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Article

Title: The integration of alien plants in mutualistic plant–hummingbird networks across the Americas: the importance of species traits and insularity

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1 Biodiversity Research

2 Running header: Alien plants in plant-hummingbird networks

3

4 **The integration of alien plants in plant-hummingbird pollination networks across**
5 **the Americas: the importance of species traits and insularity**

6

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51 **ABSTRACT**

52 **Aim** To investigate the role of alien plants in mutualistic plant-hummingbird networks,
53 assessing the importance of species traits, floral abundances and insularity on alien plant
54 integration.

55 **Location** Mainland and insular Americas.

56 **Methods** We used species-level network indices to assess the role of alien plants in 21
57 quantitative plant-hummingbird networks where alien plants occur. We then evaluated
58 whether plant traits, including previous adaptations to bird-pollination, and insularity
59 predict these network indices. Additionally, for a subset of networks for which floral
60 abundance data was available, we tested whether this relate to network indices. Finally,
61 we tested the association between hummingbird traits and the probability of interaction
62 with alien plants across the networks.

63 **Results** Within the 21 networks, we identified 32 alien plant species and 352 native
64 plant species. **On average, alien plant species attracted more hummingbird species (i.e.**
65 **aliens had a higher degree) and had a higher proportion of interactions across their**
66 **hummingbird visitors than native plants (i.e. aliens had a higher species strength). At**
67 **the same time, an average alien plant was visited more exclusively by certain**
68 **hummingbird species (i.e. had a higher level of complementary specialization). Large**
69 alien plants and those occurring on islands distributed more evenly their interactions,
70 thereby acting as connectors. Other evaluated plant traits and floral abundance were
71 unimportant predictors of species-level indices. Short-billed hummingbirds had higher
72 probability of including alien plants in their interactions than long-billed species.

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3 73 **Main conclusions** Alien plants appear strongly integrated once incorporated into plant-
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5 74 hummingbird networks, and thus may have a large influence on network dynamics.
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7 75 Plant traits and floral abundance were generally poor predictors of how well alien
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9 76 species are integrated. Short-billed hummingbirds, often characterized as functionally
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11 77 generalized pollinators, facilitate the integration of alien plants. Our results show that
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13 78 plant-hummingbird networks are open for invasion.
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20 80 **Key-words**

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23 81 Abundance, exotic plants, generalization, invasion biology, network roles, ornithophily,
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25 82 specialization
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84 INTRODUCTION

85 Alien species may become invasive and are a major threat to biodiversity and ecosystem
86 functioning, including key ecosystem services such as pollination (Colautti & MacIsaac
87 2004, Gurevitch & Padilla 2004, Pyšek et al. 2004, Morales & Traveset 2009,
88 Simberloff et al. 2013). The successful establishment of alien plant species might be
89 contingent on the acquisition of mutualistic partners, e.g. pollinators, outside their
90 native range (Richardson et al. 2000, Bufford & Daehler 2014, Traveset & Richardson
91 2014). Under such a scenario, alien plants may compete for pollinators and decrease the
92 fitness of native plants, for instance by offering greater quantities of floral rewards and
93 thereby decreasing the attractiveness of native flowers (Chittka & Schürkens 2001,
94 Morales & Traveset 2009). Conversely, alien plants could also benefit native plants by
95 increasing the overall availability of floral resources, thereby increasing pollinator
96 abundance and activity on native plants (Bjerknes et al. 2007, Lopezaraiza-Mikel et al.
97 2007, Bartomeus et al. 2008). Thus, alien plants' ability to establish, and their effect on
98 the pollination of native plants, may depend on their floral traits and the community
99 context (Bjerknes et al. 2007, Morales & Traveset 2009, Gibson et al. 2012, Simberloff
100 et al. 2013).

101 In order to understand the potential impacts of alien species on ecosystems, it is
102 therefore important to characterize the community-wide roles of these plants (Davis et
103 al. 2011). One approach to doing this is to use ecological interaction network analyses
104 to conduct community-wide studies identifying and describing the interactions between
105 organisms. Several studies have used such an approach to investigate the role of alien
106 plants on plant-pollinator communities (Memmott & Waser 2002, Olesen et al. 2002,
107 Aizen et al. 2008, Vilà et al. 2009, Albrecht et al. 2014, Stouffer et al. 2014, Traveset &

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3 108 Richardson 2014). However, most of these studies have considered either temperate
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5 109 systems, which predominantly consist of functionally generalized insect pollinators (e.g.
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7 110 Aizen et al. 2008, Bartomeus et al. 2008), or focus on generalized island communities
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9 111 where the impact of invasive species might be most severe (e.g. Olesen et al. 2002,
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11 112 Traveset et al. 2013, Traveset & Richardson 2014, but see Kaiser-Bunbury et al. 2011).
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13 113 As an interaction network's stability may be more sensitive to the integration of alien
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15 114 species in specialized than in generalized systems (Kaiser-Bunbury et al. 2011), studies
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17 115 on specialized systems and over large geographical scales can contribute to our
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19 116 understanding of the general effects of alien species.
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24 117 One such potential model system is the interaction networks between plants and
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26 118 hummingbirds across the Americas, which range from relatively specialized to
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28 119 generalized networks, and include both mainland and insular environments (Stiles 1981,
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30 120 [Dalsgaard et al. 2011](#), Martín González et al. 2015). Hummingbirds are the most
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32 121 functionally specialized group of nectar-feeding birds and the most important vertebrate
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34 122 pollinators in the Americas (Stiles 1981, Bawa 1990, Cronk & Ojeda 2008). As specific
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36 123 floral phenotypes are often associated with hummingbird pollination (Cronk & Ojeda
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38 124 2008, [Ferreira et al. 2016](#)), it could be expected that alien plants lacking a shared
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40 125 evolutionary history with hummingbirds would not be readily incorporated as important
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42 126 species in those networks (Richardson et al. 2000; Aizen et al. 2008). Conversely, Old
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44 127 World plants with convergent adaptations to bird pollination, notably to sunbirds and
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46 128 honeyeaters in Africa and South-east Asia (Cronk & Ojeda 2008, Fleming & Muchhala
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48 129 2008, Ollerton et al. 2012, Janeček et al. 2015), could be well-integrated in novel plant-
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50 130 hummingbird communities in the Americas – at least more than alien plant species not
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52 131 previously pollinated by birds (see Johnson & Raguso 2015 for examples between
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54 132 specialized flowers and long tongued hawkmoths).
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3 133 Given the increasing concerns over the effects of alien species on ecosystems
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5 134 (Davis et al. 2011, Richardson & Ricciardi 2013, Simberloff et al. 2013), community-
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7 135 wide studies on the role of alien plants across large geographic gradients could provide
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9 136 new insights into their potential threats to biodiversity. Here, we characterize the role of
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11 137 alien plants in 21 quantitative plant-hummingbird networks distributed broadly across
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13 138 the Neotropics, including both mainland and island environments (Fig. 1). We asked
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15 139 **three questions:** 1) whether an average alien plant is topologically more important than a
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17 140 native species, i.e. whether alien plants have a disproportionate large effect on plant-
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19 141 hummingbird networks; 2) whether alien plant traits, such as pre-adaptation to bird
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21 142 pollination in combination to the geographical setting of the network, i.e., insularity,
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23 143 affect the integration of plants into networks; 3) whether hummingbirds with short-bills,
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25 144 often characterized as functionally more generalized, facilitate the integration of alien
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27 145 plant species into networks.
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147 **METHODS**

148 *Plant-hummingbird networks and alien plants classification*

149 In order to investigate the role of alien plant species in pollination networks, we
150 compiled plant-hummingbird networks in which exotic plant species could be
151 confidently identified (Figure 1). For this, we used an established database on
152 quantitative plant-hummingbird interaction networks (see Dalsgaard et al. 2011 and
153 Martín González et al. 2015 for previous versions of the database, updated details in
154 Table S1-S3). We only considered legitimate interactions here, in which a hummingbird
155 was observed contacting the reproductive structures of the flowers and with potential for
156 pollination. For each network, plants were classified as either native or alien - taking
157 into account the locality of a given network and the plant distribution range according to

