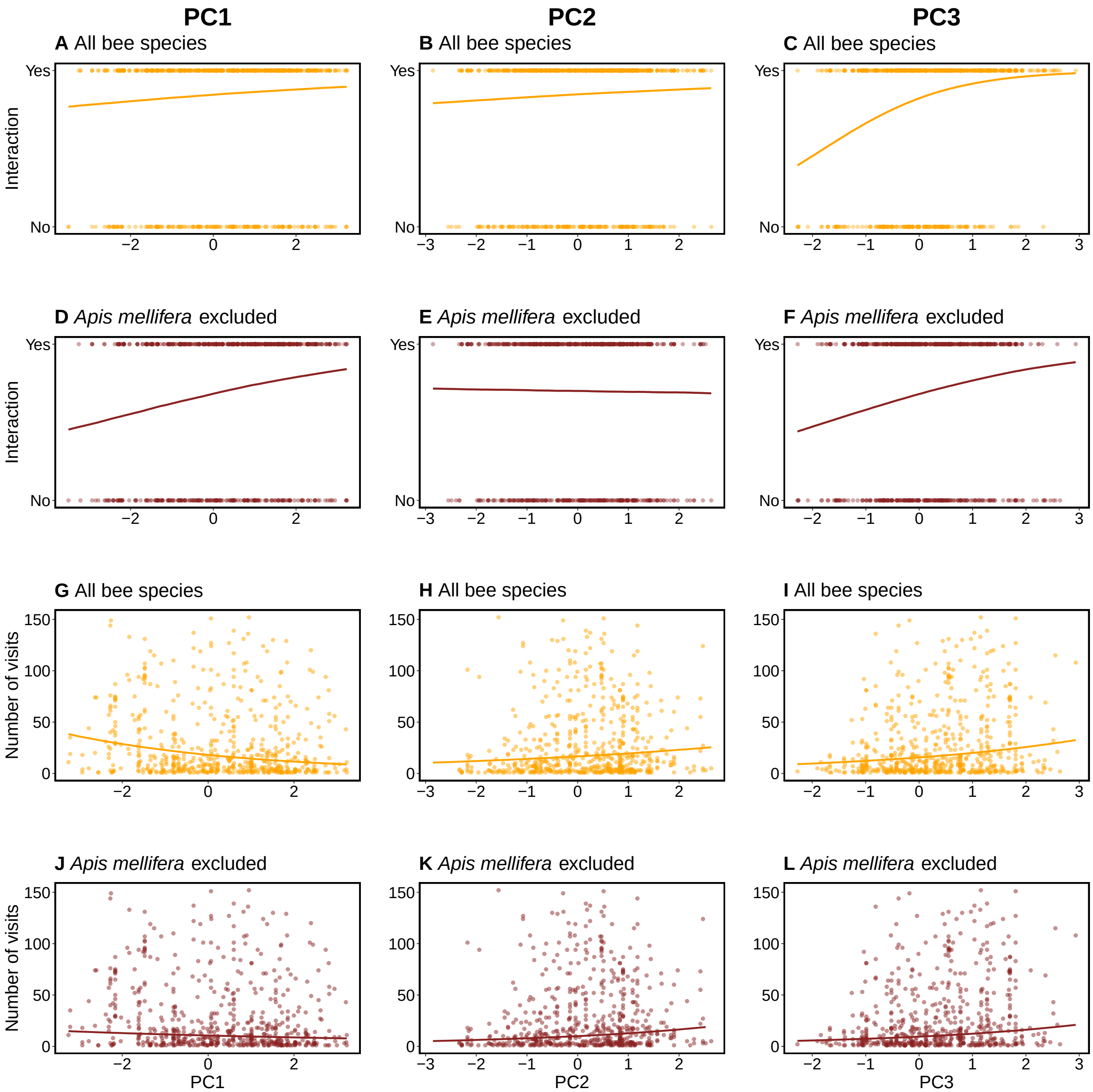


Fig. S4. Fitted posterior estimates of the interaction (yes/no) and number of visits made by bees including and exluding honey bees on the main axes of trait variation. The superior panel (plots a, b c, d, e and f) shows the comparison for presence-absence and the lower panel (plots g, h, i, j, k and l) the comparison for visitation rates.

