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Appendix 1

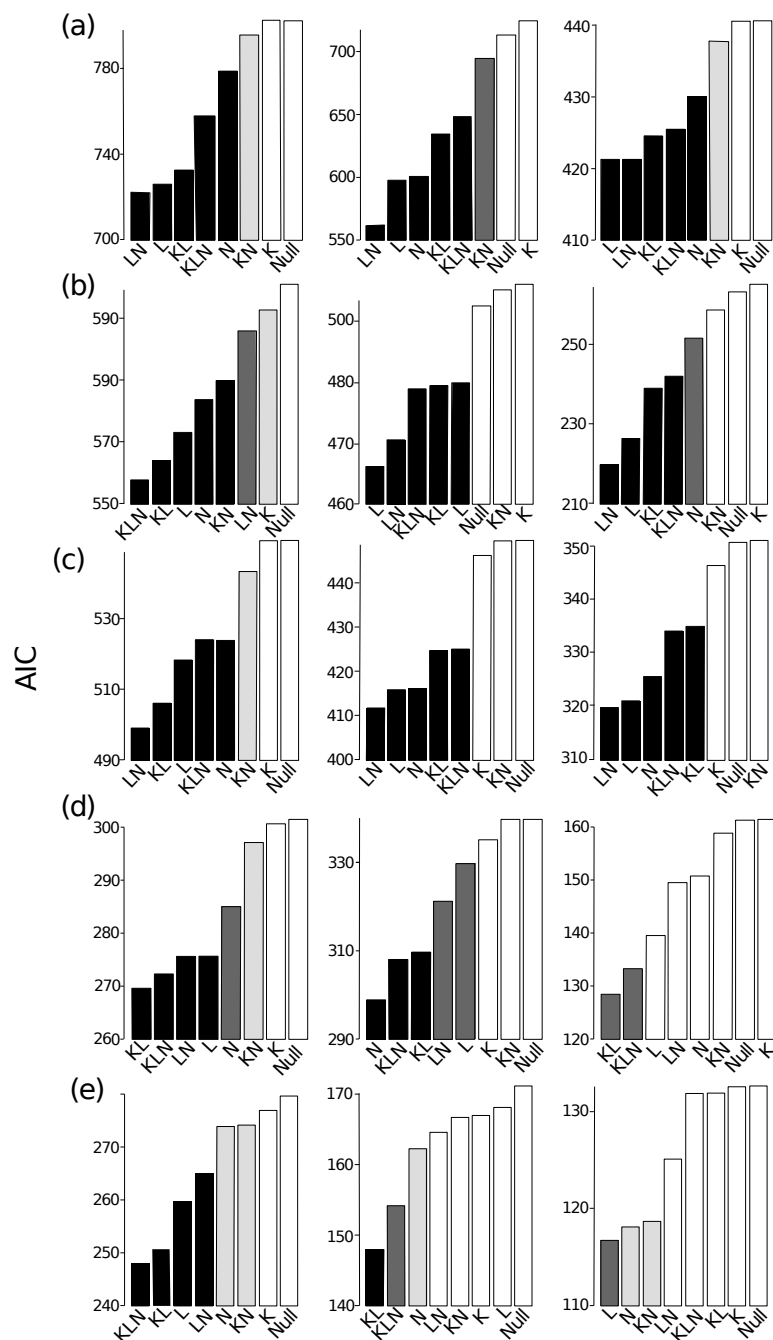


Figure A1. Regression analyses with plant species' degree. Same legend as Figure 1.