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3 158 openly available databases, notably: Tropicos (<http://www.tropicos.org/>), GRIN
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5 159 Taxonomy for Plants for North America (<http://www.ars-grin.gov/>), Flora of the West
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7 160 Indies for the Caribbean (<http://botany.si.edu/antilles/WestIndies/query.cfm>), Brazilian
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9 161 Flora Checklist for networks from Brazil (<http://floradobrasil.jbrj.gov.br/>) and The Plant
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11 162 List (<http://www.theplantlist.org/>). Plant names used here followed The Plant List
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13 163 database. A total of 75 (19%) plant occurrences in the networks were not identified to
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15 164 species level, but to genus or family level only (Table S2); for these we adopted a
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17 165 conservative approach of only attributing "alien" status if the genus/family at the given
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19 166 locality was identified as alien in the databases. **We note, however, that excluding these**
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21 167 **species did not affect the comparison between native and alien plants.** Because the
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23 168 geographical origin of some plants is poorly known, the classification of these can be
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25 169 imprecise (Pyšek et al. 2004), and the use of a single general database has been argued
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27 170 for in order to standardize possible bias (Stouffer et al. 2014). However, our dataset is
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29 171 composed primarily of networks from the Neotropical region, which has relatively poor
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31 172 historical species records compared to North America and Europe (Pyšek et al. 2004).
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33 173 Since even for well recorded regions these general databases can fail to successfully
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35 174 classify species (see Stouffer et al. 2014), we preferred to use regional databases, which
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37 175 rely on local plant specialists, e.g. the Brazilian Flora Checklist. Whenever conflicts
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39 176 among databases appeared, or we were unsure of the classification, we contacted
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41 177 experts with working experience on the flora of the specific region (listed in the
42
43 178 Acknowledgments). **We refer to the plants considered here solely as alien, since to**
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45 179 **define these as invasive require more than distributional information e.g. ecological and**
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47 180 **demographic parameters that we currently lack (Colautti & MacIssac 2004). Moreover,**
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49 181 **all hummingbirds were considered as natives.**
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183 *Species-level network metrics*

184 For each plant-hummingbird community, interactions were summarized as a bipartite
185 matrix, with each cell filled with the frequency of the pairwise interaction between a
186 plant and a hummingbird species. The role of each plant species within the networks
187 was described by five distinct indices that capture distinct topological properties of a
188 species: 1) the degree of a species (k_i) is computed as the number of partners a given
189 species i is linked to in the network; 2) species strength (s_i) is the sum of dependencies
190 across all interaction partners of a given species i ; dependency is calculated as the
191 proportion of interactions performed by species i to a specific partner (Bascompte et al.
192 2006); 3) complementary specialization, (d'_i) quantifies how interaction frequencies of a
193 given species deviate in relation to the availability of interaction partners in the network,
194 defined by their marginal totals; the higher the value of d' , the more exclusive are the
195 interactions of the species in relation to the other species in the network (Blüthgen et al.
196 2006). In addition, we calculated the level of quantitative modularity of each network,
197 i.e. formation of distinct sub-communities within an ecological network characterized
198 by high within-module prevalence over between-module interactions (Dormann &
199 Strauss 2014). For each network, we estimated the module conformation using the
200 QuanBiMo algorithm with the number of Markov Chain Monte Carlo (MCMC) moves
201 to yield no improvement before the algorithm stops set to 10^7 steps (Dormann & Strauss
202 2014). From the module conformation with the highest modularity after 20 independent
203 runs for each network (as in Maruyama et al. 2014), we calculated two species-level
204 network indices: 4) between-module connectivity c and 5) within-module connectivity
205 z . Whereas c_i describes how evenly the interactions of species i are distributed across
206 modules in the network, z_i quantifies the importance of a given species i within its
207 module (Dormann & Strauss 2014). Species-level network indices showed a positive

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3 208 correlation in some cases, indicating that species with high values for a given index
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5 209 tended to also have high values for another index (Table S4). The correlation was
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7 210 especially high between degree and species strength (Pearson's $r = 0.68$; Table S4), and
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9 211 between species strength and within module connectivity, i.e. z (Pearson's $r = 0.70$;
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11 212 Table S4). However, these indices complement each other and we therefore used all five
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13 213 indices when comparing alien vs. native plants. In order to compare the five species-
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15 214 level network indices across different networks, we transformed all network indices to
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17 215 z-scores, i.e., indices were standardized within each network by subtracting the mean
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19 216 value of each group (plants or hummingbirds) and dividing the results by its standard
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21 217 deviation (as in Vidal et al. 2014). Calculations of species-level network indices were
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23 218 conducted with the *bipartite* package (Dormann et al. 2008) in R (R Development Core
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25 219 Team 2014).

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32 221 *Question 1: Are alien plants topologically more important than native plants in the*
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34 222 *networks?*

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36 223 To test whether alien plant species differed from native species, we used a null
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38 224 model to contrast the observed difference of means of the species-level indices between
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40 225 native and alien plants to the differences of the means calculated from randomizations
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42 226 shuffling the alien or native status of the plants (the proportion of alien/natives was
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44 227 fixed; Vidal et al. 2014). The significance (p -values) was obtained by dividing the
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46 228 number of times the absolute differences generated from 10,000 randomizations were
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48 229 equal or larger than the observed difference of the means by the number of
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50 230 randomizations (Manly 1997). Whenever a plant species occurred in more than a single
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52 231 network (74 species, 19.3% of all plants), the average for each of the standardized
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54 232 indices was calculated and used for the null model analysis. We note that with the
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3 233 exception of the degree (k) which becomes non-significant, results were qualitatively
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5 234 similar if we consider the instances in which the same species occurred in different
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7 235 networks as distinct samples. Thus, we kept the same approach adopted in Vidal et al.
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9 236 (2014). To quantify the magnitude of the difference between native and alien plant
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11 237 species, we calculated Cohen's d effect size as the standardized mean difference
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13 238 between the indices of each group, i.e. the difference between means divided by the
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15 239 standard deviation of the respective index for all plants (Nakagawa & Cuthill 2007,
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17 240 Sullivan & Feinn 2012). For example, an effect size of around 0.5 is considered a
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19 241 medium effect, meaning that an average alien plant species has a higher index value
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21 242 than 69% of the natives (Nakagawa & Cuthill 2007, Sullivan & Feinn 2012).
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27 244 *Question 2: Do plant traits and insularity affect the network roles of alien plants?*

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29 245 For all alien plants identified in the 21 networks, we classified the species according to
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31 246 traits we hypothesized as relevant for their role in the networks. Trait information was
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33 247 gathered from the original sources of the network data (Table S1), as well as by a
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35 248 follow-up literature search using Google Scholar® with the species name as the search
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37 249 term. All alien plants were classified according to (a) the size of the plant, which
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39 250 potentially reflects their floral display (i.e. large or small, the former including trees and
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41 251 large herbs such as bananas, and the latter including shrubs, climbers and small herbs);
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43 252 (b) flower type (tubular, brush or other), (c) **the length of the floral corolla or equivalent**
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45 253 **structures restricting the access to pollinator (mm)**, and (d) whether or not they are bird-
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47 254 pollinated in their native range (Tables S5-S6). To determine the latter, we used
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49 255 references from the plant-hummingbird network database as well as field based studies
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51 256 on the floral morphology and pollination biology of the plants, including information on
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53 257 the associated floral visitors and pollinators (Table S5-S6). Additionally, we classified
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3 258 whether an alien plant occurred on an island or on mainland communities. As we were
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5 259 only able to evaluate alien plant traits, and not the traits of the native plants, we asked
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7 260 whether particular characteristics of the aliens influence its integration into the
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9 261 networks.

11 262 We evaluated how plant traits and insularity related to plant species-level
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13 263 network indices with linear mixed effects models (LMM) using the *lme4* package
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15 264 (Bates 2014) in R (R Development Core Team. 2014). We used the plant traits (i.e. size,
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17 265 flower type, flower length and previous association to bird pollination) and insularity of
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19 266 the network as fixed factors. Here, we also included the plant family as a fixed factor to,
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21 267 at least partly, account for taxonomic relatedness. Alien plant species identity was
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23 268 included as a random effect to account for non-independence of the observations of the
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25 269 same species in different networks (Bolker et al. 2009, Zuur et al. 2009). We ran models
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27 270 separately for each of the five distinct species-level network indices. The full models
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29 271 included all predictors and were compared to reduced models using the function
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31 272 "dredge" in R package *MuMIn* (Barton 2014), according to their Akaike information
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33 273 criteria (AIC) values, corrected for small sample sizes (AICc - Bolker et al. 2009, Zuur
34
35 274 et al. 2009). Models with $\Delta\text{AICc} \leq 2$ were considered to be equivalent. We also
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37 275 estimated the proportion of variance explained by the fixed factors in the selected best
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39 276 model as marginal R^2 , and the proportion of variance explained by fixed and random
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41 277 factors as conditional R^2 (Nakagawa & Schielzeth 2013, Barton 2014). For 12 of the
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43 278 networks (57.1% of the dataset), floral abundance data were available and thus we
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45 279 conducted additional analyses evaluating its role on species-level network indices.
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47 280 Following the same procedure to what was done for the entire dataset, we fitted LMMs
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49 281 to evaluate simultaneously the effect of alien plant traits, floral abundance and insularity
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3 282 on the species-level indices. Here, as for network indices, the floral abundances were
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5 283 standardized within each network.
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9 285 *Question 3: Do hummingbird traits relate to facilitation of alien plant integration?*