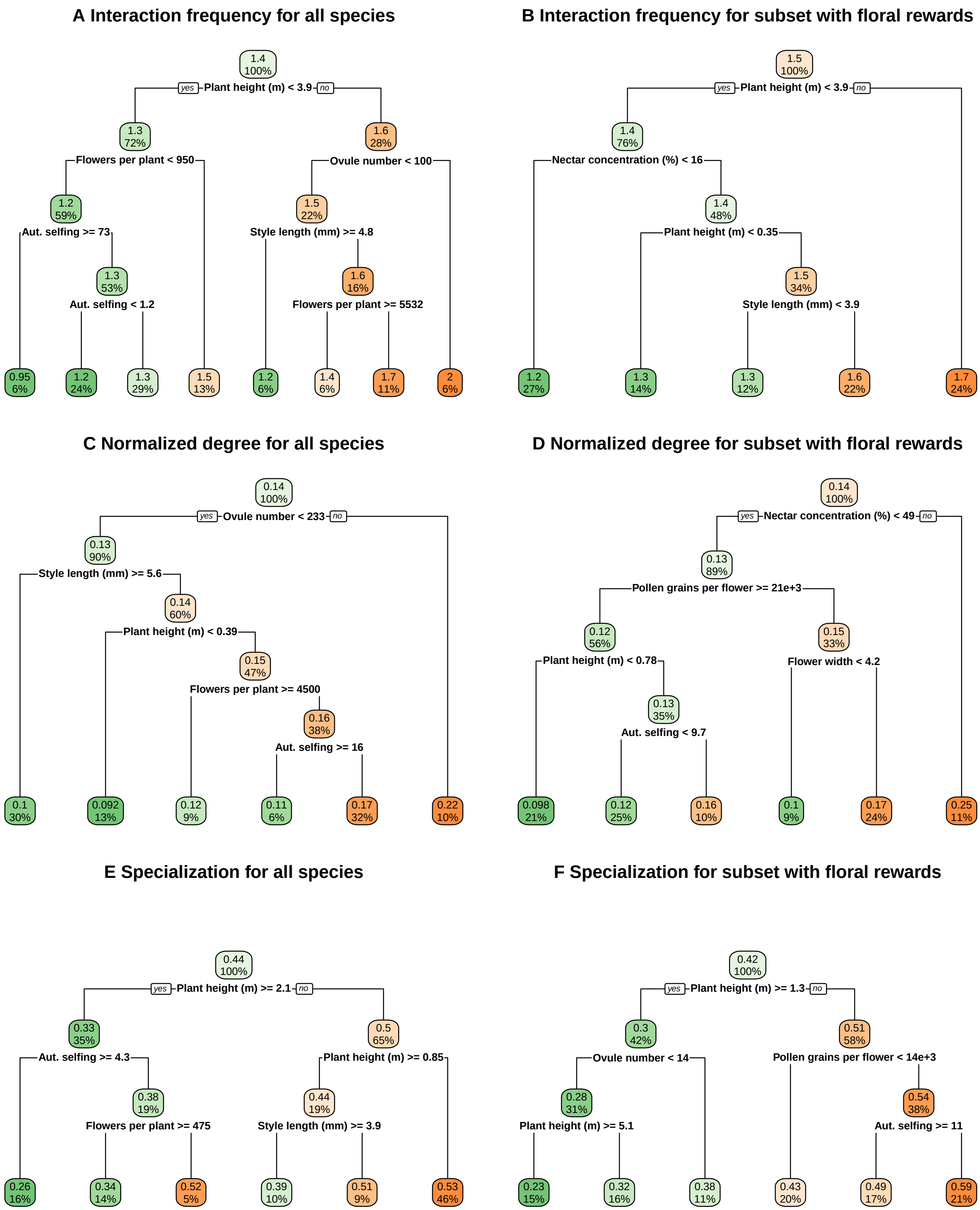


Fig. S5. Regression tree analyses. Comparison of the regression tree analyses between the full set of species and the subset of species with floral rewards for each plant species level metric.