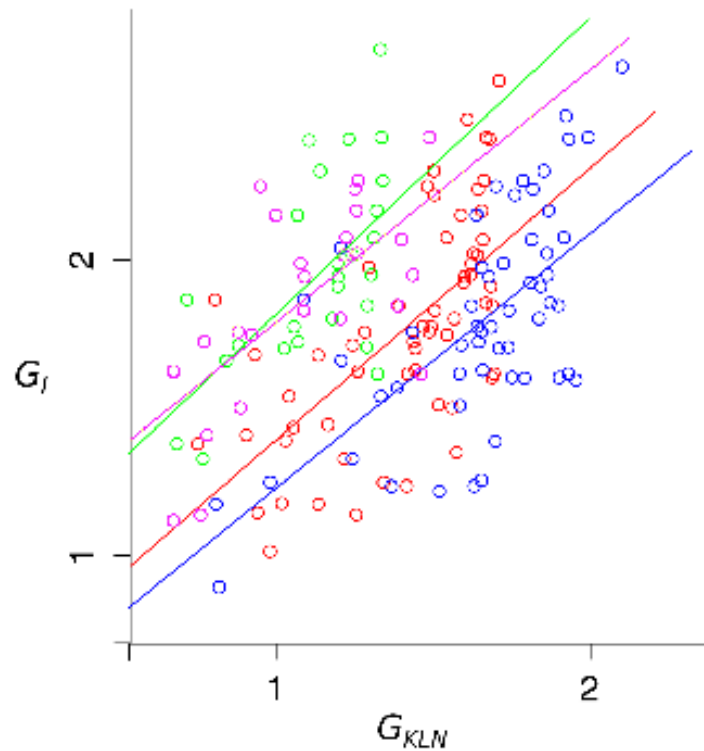


Figure A2. Observed plant generalization (G_I ; Shannon's diversity index) as a function of plant generalization predicted by the combined effect of color matching, spatiotemporal overlap and coabundance (G_{KLN}) in pollinator-defined subnetworks from Alb. One circle represents generalization of one plant species to bees (red), flies (blue), beetles (green) and butterflies (violet). Colored lines are linear fits to the models $G_I = f(G_{KLN})$.

Table A1. Mean color matching (upper table) and mean Shannon's diversity index for plants (lower table) in global and sub- networks.

K	Alb	Hainich	Schorfheide
global	0.262	0.218	0.198
bee	0.273	0.221	0.196
fly	0.291	0.227	0.213
beetle	0.249	0.271	0.272
butterfly	0.258	0.232	0.229

G_I	Alb	Hainich	Schorfheide
global	1.33	1.71	1.64
bee	1.75	1.91	2.00
fly	1.78	1.97	1.88
beetle	1.94	2.13	2.66
butterfly	1.85	2.11	2.69

Methods A1

Parameters for the probability matrix of color matching

Stimulation landscapes

For details on the model of stimulation landscape, see Renoult et al. (2013). We built eleven stimulation landscapes, one for each visual system. A stimulation landscape consists of a spectral space, which does not vary across visual systems, plus one dimension indicating for any color depicted in the spectral space its color contrast against predefined, average background coloration. This last dimension is specific to a visual system. Following recommendations from Renoult et al. (2013), we set the dimensionality of the spectral space to eight. The color contrast was calculated as the distance between signal and background coloration in a chromaticity diagram reconstructed from the number and sensitivity of photoreceptor types characterizing a given visual system (for details see Endler and Mielke 2005). The illuminant was the CIED65. For background coloration, we recorded reflectance spectra ($n = 170$) of plant and other natural materials (e.g. soil) at 0.5 m intervals along 5 m transects at the north-east and the southwest corners of each of the 120 plots. An overall average background spectrum was then calculated as the mean of all 170 reflectance spectra.

Number and sensitivity of photoreceptor types

We attributed to each insect species a visual system based on its phylogenetic position. See “Phylogenetic reconstruction” for details on pollinator phylogeny. A visual system is characterized by the number of photoreceptor types and the location of the peak of their maximal sensitivity λ_{\max} for each photoreceptor type. λ_{\max} values were mainly retrieved from Briscoe and Chittka (2001) and were complemented with data from specific studies when available. Based on λ_{\max} , we reconstructed the full photoreceptor sensitivity curve using templates by Govardosvskii et al. (2000).

Hymenoptera. – The diversity of bee and wasp photoreceptors has been relatively well studied owing to the comparative study of Peitsch et al. (1992), reinvestigated by Briscoe and Chittka (2001). In the basal Symphyta families, species possess a red sensitive photoreceptor. In more recent Apocrita families, a relatively invariant bee-like trichromatic system was found in nearly all species. Exceptions include wasps belonging to genus *Sphex* (Sphecidae) that possess red filter pigments generating a red-sensitive photoreceptor (Ribi 1978). We thus attributed four photoreceptor types with maximal sensitivity peaking at 340, 430, 540 and 600 nm to species of family Argidae, Tenthredinidae or Cephidae (Symphyta families), two photoreceptor types peaking at 350 and 510 nm to ants and three photoreceptors peaking at 340, 430 and 535 nm to all other families.