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11 286 Finally, we asked whether hummingbird bill length, a functional bird trait
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13 287 associated with flower choice (Dalsgaard et al. 2009, Maruyama et al. 2014, Maglianesi
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15 288 et al. 2014), was related to the probability of hummingbirds including alien plants in
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17 289 their array of interactions. Longer billed-hummingbirds are considered functionally
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19 290 more specialized (Dalsgaard et al. 2009, Maruyama et al. 2014, Maglianesi et al. 2014).
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21 291 For this, we compiled information on hummingbird bill lengths (Table S3) and assessed
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23 292 whether a given hummingbird species interacted with an alien plant across the
24
25 293 networks. Then, we fitted a generalized linear model with binomial error distribution
26
27 294 containing hummingbird bill length as predictor of the probability that a hummingbird
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29 295 species interacted with alien plant species (Zuur et al. 2009). This analysis was
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31 296 conducted at species level, contrasting each species' bill length to the presence of
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33 297 interaction with alien plants across all the networks in which a given hummingbird
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35 298 species occurred. *We also conducted a similar analysis excluding hummingbird species*
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37 299 *occurring on Caribbean islands where networks are small (Dalsgaard et al. 2009)*, as
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39 300 well as using the body mass instead of the bill length. As bill length and body mass in
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41 301 hummingbirds show strong phylogenetic signal (Graham et al. 2012), we also included
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43 302 the hummingbird clades (McGuire et al. 2014) as another *fixed* factor in these analysis.
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45 303 The models with and without clade identity were compared by an analysis of deviance
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47 304 test and their AIC values (Zuur et al. 2009).
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56 306 **RESULTS**
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3 307 The 21 plant-hummingbird networks included a total of 74 hummingbird and 384 plant
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5 308 species, of which 32 plants were classified as being alien to the networks in which they
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7 309 occurred. Individual networks contained between seven and 65 plant species, with a
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9 310 mean of $10.8 \pm 8.2\%$ (\pm sd) and up to 28.6% alien plant species (Figure 1, Table S7).
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11 311 Alien plants belonged to 16 plant families, with Musaceae and Myrtaceae constituting
12
13 312 the most frequent families (Table S5-S6). Most alien plant species (~63%) had tubular
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15 313 flowers, and about half of them (~47%) had previous association with bird pollinators
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17 314 (Table S5-S6). Around 50% of alien species originated from Asia, about 19% originated
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19 315 from Africa and 19% from other regions of the Americas (Table S5).
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25 317 *Question 1: Are alien plants topologically more important than native plants in the*
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27 318 *networks?*
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29 319 Overall, alien plant species had higher values of species strength than native species
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31 320 (effect size, k : Cohen's $d = 0.56$; 95% Confidence Interval = 0.36-0.77; null model $p =$
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33 321 0.003; Figure 2). Likewise, alien plants also had higher values of within module
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35 322 connectivity (z : Cohen's $d = 0.49$; 95% CI = 0.29-0.69; $p = 0.006$; Figure 2). For degree
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37 323 (k) and complementary specialization (d'), 95% CI of effect sizes did also not overlap
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39 324 zero and null models were significant (k : Cohen's $d = 0.35$; 95% CI = 0.15-0.56; $p =$
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41 325 0.049; d' : Cohen's $d = 0.35$, 95% CI = 0.15-0.55; $p = 0.050$; Figure 2). However, alien
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43 326 plants did not differ from native species in connecting distinct modules (c : Cohen's $d =$
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45 327 0.07; 95% CI = -0.12-0.27; $p = 0.662$). Hence, an average alien plant is more important
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47 328 for hummingbirds **than an average native plant** in terms of relative interaction
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49 329 frequency. There is also a tendency for alien plant species to have more partners and for
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51 330 some hummingbird species to interact more exclusively with alien plants **than natives**.
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3 332 *Question 2: Do plant traits and insularity affect the network roles of alien plants?*
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5 333 Alien plant traits did not relate to species-level network indices, except for
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7 334 between-module connectivity (c), since the model containing only the intercept was
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9 335 always included within the best models (Table S8). For c , the best two models included
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11 336 insularity and size of the alien plants; the model containing both terms had R^2 marginal
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13 337 = 0.22 and R^2 conditional = 0.33. Specifically, aliens on islands (estimate = 0.35, SE =
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16 338 0.30) and larger alien plants (estimate = 0.75, SE = 0.27) had higher values for
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18 339 connectivity, i.e. were more important for interconnecting modules. Plant family was
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20 340 not included in any of the best models. Considering the subset of networks for which we
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22 341 had floral abundance data, this did not relate to species topological roles in any of the
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24 342 LMMs, as in all cases the intercept only model was as good as models including floral
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26 343 abundance (Table S9). Importantly, the results of LMMs for this reduced dataset were
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28 344 fairly consistent and we again have that insularity (estimate = 0.68, SE = 0.18) and plant
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30 345 size (estimate = 1.18, SE = 0.36) relate to c (R^2 marginal = 0.42 and R^2 conditional =
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32 346 0.97).
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38 348 *Question 3: Do hummingbird traits relate to facilitation of alien plant integration?*
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40 349 We found that short-billed hummingbirds were more likely to interact with alien plants
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42 350 than were long-billed hummingbirds (slope: -0.10; $p < 0.01$; Figure 3). The model
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44 351 including the hummingbird clades did not differ from the one without (Deviance = 6.68,
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46 352 $p > 0.46$) and had higher value of AIC ($\Delta AIC = 9.32$). Excluding the hummingbird
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48 353 species occurring in the Caribbean islands did not change our results (slope: -0.08; $p =$
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50 354 0.036; Figure S1) and body mass was found unrelated to the probability of using alien
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52 355 plants ($p = 0.091$).
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357 **DISCUSSION**

358 We have shown that alien plants are strongly integrated into plant-hummingbird
359 networks, playing key roles in the networks where they occur. Alien plants have more
360 partners (higher degree) and hummingbirds show higher dependency on them than on
361 an average native plant, both across the entire network and within their modules.
362 Although we note that the networks contained many more native than alien plant
363 species (352 versus 32 species, range 2.0% to 28.6% of the species), these results
364 suggest that alien plants are important and act as core generalists in these networks
365 (Aizen et al. 2008, Bartomeus et al. 2008, Vilà et al. 2009, Stouffer et al. 2014, Traveset
366 & Richardson 2014). Moreover, some alien plants may function as private or somewhat
367 exclusive floral resources for some hummingbird species, as revealed by their high
368 degree of complementary specialization (Blüthgen et al. 2006, Stouffer et al. 2014).

369 The traits we hypothesized *a priori* to determine how alien plants would
370 integrate into the networks showed little importance. For instance, convergent evolution
371 to bird pollination has been suggested as an example of previous adaptation to specific
372 pollinator types aiding the incorporation of aliens to novel plant-pollinator networks
373 (Richardson et al. 2000, Ollerton et al. 2012). However, this pre-adaptation did not
374 apply to network roles of alien plants in plant-hummingbird networks. Hummingbirds
375 may favour specific floral traits (Cronk & Ojeda 2008, Ferreira et al. 2016), but they
376 may also show opportunism in flower use by legitimately visiting plants that do not
377 obviously conform to the bird pollination syndrome of ornithophily (e.g. Dalsgaard et
378 al. 2009, Maruyama et al. 2013). Due to this opportunism, specialized floral traits may
379 not relate to plant species roles in plant-hummingbird networks (Maruyama et al. 2013).
380 Nevertheless, one possible limitation is the fact that we only considered plant species
381 recorded as visited by hummingbirds, i.e., participating in the web of interactions. It is

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3 382 possible that other alien plants were present in the studied communities and that these
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5 383 were not visited by hummingbirds. If such non-participating alien species had been
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7 384 considered, plant traits, including the previous adaptation to bird-pollination, could have
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9 385 emerged as important for alien integration into the plant-hummingbird web. Likewise
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11 386 we did not include non-hummingbird pollinators and insects may overlap with
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13 387 hummingbirds on the phenotypically more generalised plant species (e.g. Dalsgaard et
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15 al. 2009, Maruyama et al. 2013); thus other pollinators may also influence alien plant
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17 388 integration.
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21 390 It has been suggested that invasive plants, i.e. widespread and abundant alien
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23 391 plants, may become core components of plant-insect pollinator networks due to their
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25 392 high abundance in invaded communities (Lopezaraiza-Mikel et al. 2007, Aizen et al.
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27 393 2008, Albrecht et al. 2014). However, recent studies have shown that abundance has
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29 394 minor importance in structuring interactions among plants and hummingbirds, in
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31 395 contrast to more generalized insect pollination systems (Maruyama et al. 2014,
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33 396 Vizentin-Bugoni et al. 2014, 2016). In accordance, analyses conducted with the subset
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35 397 of the networks for which we have floral abundance data show that there is no
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37 398 association between floral abundance and their species-level indices. Thus, for plant-
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39 399 hummingbird networks, floral abundance is a poor predictor of alien topological
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41 400 importance. Instead, we suggest that other plant traits that we lack in our dataset, such
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43 401 as the temporal availability of alien flowers in relation to native plants (i.e. phenology),
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45 402 or higher nectar secretion rates, could be important for explaining the integration of
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47 403 alien species in these networks (see Chittka & Schürkens 2001, Godoy et al. 2009).