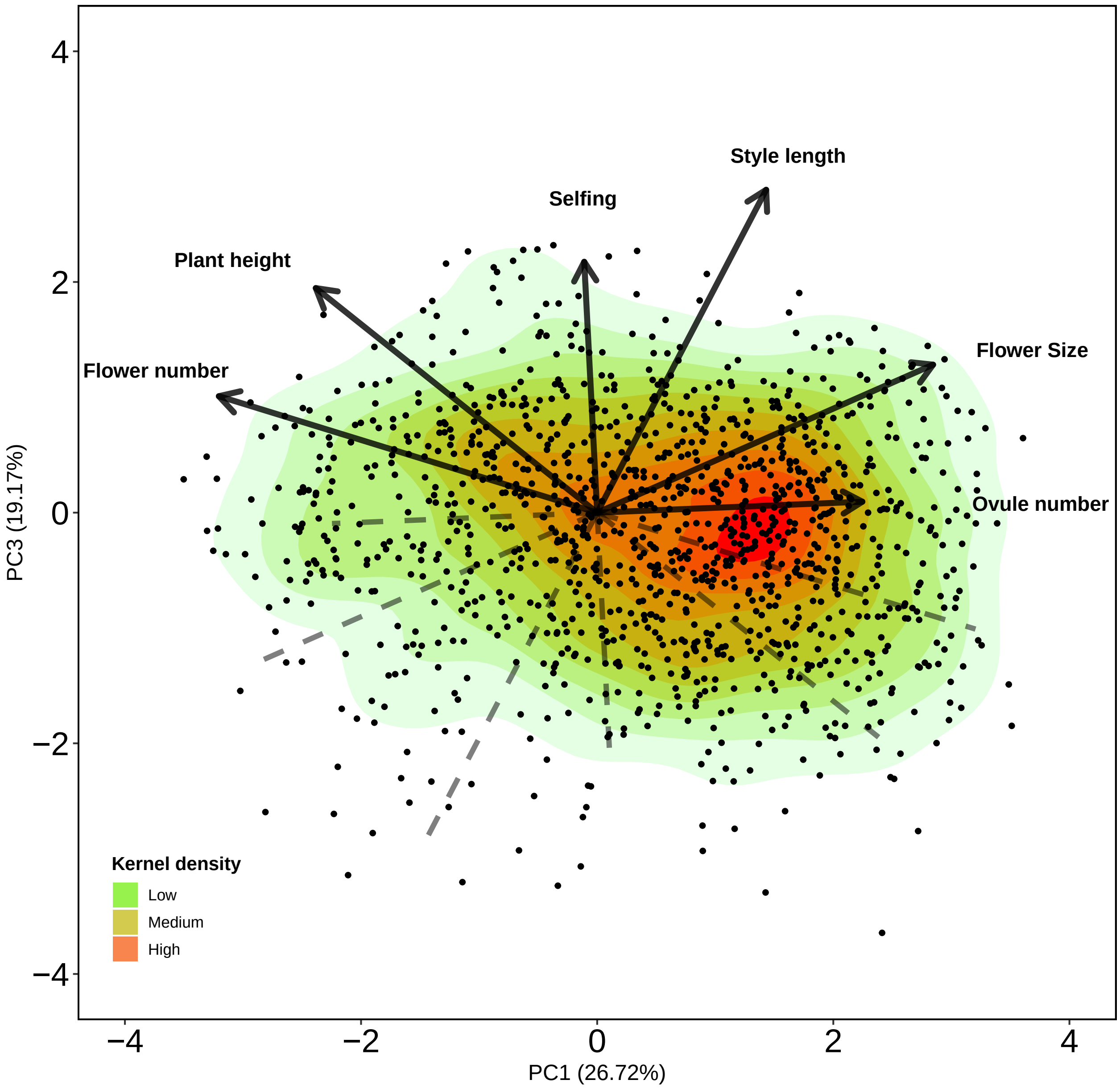


Fig. S6. PC1 and PC3 of the phylogenetically informed principal component analysis with the full set of species.