Diptera.— The number and the sensitivity of photoreceptor types have been well studied in *Drosophila melanogaster* (Drosophilidae; Feiler et al. 1992, 1988), *Musca domestica* (Muscidae; Hardie and Kirschfeld 1983) and in *Eristalis tenax* (Syrphidae; Bishop 1974, Horridge et al. 1975). These species invariably use four types of photoreceptor for color vision (Kelber 2001). Spectral sensitivities of Calliphoridae and Anthomyiidae showed great similarities with those of *Musca domestica* (Brown and Anderson 1996). In addition, although the spectral sensitivity has not been extensively studied in the phylogenetically more distant Dolichopodidae and Tabanidae, insects of these two families possess the typical internal morphology of muscoid flies (Lunau and Knüttel 1995). Concerning the paraphyletic group of Nematocera, Burkhart and De LaMotte (1972) and Kirschfeld (1986) reported high spectral sensitivity at 340 and 520 nm in the genus *Bibio* (Bibionidae), suggesting that this species possesses the same photopigments as brachyceran flies. Given that Bibionidae is the most basal family in the fly phylogeny, we considered that flies were all tetrachromatic. We attributed to every fly species the same set of photoreceptor types peaking at 350, 360, 460 and 540 nm, which represents the averaged values for the family (Briscoe and Chittka 2001).

Coleoptera.— In our study, most beetles that visited flowers belonged to the Cantharidae, for which no data on spectral sensitivity is available. Cantharid and Lampyrid beetles are monophyletic with respect to Elaterid beetles (Bocakova et al. 2007). All investigated Lampyrid and Elaterid species are confirmed trichromats (Lall et al. 2010). It is therefore highly likely that Cantharid beetles are trichromatic too. Other trichromatic beetles are Chrysomelidae (Döring and Skorupski 2007) and Coccinellidae (Lin and Wu 1992). More basally in the beetle phylogeny, two species of Carabidae and one of Glaphyridae (closely related to Scarabaeidae) possess a fourth, red photoreceptor (Briscoe and Chittka 2001). We therefore hypothesize that the ancestral state in Coleoptera is tetrachromacy and that the shift to trichromacy appeared later in the Elateriformia–Bostrichiformia–Cucujiformia clade. We thus attributed to every beetle species the same set of photoreceptors peaking at 350, 440 and 530 nm except for species belonging to family Carabidae, Staphylinidae, Cetonidae, Scarabaeidae for which we attributed four photoreceptors peaking at 350, 430, 500 and 620 nm (Briscoe and Chittka 2001).

Lepidoptera.— Most butterfly species possess the typical set of three photoreceptor types with maximal sensitivity in ultraviolet, blue and green wavelengths, respectively. However, butterflies differ from other insect orders in having undergone a remarkable radiation of photoreceptor spectral sensitivities from the three ancestral types (Briscoe 2008). In *Papilio xuthus*, up to eight

photoreceptor types have been recorded (Koshitaka et al. 2008). In that species, however, it has been shown that only four photoreceptor types are used when foraging. Butterflies are therefore most likely either trichromatic or tetrachromatic (Kelber and Osorio 2010). To identify which species are potentially trichromatic or tetrachromatic, we used the phylogenetic relationships of spectral sensitivities published in Briscoe and Chittka (2001). From this review, families Hesperidae, Sphingidae, Geometridae, Crambidae (closely related to Pyralidae) are most likely trichromatic. From our phylogeny of butterflies, we treated basal Zygaenidae as trichromatic too. According to Briscoe and Chittka (2001), tetrachromacy seems to represent the general state in Noctuidae, Papilionidae, Pieridae and Lycaenidae. We considered that Arctiidae, which are closely related to Noctuidae, are also tetrachromatic. In the last butterfly family represented in our study, the Nymphalidae, tetrachromacy appeared at least twice: in the Nymphalini and in the Argynnini tribes. Within each of these two tribes, some species have also been demonstrated to lack a red photoreceptor. We therefore arbitrarily considered that all Nymphalid butterflies, even those belonging to the Nymphalini and in the Argynnini tribes, are trichromatic. Note that interactions with Nymphalid butterflies represent 1.2% of all interactions recorded in this study. Concerning photoreceptor sensitivities, most of the variation occurs within families, complicating any extrapolation from phylogenetic relatedness. We thus attributed to all trichromatic species maximal sensitivities at 360, 460 and 530 nm, complemented by a fourth receptor peaking at 600 nm in tetrachromatic species (averaged values from Briscoe and Chittka 2001).