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49 404 Although most plant traits evaluated here did not relate to the role of alien plants
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51 405 in the networks, we found that larger alien plants had higher values of between module
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53 406 connectivity than smaller alien plants. Thus, presumably those alien plants that have
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3 407 bigger floral display distribute their interactions more widely among modules in
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5 408 networks, acting as connectors in these networks. This is important since connectors are
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7 409 suggested to blur the boundaries between modules affecting the network dynamics
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9 410 (Albrecht et al. 2014). Alien plants occurring in depauperate island networks were also
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11 411 better connectors than alien plants on the mainland, which indicates that they may have
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13 412 greater potential to affect insular than mainland communities (e.g. Traveset et al. 2013,
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15 413 but see Kaiser-Bunbury et al. 2011).

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17 414 From the hummingbird perspective, we show that shorter billed hummingbirds
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19 415 have higher probabilities of incorporating alien plant species in their web of
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21 416 interactions. Although there is variation in this trend, since some longer-billed
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23 417 hummingbirds used alien plants (Figure 3), this result is consistent to the setting in
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25 418 which longer-billed hummingbirds avoid interacting with more generalised flowers due
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27 419 competition with shorter-billed hummingbirds (Maglianesi et al. 2015). Studies have
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29 420 suggested that generalist insect pollinators facilitate alien plant establishment, since
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31 421 these often include alien plants in their interactions (Richardson et al. 2000, Memmott
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33 422 & Waser 2002, Olesen et al. 2002, Lopezaraiza-Mikel et al. 2007, Aizen et al. 2008,
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35 423 Bartomeus et al. 2008, Traveset et al. 2013, Stouffer et al. 2014). In previous studies,
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37 424 however, "generalists" were defined based in their roles in networks, e.g., number of
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39 425 partners. Here, we show a link between integration of alien plants and a functional trait
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41 426 of the pollinators, i.e. bill length of hummingbirds.
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49 428 **CONCLUSION**

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51 429 Invasive plants are regarded as one of the major current threats to biodiversity. One of
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53 430 the key components for alien plants to establish in novel ecosystems is their successful
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55 431 integration into mutualistic networks (Richardson et al. 2000, Traveset & Richardson
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3 432 2014). Although examples of successful integration of alien species in temperate and
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5 433 insular insect-plant systems are common (e.g. Olesen et al. 2002, Aizen et al. 2008,
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7 434 Bartomeus et al. 2008, Vilà et al. 2009, Stouffer et al. 2014), here we show that alien
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9 435 plants are strongly integrated into the web of interactions even for more specialized
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11 436 tropical pollination systems, such as hummingbird pollination. Further research
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13 437 incorporating complementary data, such as interspecific pollen deposition or the
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15 438 contribution of hummingbirds to alien plant reproduction, are essential next steps to
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17 439 fully assess the impact and integration of alien plants in this system (Richardson et al.
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19 440 2000, Lopezaraiza-Mikel et al. 2007, Bufford & Daehler 2014, Traveset & Richardson
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21 441 2014). By acting as core generalist species in the networks, these plants may impact the
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23 442 entire plant-pollinator network (Traveset et al. 2013) and even modify their eco-
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25 443 evolutionary dynamics (Guimarães et al. 2011). In sum, our results here show that
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27 444 plant-hummingbird networks are dynamic and open for invasion, emulating what
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29 445 happens in other plant-pollinator systems.
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3 640 **SUPPORTING INFORMATION:**

4 641 **Figure S1** Probability of hummingbirds incorporating alien plants into their interactions
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7 642 in relation to their bill length, excluding island networks.

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9 643 **Table S1** Coordinates, description, location and data references for each studied plant-
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11 644 hummingbird network.

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13 645 **Table S2** List of plant species found across plant-hummingbird networks.

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15 646 **Table S3** List of hummingbird species found across plant-hummingbird networks.

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18 647 **Table S4** Pearson correlation r among distinct species-level network indices.

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21 648 **Table S5** List of the alien plant species found across plant-hummingbird networks.

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24 649 **Table S6** Details on the assessment of alien plants' pollination system.

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27 650 **Table S7** Proportion of alien plant species and their interactions across networks.

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31 651 **Table S8** Model selection results for linear mixed effect models explaining network
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33 652 indices of the alien plant species.

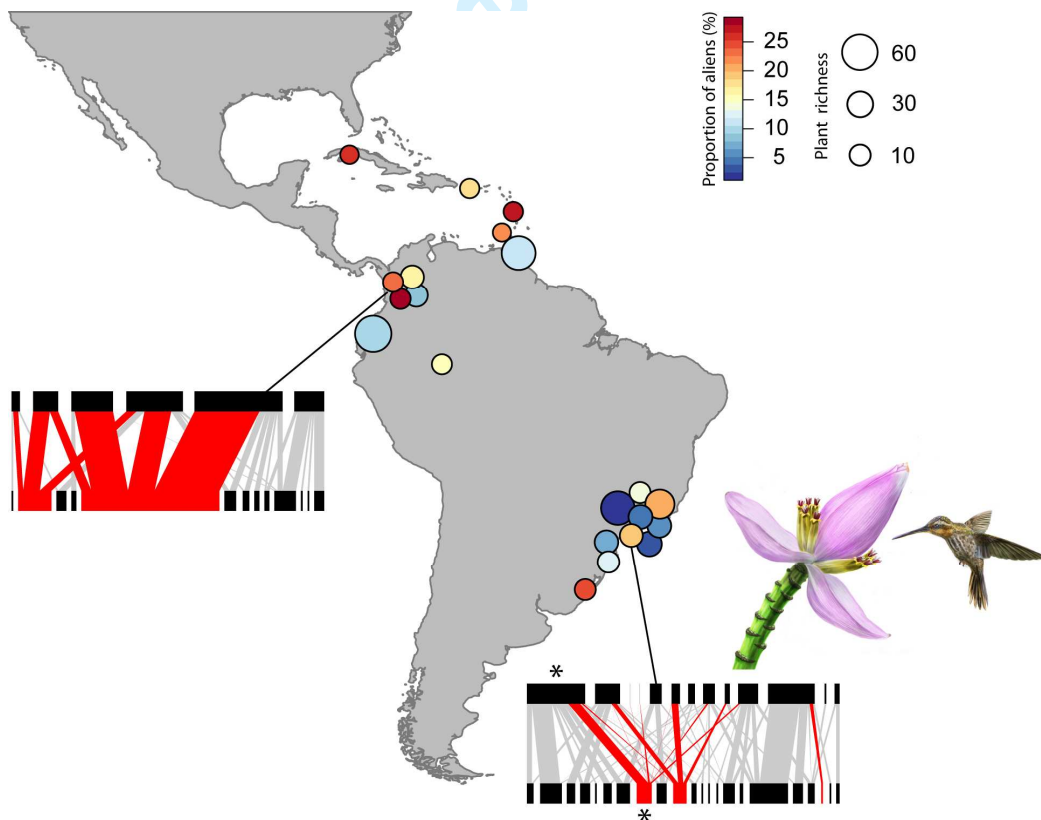
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36 653 **Table S9** Model selection results for the subset of 12 networks with floral abundance
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38 654 data.

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41 655 **BIOSKETCH**

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43 656 **Pietro K. Maruyama** is an ecologist, especially interested in natural history and plant-
44 657 animal mutualistic interactions in megadiverse tropical ecosystems, such as the Cerrado
45 658 and Atlantic Rainforest. This study is part of an ongoing research collaboration on
46 659 plant-hummingbird networks across the Americas, involving numerous researchers.

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4 663 **Figure 1** Distribution of 21 Neotropical plant-hummingbird networks containing alien
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6 664 plant species. Circle size represents the total number of plant species in each network;
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8 665 colours indicate the proportion of alien plants in each network. Note that some points
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10 666 have been slightly moved to avoid overlap. Two network representations illustrate how
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12 667 alien plants are integrated into the networks (top network, Colombian Andes, Snow &
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14 668 Snow 1980; bottom network, Brazilian Atlantic Rainforest, Maruyama et al. 2015). Top
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16 669 and bottom rectangles denote hummingbirds and plants, respectively. Alien plants and
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18 670 their interactions are marked in red. The illustration depicts one such interaction from
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20 671 the bottom network, between the Saw-billed hermit *Ramphodon naevius* and the
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22 672 Flowering banana *Musa ornata* originally from Southeast Asia (credit: Pedro Lorenzo).
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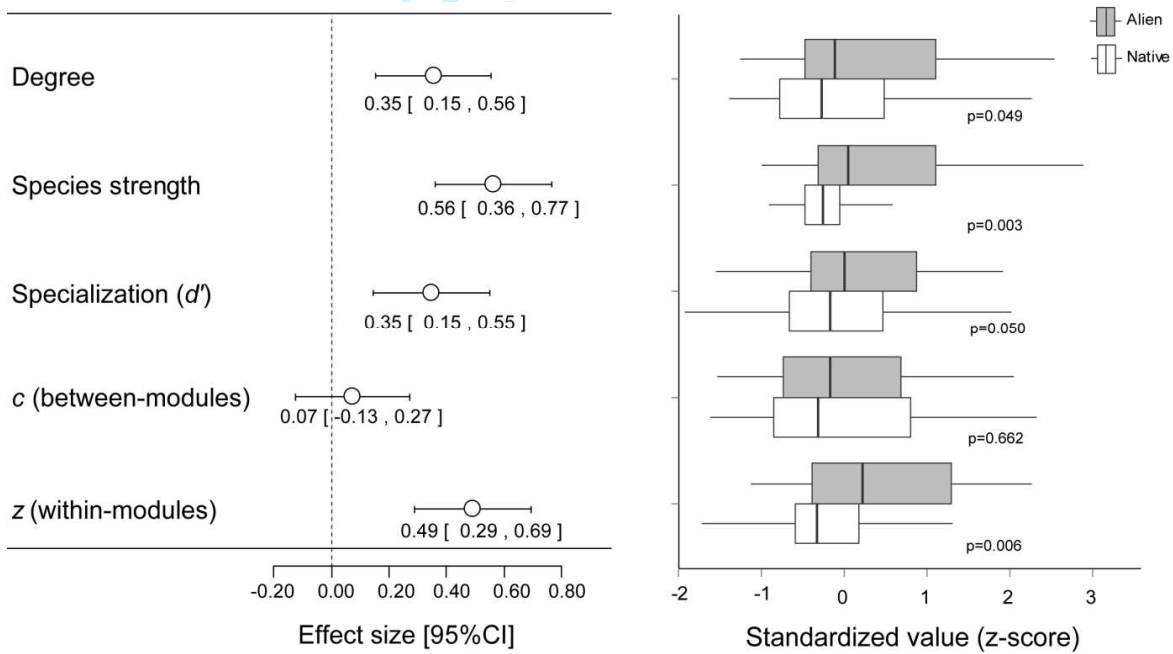