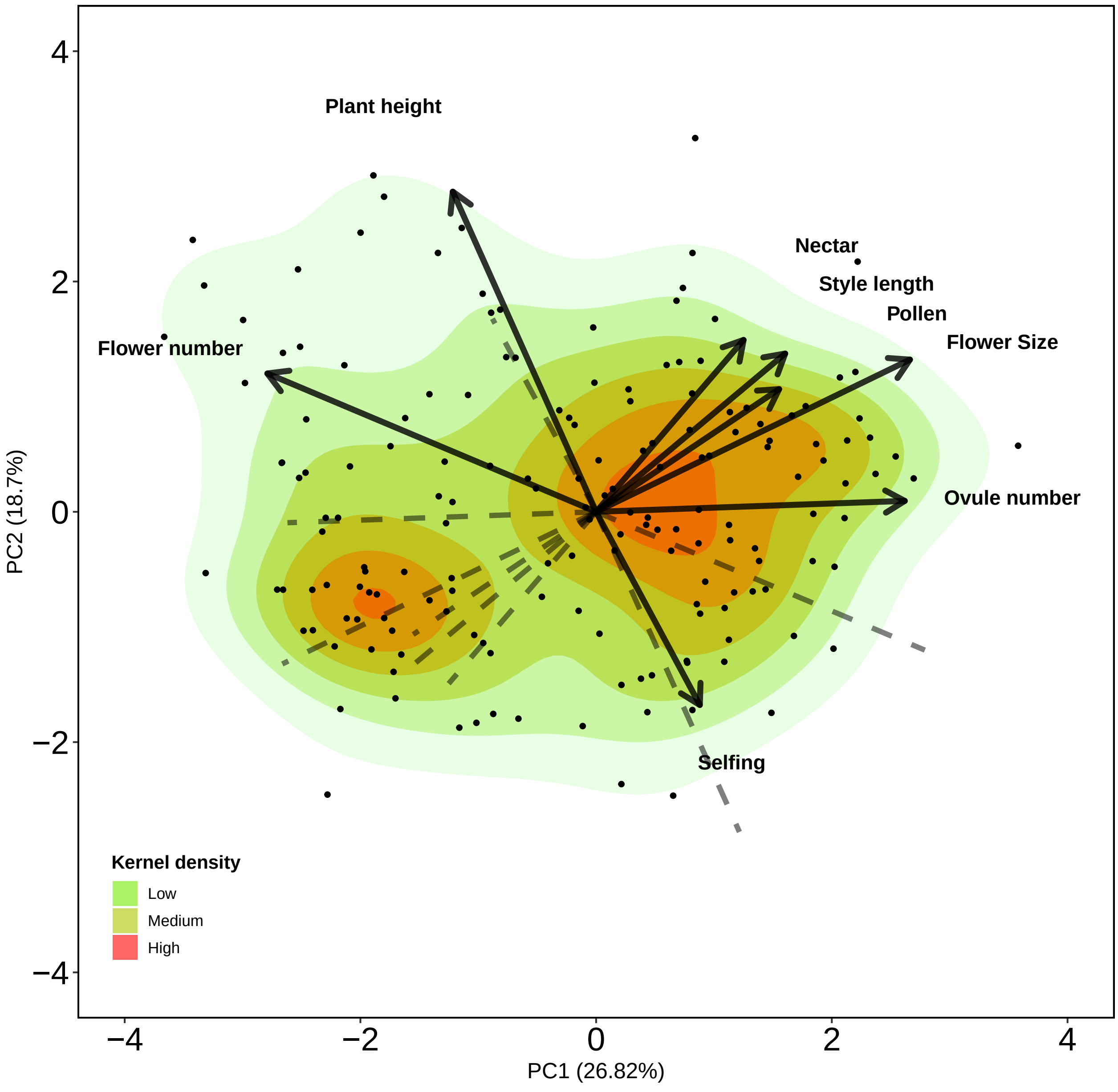


Fig. S7. Phylogenetic informed principal component analysis for the subset of species with floral rewards.