Methods A2

Phylogenetic reconstructions

We reconstructed two global phylogenetic trees, one for plants and one for pollinators, which include all species recorded in the three regions. The plant phylogeny was used to estimate the importance of phylogenetic relationships in plant generalization (see main text). The pollinator phylogeny was used to attribute visual systems. For the plant phylogeny, we first established relationships between families by discarding all but the 23 families included in our study from a published phylogeny of the angiosperms (Davies et al. 2004). Relationships between genera were obtained from the literature when available. For the pollinator phylogeny, we defined relationships between families from the Tree of Life Project (Maddison et al. 2007). We refined relationships among families using either published phylogenies or the traditional systematics as reported on the Fauna Europaea web site (Europaea 2011). The global trees include 140 species for the plant phylogeny and 744 species for the pollinator phylogeny.

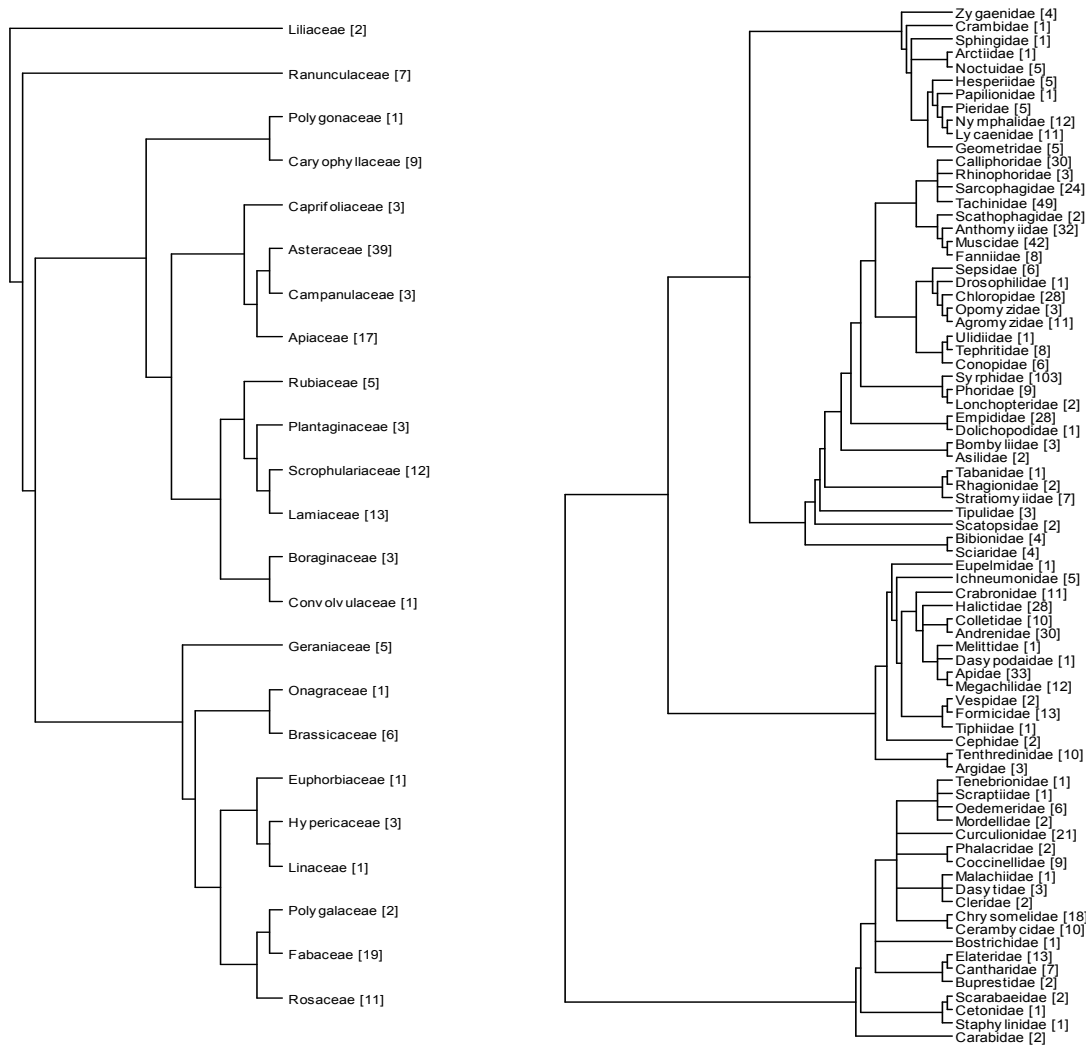


Figure A3. Phylogenetic tree of plants (left) and pollinators (right). For display purpose, phylogenetic relationships are provided up to the family level only. Numbers within brackets indicate the number of species included in the study for each family.

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