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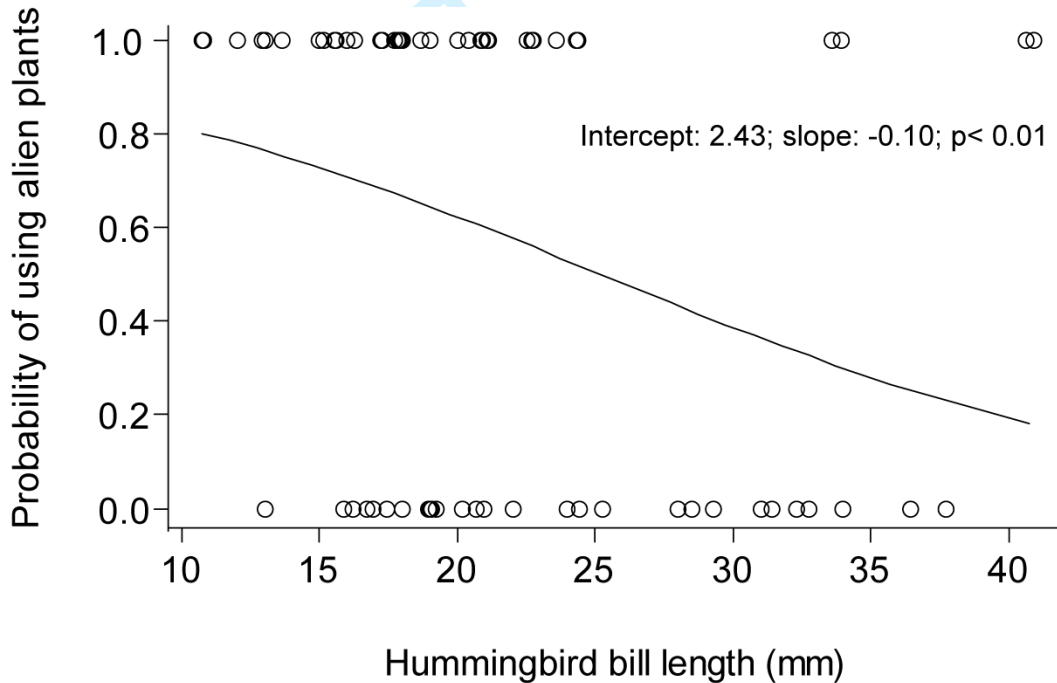
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675 **Figure 2** Species-level network indices for 352 native and 32 alien plant species across 21 plant-hummingbird networks. On the left, we show
676 the effect sizes (Cohen's d) comparing alien and native plant species for various network indices; an effect size is considered significant if the
677 95% CI of the mean differences do not overlap zero (Nakagawa & Cuthill 2007). On the right, box-plots illustrate the distribution of standardized
678 index values along with their significance, as obtained from null model analysis. With the exception of *c*, both approaches found that an average
679 alien plant have higher network index values than an average native plant.



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681 **Figure 3** Probability of hummingbird species incorporating alien plant species into their
 682 interactions in relation to their bill length. Each circle illustrates whether a given
 683 hummingbird species incorporates alien plants (1), or not (0). The fitted line reflects the
 684 modelled probability of hummingbird species feeding on alien plants; showing that
 685 short-billed hummingbirds have a higher probability of feeding on alien plants than do
 686 long-billed hummingbird species. We used Generalized Linear Models with binomial
 687 error distribution to assess the significance of the relationships. A Mann-Whitney test
 688 likewise shows significant difference between the bill length of those hummingbirds
 689 incorporating and those not incorporating alien plants in their interactions ($p = 0.004$).



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Figure S1. Probability of hummingbird species incorporating alien plant species into their interactions in relation to their bill length, here species occurring at Caribbean islands networks were excluded. Each circle illustrates whether a given hummingbird species incorporates alien plants (1), or not (0). The fitted line reflects the modelled probability of hummingbird species feeding on alien plants; showing that short-billed hummingbirds have a higher probability of feeding on alien plants than do long-billed hummingbird species. We used Generalized Linear Models with binomial error distribution to assess the significance of the relationships.

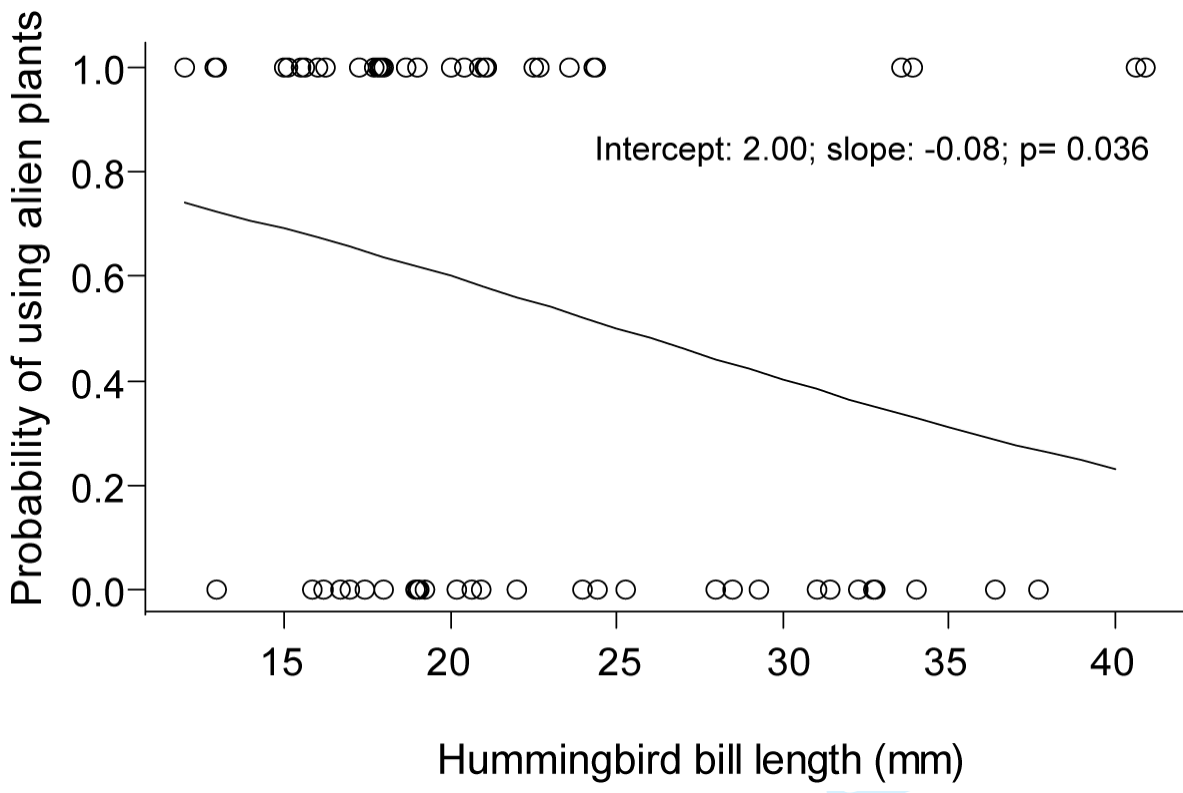


Table S1. Coordinates, description, location and data references for each studied plant-hummingbird network.