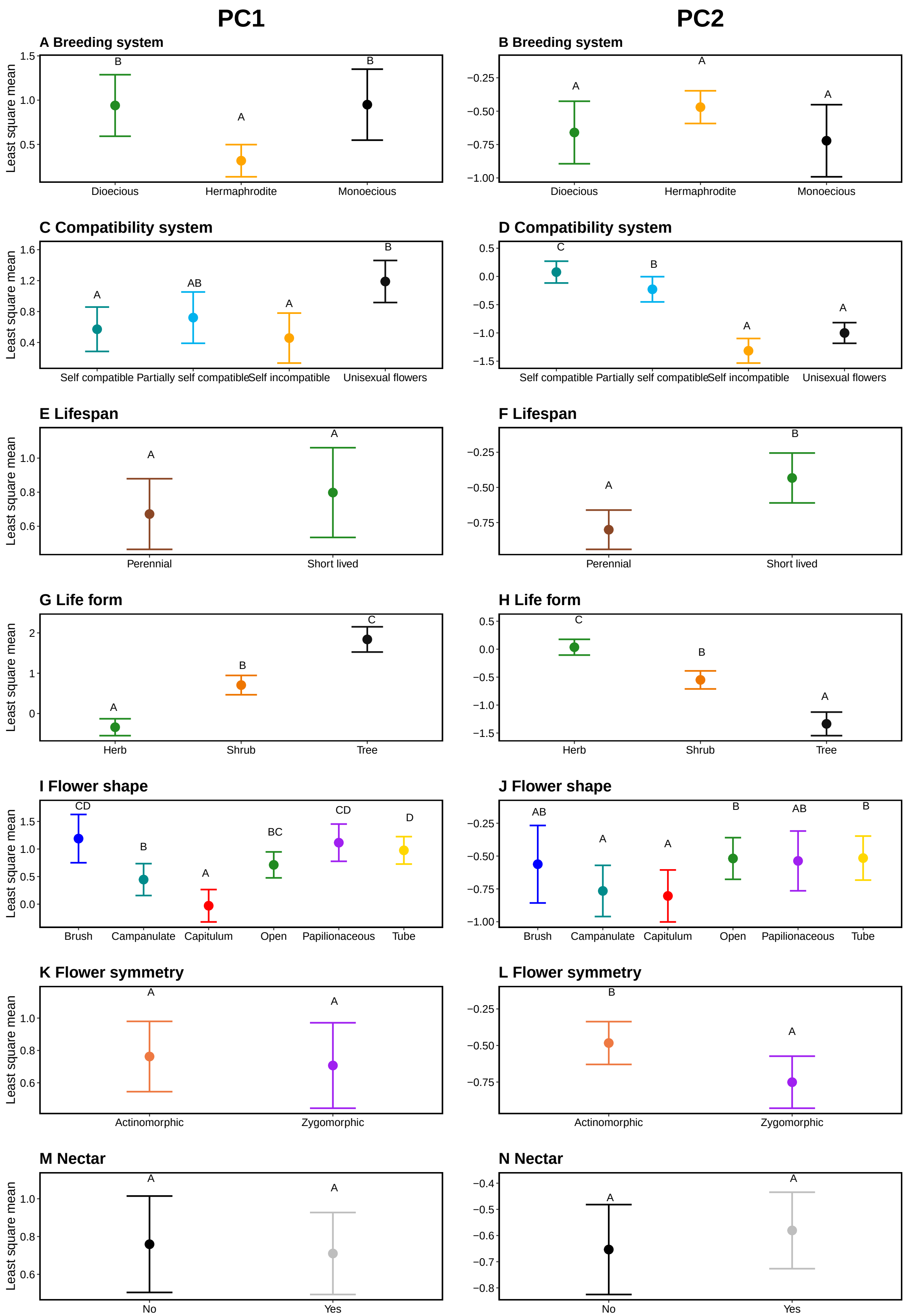


Fig. S8. Statistical comparison of the different categories of qualitative traits on the main two axes of trait variation with the full set of species. Categories that differ significantly are denoted with a different letter.