ID number	Latitude	Longitude	Site description and general location	Data Source Reference
1	22.28	-81.20	Swamp forest, Hurricane disturbed, Cuba	Baquero, A.C. (2014) Evolutionary and ecological insight into hummingbird-plant communities in the Caribbean. <i>MSc Thesis</i> . University of Copenhagen, Denmark.
2	18.13	-66.82	Elfin forest, Puerto Rico	Dalsgaard, B., Martín González, A.M., Olesen, J.M., Ollerton, J., Timmermann, A., Andersen, L.H. & Tossas, A.G. (2009) Plant-hummingbird interactions in the West Indies: floral specialisation gradients associated with environment and hummingbird size. <i>Oecologia</i> , 159 , 757-766.
3	15.25	-61.37	Coastal dry scrubland, Dominica	Dalsgaard, B., Martín González, A.M., Olesen, J.M., Ollerton, J., Timmermann, A., Andersen, L.H. & Tossas, A.G. (2009) Plant-hummingbird interactions in the West Indies: floral specialisation gradients associated with environment and hummingbird size. <i>Oecologia</i> , 159 , 757-766.
4	12.10	-61.68	Rainforest, Grenada	Dalsgaard, B., Martín González, A.M., Olesen, J.M., Ollerton, J., Timmermann, A., Andersen, L.H. & Tossas, A.G. (2009) Plant-hummingbird interactions in the West Indies: floral specialisation gradients associated with environment and hummingbird size. <i>Oecologia</i> , 159 , 757-766.
5	10.67	-61.28	Mixed forest, Trinidad	Snow, B.K. & Snow, D.W. (1972) Feeding niches of hummingbirds in a Trinidad Valley. <i>Journal of Animal Ecology</i> , 41 , 471-485.
6	5.92	-73.53	Andean humid montane forest, Colombia	Snow, D.W. & Snow, B.K. (1980) Relationships between hummingbirds and flowers in the Andes of Colombia. <i>Bulletin of the British Museum of Natural History (Zoology)</i> , 38 , 105-139.
7	5.90	-73.42	Andean humid montane forest, Colombia	Snow, D.W. & Snow, B.K. (1980) Relationships between hummingbirds and flowers in the Andes of Colombia. <i>Bulletin of the British Museum of Natural History (Zoology)</i> , 38 , 105-139.
8	4.54	-75.77	Andean second growth humid forest, Colombia	Cardona, J., & Cardona P.A. (2011) Uso de recursos florales por el ensamble de aves nectarívoras en el campus de la Universidad del Quindío. <i>BSc Thesis</i> . Universidad del Quindío, Colombia.
9	4.50	-75.60	Andean second growth humid forest, Colombia	Marín-Gómez, O.H. <i>Unpublished data</i> .
10	-0.02	-78.77	Andean rainforest, mid-elevation, Ecuador.	Walther, B.A. & Brieschke, H. (2001) Hummingbird-flower relationships in a mid-elevation rainforest near Mindo, northwestern Ecuador. <i>International Journal of Ornithology</i> , 4 , 115-135.
11	-3.82	-70.27	Amazonian rainforest, SE Colombia	Cotton, P.A. (1998) The hummingbird community of a lowland Amazonian rainforest. <i>Ibis</i> , 140 , 512-521.
12	-22.73	-45.58	Montane Forest, SE Brazil	Sazima, I., Buzato, S. & Sazima, M. (1996) An assemblage of hummingbird-pollinated flowers in a montane forest in southeastern Brazil. <i>Botanica Acta</i> , 109 , 149-160.

ID number	Latitude	Longitude	Site description and general location	Data Source Reference
13	-23.28	-45.05	Motane Atlantic forest, SE Brazil	Vizentin–Bugoni, J., Maruyama, P.K. & Sazima, M. (2014) Processes entangling interactions in communities: forbidden links are more important than abundance in a hummingbird–plant network. <i>Proceedings of the Royal Society of London B</i> , 281 , 1–8.
14	-23.35	-44.83	Atlantic forest, SE Brazil	Araujo, A.C. (1996) Beija-flores e seus recursos florais numa área de planície costeira do litoral norte de São Paulo, sudeste do Brasil. <i>MSc. Thesis</i> . Universidade Estadual de Campinas, Brazil.
15	-23.37	-45.04	Secondary Atlantic forest, SE Brazil	Maruyama, P.K, Vizentin-Bugoni, J., Dalsgaard, B., Sazima, I. & Sazima, M. (2015) Nectar robbery by a hermit hummingbird: association to floral phenotype and its influence on flowers and network structure. <i>Oecologia</i> , 178,783–793.
16	-23.48	-44.87	Restinga, Atlantic forest, SE Brazil	Maruyama, P.K, Vizentin-Bugoni, J., Dalsgaard, B., Sazima, I. & Sazima, M. (2015) Nectar robbery by a hermit hummingbird: association to floral phenotype and its influence on flowers and network structure. <i>Oecologia</i> , 178,783–793.
17	-23.58	-45.07	Coastal Atlantic Forest, SE Brazil	Maruyama, P.K, Vizentin-Bugoni, J., Dalsgaard, B., Sazima, I. & Sazima, M. (2015) Nectar robbery by a hermit hummingbird: association to floral phenotype and its influence on flowers and network structure. <i>Oecologia</i> , 178,783–793.
18	-23.63	-45.85	Coastal cloud Atlantic forest, SE Brazil	Snow D.W. & Snow, B.K. (1986) Feeding ecology of hummingbirds in the Serra do Mar, southeastern Brazil. <i>Hornero</i> , 12 , 286–296.
19	-25.32	-48.707	Atlantic Forest, S Brazil	Malucelli, T. S. (2014) Fatores envolvidos na estruturação das redes de polinização beija-flor-planta em um gradiente sucessional. <i>MSc. Thesis</i> . Universidade Federal do Paraná, Brazil.
20	-27.27	-49.01	Atlantic Forest, S Brazil	Kohler, G. (2011) Redes de interação planta-beija-flor em um gradiente altitudinal de Floresta Atlântica no Sul do Brasil. <i>MSc. Thesis</i> . Universidade Federal do Paraná, Brazil.
21	-31.80	-52.42	Pampa, S Brazil	Vizentin-Bugoni, J. & Rui, A.M. <i>Unpublished data</i> .

Table S2. List of plant species found across 21 plant-hummingbird networks.

Family	Plant species	Author	Network ID
Acanthaceae	<i>Aphelandra colorata</i>	(Vell. Conc.) Wass.	13
Acanthaceae	<i>Aphelandra</i> sp.		6
Acanthaceae	<i>Dicliptera pohliana</i>	Ness	21
Acanthaceae	<i>Dicliptera squarrosa</i>	Ness	8
Acanthaceae	<i>Geissomeria</i> sp.		13
Acanthaceae	<i>Justicia brasiliana</i>	Roth	20,21
Acanthaceae	<i>Justicia carnea</i>	Lindl.	17,18,20
Acanthaceae	<i>Justicia secunda</i>	Vahl	4
Acanthaceae	<i>Justicia</i> sp.1		13
Acanthaceae	<i>Justicia</i> sp.2		13
Acanthaceae	<i>Justicia</i> sp.3		5
Acanthaceae	<i>Mendoncia</i> sp.		13
Acanthaceae	<i>Mendoncia velloziana</i>	(Mart.) Nees	15,18,19
Acanthaceae	<i>Pachystachys coccinea</i>	Nees	5,19
Acanthaceae	<i>Ruellia elegans</i>	Poir.	15
Acanthaceae	<i>Sanchezia munita</i>	Ruiz & Pav./Ruiz & Pav.	11
Acanthaceae	<i>Sanchezia nobilis</i>	Hook.f.	17
Acanthaceae	<i>Sanchezia putumayensis</i>	Leonard	11
Acanthaceae	<i>Trichanthera gigantea</i>	(Humb. & Bonpl.) Nees	9
Adoxaceae	<i>Sambucus</i> sp.		10
Alstromeriaceae	<i>Alstroemeria inodora</i>	Herb.	12,13,18
Alstromeriaceae	<i>Alstroemeria isabellana</i>	Herb.	18
Alstromeriaceae	<i>Bomarea carderi</i>	Mast.	6,9
Alstromeriaceae	<i>Bomarea edulis</i>	(Tussac) Herb.	15,16
Alstromeriaceae	<i>Bomarea pardina</i>	Herb.	10
Alstromeriaceae	<i>Bomarea</i> sp.		9
Amaryllidaceae	<i>Hippeastrum aulicum</i>	(Ker Gwal.) Herb.	20
Amaryllidaceae	<i>Hippeastrum aviflorum</i>	(Ravenna) Dutilh	12
Apocynaceae	<i>Mandevilla aff.mollissima</i>	(Kunth) K. Schum.	7

Family	Plant species	Author	Network ID
Apocynaceae	<i>Mandevilla funiformis</i>	(Vell.) K. Schum.	18
Apocynaceae	<i>Mandevilla hirsuta</i>	(Rich.) K. Schum.	5
Apocynaceae	<i>Pentalinon luteum</i>	(L.) B.F. Hansen & Wunderlin	1
Apocynaceae	<i>Tabernaemontana alba</i>	Mill.	1
Apocynaceae	<i>Tabernaemontana cymosa</i>	Jacq.	5
Asparagaceae	<i>Furcraea</i> sp.		10
Balsaminaceae	<i>Impatiens</i> sp.		10
Balsaminaceae	<i>Impatiens walleriana</i>	Hook. f.	2,15,16
Bignoniaceae	<i>Arrabidaea</i> sp.		14
Bignoniaceae	<i>Campsis grandiflora</i>	(Thunb.) K.Schum.	21
Bignoniaceae	<i>Cuspidaria inaequalis</i>	(DC. ex Splitg.) L.G.Lohmann	5
Bignoniaceae	<i>Dolichandra unguis.cati</i>	(L.) L.G.Lohmann	5
Bignoniaceae	<i>Handroanthus chrysanthus</i>	(Jacq.) S.O.Grose	8
Bignoniaceae	<i>Handroanthus umbellatus</i>	(Sond.) Mattos	19
Bignoniaceae	<i>Jacaranda mimosifolia</i>	D.Don	21
Bignoniaceae	<i>Jacaranda puberula</i>	Cham.	14
Bignoniaceae	<i>Lundia cordata</i>	(Vell.) DC.	14
Bignoniaceae	<i>Pyrostegia venusta</i>	(Ker Gwal.) Miers	13
Bignoniaceae	<i>Spathodea campanulata</i>	P.Beauv.	8
Bignoniaceae	<i>Tabebuia cassinoides</i>	(Lam.) DC.	14
Bignoniaceae	<i>Tabebuia heterophylla</i>	(DC.) Britton	3
Bignoniaceae	<i>Tabebuia stenocalyx</i>	Sprague & Stapf	5
Bignoniaceae	<i>Tecoma stans</i>	(L.) Juss. ex Kunth	3
Boraginaceae	<i>Cordia bicolor</i>	A.DC. ex DC.	5
Boraginaceae	<i>Cordia bullata</i>	(L.) Roem. & Schult.	3
Boraginaceae	<i>Cordia curassavica</i>	(Jacq.) Roem. & Schult.	5
Boraginaceae	<i>Cordia multispicata</i>	Cham.	14
Bromeliaceae	<i>Aechmea aquilega</i>	(Salisb.) Griseb.	5
Bromeliaceae	<i>Aechmea blumenavii</i>	Reitz	20
Bromeliaceae	<i>Aechmea coelestis</i>	(K.Koch) E.Morren	16

Family	Plant species	Author	Network ID
Bromeliaceae	<i>Aechmea contracta</i>	(Mart. ex Schult. & Schult.f.) Baker	11
Bromeliaceae	<i>Aechmea dichlamydea</i>	Baker	5
Bromeliaceae	<i>Aechmea distichantha</i>	Lem,	12,13,14,16
Bromeliaceae	<i>Aechmea fendleri</i>	André ex Mez	5
Bromeliaceae	<i>Aechmea gamosepala</i>	Wittm.	13
Bromeliaceae	<i>Aechmea nudicaulis</i>	(L.) Griseb.	5,12,13,14,16,19,21
Bromeliaceae	<i>Aechmea organensis</i>	Wawra	13
Bromeliaceae	<i>Aechmea pectinata</i>	Baker	14,16,18
Bromeliaceae	<i>Aechmea recurvata</i>	(Klotzsch) L.B.Sm.	21
Bromeliaceae	<i>Aechmea williamsii</i>	(L.B.Sm.) L.B.Sm. & M.A.Spencer	11
Bromeliaceae	<i>Billbergia amoena</i>	(Lodd.) Lindl.	13,20
Bromeliaceae	<i>Billbergia distachya</i>	(Vell.) Mez	12
Bromeliaceae	<i>Billbergia pyramidalis</i>	(Sims) Lindl.	5,14,16,17
Bromeliaceae	<i>Bromelia antiacantha</i>	Bertol.	16,21
Bromeliaceae	<i>Canistropsis seidelii</i>	(L.B.Sm. & Reitz) Leme	14,16,17
Bromeliaceae	<i>Canistrum cf. fragrans</i>	(Linden) Mabb.	13
Bromeliaceae	<i>Canistrum cyathiforme</i>	(Vell.) Mez	12
Bromeliaceae	<i>Canistrum giganteum</i>	(Baker) L.B.Sm.	18
Bromeliaceae	<i>Canistrum perplexum</i>	L.B.Sm.	13
Bromeliaceae	<i>Guzmania berteroniana</i>	(Schult. & Schult.f.) Mez	2
Bromeliaceae	<i>Guzmania danielii</i>	L.B.Sm.	10
Bromeliaceae	<i>Guzmania jaramilloi</i>	H.E.Luther	10
Bromeliaceae	<i>Guzmania monostachia</i>	(L.) Rusby ex Mez	5
Bromeliaceae	<i>Guzmania sp.1</i>		10
Bromeliaceae	<i>Guzmania sp.2</i>		10
Bromeliaceae	<i>Guzmania sp.3</i>		9
Bromeliaceae	<i>Guzmania sp.4</i>		7
Bromeliaceae	<i>Guzmania squarrosa</i>	(Mez & Sodiro) L.B.Sm. & Pittendr.	6
Bromeliaceae	<i>Guzmania teuscheri</i>	L.B.Sm.	10
Bromeliaceae	<i>Mezobromelia sp.</i>		9
Bromeliaceae	<i>Neoregelia johannis</i>	(Carrière) L.B.Sm.	15,17

Family	Plant species	Author	Network ID
Bromeliaceae	<i>Nidularium angustifolium</i>	Ule	17
Bromeliaceae	<i>Nidularium innocentii</i>	Lem.	13,14,16,17,18,19,20
Bromeliaceae	<i>Nidularium longiflorum</i>	Ule	13
Bromeliaceae	<i>Nidularium marigoii</i>	Leme	12
Bromeliaceae	<i>Nidularium procerum</i>	Lindm.	13,14,19
Bromeliaceae	<i>Nidularium rutilans</i>	E.Morren	13
Bromeliaceae	<i>Pitcairnia nigra</i>	(Carrière) André	10
Bromeliaceae	<i>Pitcairnia</i> sp.		6
Bromeliaceae	<i>Quesnelia</i> sp.		13
Bromeliaceae	<i>Tillandsia aeranthos</i>	(Loisel.) L.B.Sm.	21
Bromeliaceae	<i>Tillandsia aff.turneri</i>	Baker	6
Bromeliaceae	<i>Tillandsia fasciculata</i>	Sw.	5
Bromeliaceae	<i>Tillandsia geminiflora</i>	Brongn.	13,15,16
Bromeliaceae	<i>Tillandsia</i> sp.1		13
Bromeliaceae	<i>Tillandsia</i> sp.2		13
Bromeliaceae	<i>Tillandsia</i> sp.3		20
Bromeliaceae	<i>Tillandsia stricta</i>	Sol.	12,13,18
Bromeliaceae	<i>Tillandsia utriculata</i>	L.	5
Bromeliaceae	<i>Vriesea carinata</i>	Wawra	13,19,20
Bromeliaceae	<i>Vriesea ensiformis</i>	(Vell.) Beer	14,16,17,19
Bromeliaceae	<i>Vriesea erythrodactylon</i>	E.Morren ex Mez	13,20
Bromeliaceae	<i>Vriesea incurvata</i>	Gaudich.	13,18,19,20
Bromeliaceae	<i>Vriesea inflata</i>	(Wawra) Wawra	13
Bromeliaceae	<i>Vriesea jonghei</i>	(K. Koch) E.Morren	18
Bromeliaceae	<i>Vriesea procera</i>	(Mart. ex Schult. & Schult.f.) Wittm.	5,14,15,16
Bromeliaceae	<i>Vriesea rodigasiana</i>	E.Morren	14,15,17
Bromeliaceae	<i>Vriesea sceptrum</i>	Mez	12
Bromeliaceae	<i>Vriesea simplex</i>	(Vell.) Beer	13
Bromeliaceae	<i>Vriesea</i> sp.		13
Bromeliaceae	<i>Vriesea vagans</i>	(L.B.Sm.) L.B.Sm.	20
Bromeliaceae	<i>Wittrockia superba</i>	Lindm.	13