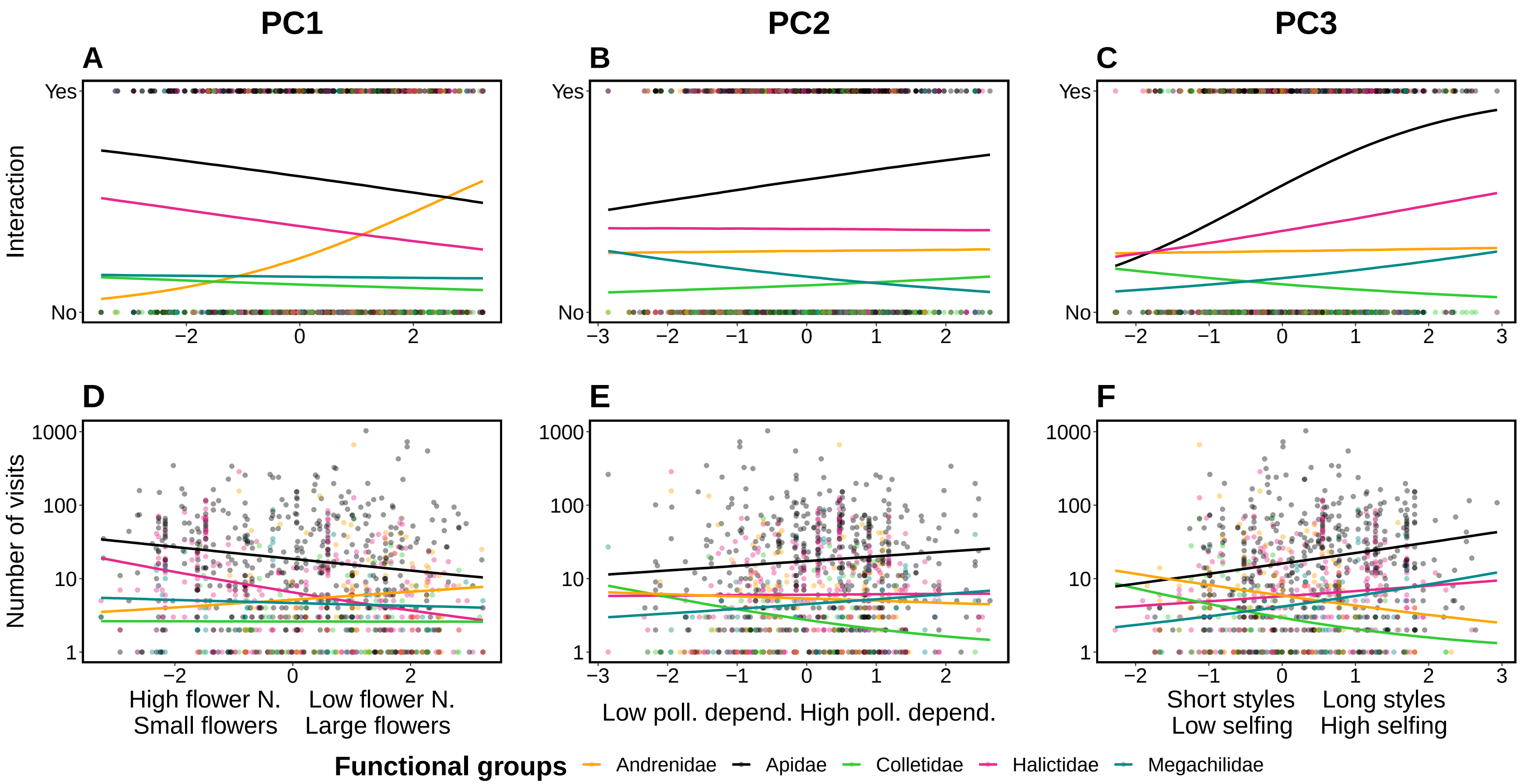


Fig. S9. Interaction (yes/no) and visitation rate of the main bee families on the main axes of trait variation. Fitted posterior estimates of the presence-absence of interaction (plots a, b and c) and visitation rate (plots e, f and g) of Andrenidae, Apidae, Colletidae, Halictidae and Megachilidae across PC1, PC2 and PC3. For visualization purposes, the response variable of number of visits was log-transformed (Y-axis of lower panel)

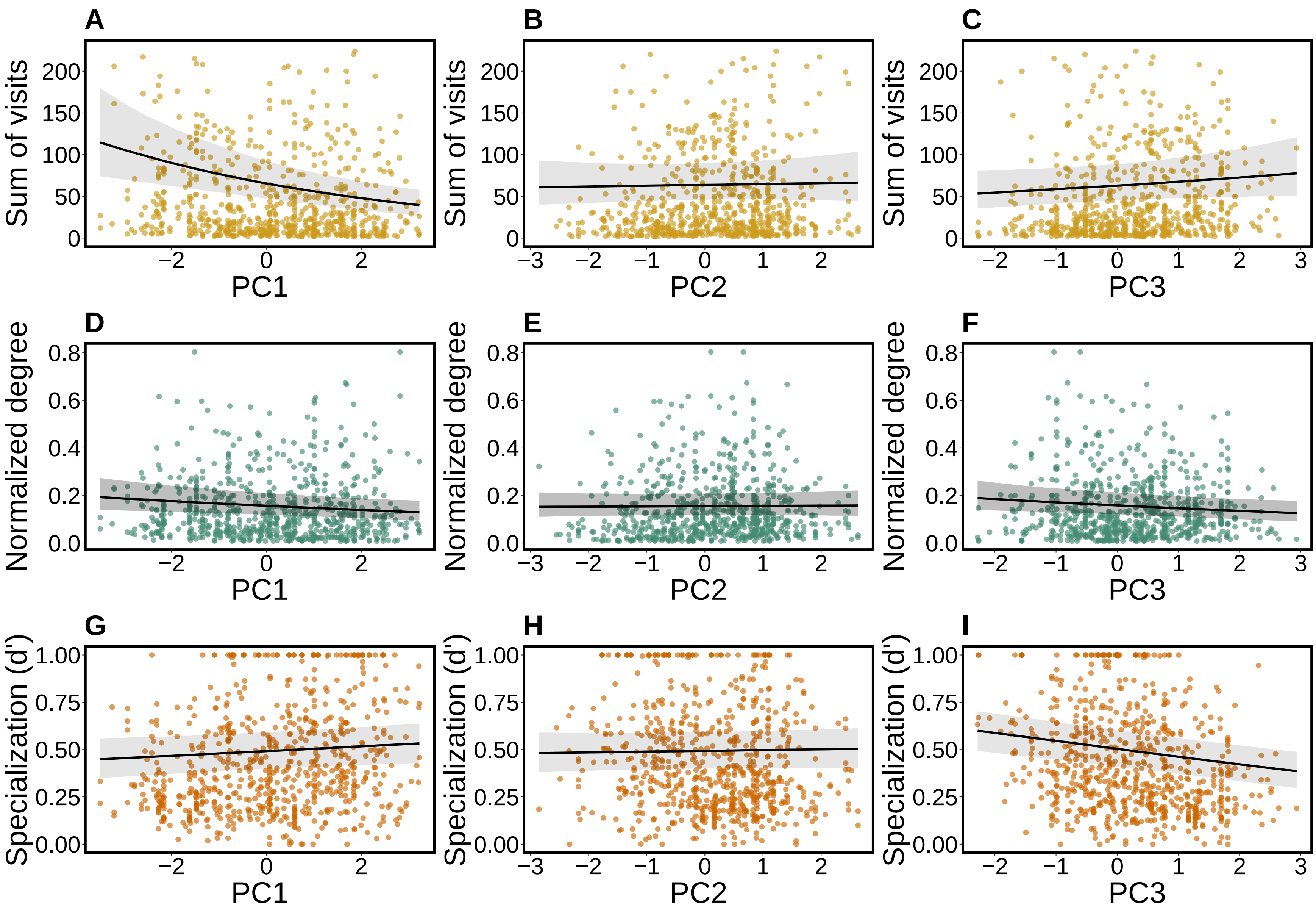


Fig. S10. Plant species level metrics across the three main axes of trait variation.

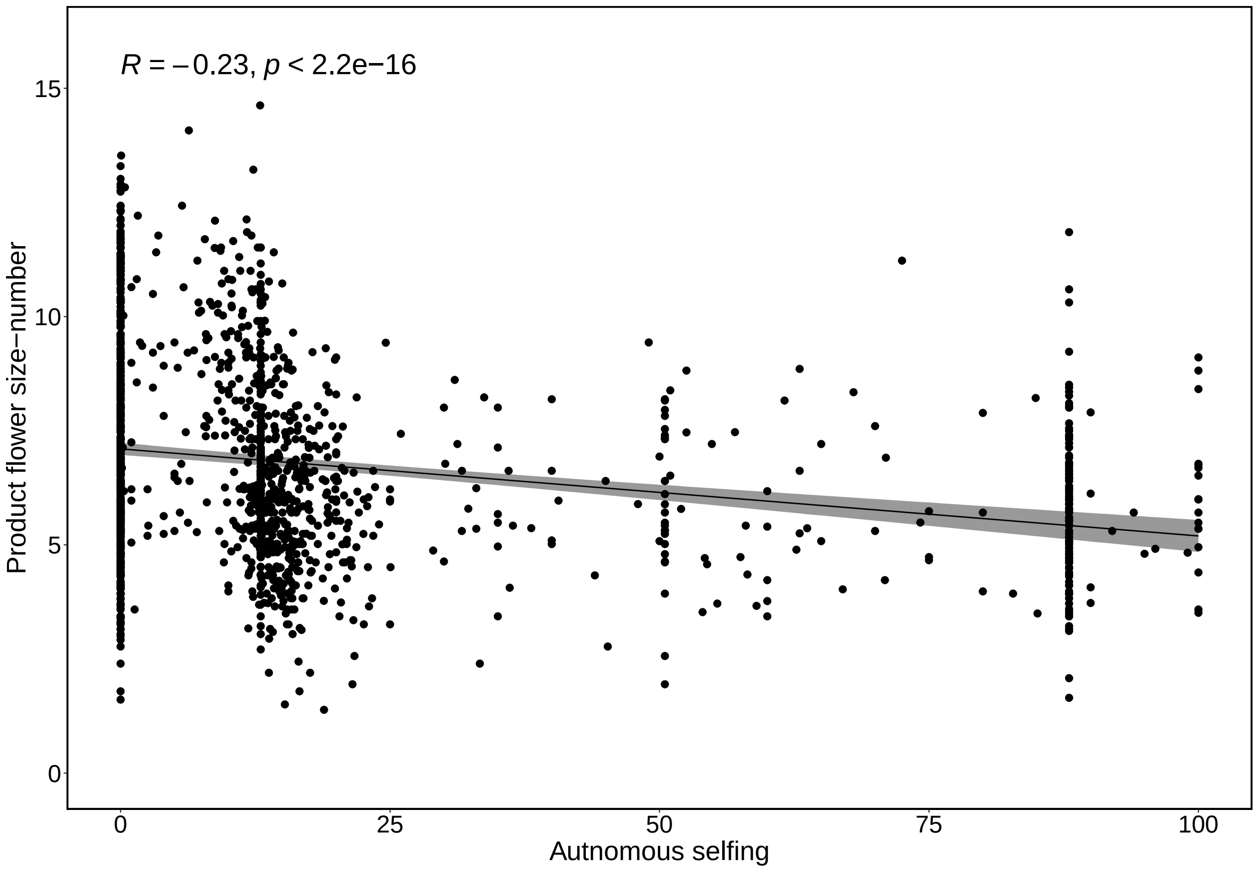


Fig. S11. Pearson correlation between the product of flower number-flower size and autonomous selfing level.