Family	Plant species	Author	Network ID
Campanulaceae	<i>Burmeistera cyclostigmata</i>	Donn. Sm.	10
Campanulaceae	<i>Burmeistera globosa</i>	E. Wimm.	6
Campanulaceae	<i>Burmeistera</i> sp.		10
Campanulaceae	<i>Centropogon cornutus</i>	(L.) Druce	4,5,8,9,13,14,15,16
Campanulaceae	<i>Centropogon latisepalus</i>	Gleason	9
Campanulaceae	<i>Centropogon</i> sp.		10
Campanulaceae	<i>Siphocampylus convolvulaceus</i>	(Cham.) G.Don	13
Campanulaceae	<i>Siphocampylus longipedunculatus</i>	Pohl	13
Campanulaceae	<i>Siphocampylus</i> sp.		13
Campanulaceae	<i>Siphocampylus sulfureus</i>	E.Wimm.	12
Campanulaceae	<i>Siphocampylus westinianus</i>	(Thunb.) Pohl	12
Cannaceae	<i>Canna indica</i>	L.	7, 8
Cannaceae	<i>Canna panniculata</i>	Ruiz & Pav.	13,15
Cannaceae	<i>Canna</i> sp.		10
Caprifoliaceae	<i>Lonicera japonica</i>	Thunb.	12
Chrysobalanaceae	<i>Couepia schottii</i>	Fritsch	14
Clusiaceae	<i>Clusia</i> sp.1		6
Clusiaceae	<i>Clusia</i> sp.2		10
Clusiaceae	<i>Symphonia globulifera</i>	L.f.	5
Combretaceae	<i>Combretum llewelyinii</i>	Macbride	11
Compositae	<i>Mutisia speciosa</i>	Aiton ex Hook.	12,13,14,16
Compositae	<i>Piptocarpha notata</i>	(Less.) Baker	18
Convolvulaceae	<i>Ipomoea</i> sp.1		7
Convolvulaceae	<i>Ipomoea</i> sp.2		20
Convolvulaceae	<i>Jacquemontia sphaerostigma</i>	(Cav.) Rusby	14
Costaceae	<i>Costus scaber</i>	Ruiz & Pav.	4,11
Costaceae	<i>Costus</i> sp.1		5
Costaceae	<i>Costus</i> sp.2		9
Costaceae	<i>Costus spiralis</i>	(Jacq.) Roscoe	5,11,14,19
Crassulaceae	<i>Kalanchoe</i> sp.	Adans.	10

Family	Plant species	Author	Network ID
Cucurbitaceae	<i>Gurania lobata</i>	(L.) J.F. Pruski	5,11
Cucurbitaceae	<i>Gurania rhizantha</i>	(Poepp. & Endl.) C.Jeffrey	11
Ericaceae	<i>Agarista</i> sp.		12
Ericaceae	<i>Cavendishia bracteata</i>	(Ruiz & Pav. ex A. St. Hilaire) Horold	6,9
Ericaceae	<i>Cavendishia grandifolia</i>	Horold	10
Ericaceae	<i>Cavendishia guatapeensis</i>	Mansfeld	6
Ericaceae	<i>Cavendishia pubescens</i>	(Kunth) Hemsl.	6,7
Ericaceae	<i>Cavendishia tarapotana</i>	(Meissner) Bentham & Hooker f.	10
Ericaceae	<i>Disterigma</i> sp.		6
Ericaceae	<i>Ericaceae</i> sp.		10
Ericaceae	<i>Macleania pentaptera</i>	Horold	10
Ericaceae	<i>Macleania recumbens</i>	Horold	10
Ericaceae	<i>Psammisia aberrans</i>	A.C. Smith	10
Ericaceae	<i>Psammisia ecuadorensis</i>	Horold	10
Ericaceae	<i>Psammisia falcata</i>	(Kunth) Klotzsch	6
Ericaceae	<i>Psammisia oreogenes</i>	Sleum.	10
Ericaceae	<i>Psammisia pauciflora</i>	Griseb	10
Ericaceae	<i>Psammisia penduliflor</i>	(Dunal) Klotzsch	7
Ericaceae	<i>Psammisia sodiroi</i>	Horold	10
Ericaceae	<i>Psammisia ulbrichiana</i>	Horold	10
Ericaceae	<i>Thibaudia rigidiflora</i>	A.C. Smith	6
Gentianaceae	<i>Chelonanthus alatus</i>	(Aubl.) Pulle	5
Gentianaceae	<i>Macrocarpaea</i> sp.		6
Gentianaceae	<i>Macrocarpea rubra</i>	Malme	13
Gesneriaceae	<i>Alloplectus</i> sp.		10
Gesneriaceae	<i>Besleria longimucronata</i>	Hoehne	13,15,17
Gesneriaceae	<i>Besleria solanoides</i>	C.V. Morton	9,10
Gesneriaceae	<i>Columnea ciliata</i>	(Wiehler) L.P. Kvist & L.E. Skog	10
Gesneriaceae	<i>Columnea dimidiata</i>	(Benth.) Kuntze	9
Gesneriaceae	<i>Columnea medicinalis</i>	(Wiehler) L.P. Kvist & L.E. Skog	10

Family	Plant species	Author	Network ID
Gesneriaceae	<i>Columnnea strigos</i>	Benth.	10
Gesneriaceae	<i>Gasteranthus</i> sp.		10
Gesneriaceae	<i>Gesneriaceae</i> sp.1		10
Gesneriaceae	<i>Gesneriaceae</i> sp.2		10
Gesneriaceae	<i>Gesneriaceae</i> sp.3		10
Gesneriaceae	<i>Gesneriaceae</i> sp.4		11
Gesneriaceae	<i>Glossoloma bolivianum</i>	(Britton ex Rusby) J.L. Clark	10
Gesneriaceae	<i>Huilaea minor</i>	(L.Uribe) Lozano & N.Ruiz-R.	6
Gesneriaceae	<i>Kohleria affinis</i>	(Fritsch) Roalson & Boggan	9
Gesneriaceae	<i>Kohleria inaequalis</i>	(Benth.) Wiehler	9
Gesneriaceae	<i>Kohleria spicata</i>	(Kunth) Oerst.	10
Gesneriaceae	<i>Nematanthus australis</i>	Chautems	20
Gesneriaceae	<i>Nematanthus fissus</i>	(Vell.) L.E. Skog	16
Gesneriaceae	<i>Nematanthus fluminensis</i>	(Vell.) Fritsch	13,14,16,17
Gesneriaceae	<i>Nematanthus fornix</i>	(Vell.) Chautems	12
Gesneriaceae	<i>Nematanthus fritschii</i>	Hoehne	13,18
Gesneriaceae	<i>Nematanthus gregarius</i>	D.L. Denham	13,18
Gesneriaceae	<i>Nematanthus maculatus</i>	(Fritsch) Wiehler	13
Gesneriaceae	<i>Nematanthus</i> sp.1		13
Gesneriaceae	<i>Nematanthus tessmannii</i>	(Hoehne) Chautems	19
Gesneriaceae	<i>Sinningia cooperi</i>	(Paxton) Wiehler	13
Gesneriaceae	<i>Sinningia douglasii</i>	(Lindl.) Chautems	12,20
Gesneriaceae	<i>Sinningia elatior</i>	(Kunth) Chautems	13
Gesneriaceae	<i>Sinningia glazioviana</i>	(Fritsch) Chautems	13
Heliconiaceae	<i>Heliconia angusta</i>	Vell.	14,16,17
Heliconiaceae	<i>Heliconia bihai</i>	(L.) L.	4,5
Heliconiaceae	<i>Heliconia burleana</i>	Abalo & G. Morales	10
Heliconiaceae	<i>Heliconia farinosa</i>	Raddi	15,17,18,19,20
Heliconiaceae	<i>Heliconia griggsiana</i>	L.B.Sm.	8,9
Heliconiaceae	<i>Heliconia hirsuta</i>	L.f.	5
Heliconiaceae	<i>Heliconia juruana</i>	Loes.	11

Family	Plant species	Author	Network ID
Heliconiaceae	<i>Heliconia latispatha</i>	Benth.	8,9
Heliconiaceae	<i>Heliconia psittacorum</i>	L.f.	5
Heliconiaceae	<i>Heliconia schumanniana</i>	Loes.	11
Heliconiaceae	<i>Heliconia</i> sp.		5
Heliconiaceae	<i>Heliconia</i> sp.1		7
Heliconiaceae	<i>Heliconia</i> sp.2		10
Heliconiaceae	<i>Heliconia spathocircinata</i>	Aristeg.	14,15
Heliconiaceae	<i>Heliconia stricta</i>	Huber	11
Heliconiaceae	<i>Heliconia venusta</i>	Abalo & G.Morales	9
Iridaceae	<i>Crocasmia × crocosmiiflora</i>	(Lemoine) N.E.Br.	13
Iridaceae	<i>Iridaceae</i> sp.		10
Lamiaceae	<i>Aegiphila perplexa</i>	Moldenke	5
Lamiaceae	<i>Clerodendrum aculeatum</i>	L.	1
Lamiaceae	<i>Lamiaceae</i> sp.		10
Lamiaceae	<i>Leonotis nepetifolia</i>	(L.) R. Br.	3
Lamiaceae	<i>Salvia arenaria</i>	Willd. ex Schult.	12
Lamiaceae	<i>salvia articulata</i>	A.St.-Hil. ex Benth.	18
Lamiaceae	<i>Salvia</i> sp.		10
Lamiaceae	<i>Vitex divaricata</i>	Sw.	5
Lecythidaceae	<i>Lecythidoideae</i> sp.		10
Leguminosae	<i>Abarema brachystachya</i>	Barneby & J.W. Grimes	14
Leguminosae	<i>Albizia pedicellaris</i>	(Dc.) L.Rico	14
Leguminosae	<i>Albizia saman</i>	(Jacq.) Merr.	1,5
Leguminosae	<i>Brownea coccinea</i> subsp. <i>capitella</i>	(Jacq.) D. Velásquez & G. Agostini	5
Leguminosae	<i>Calliandra brevipes</i>	Benth.	21
Leguminosae	<i>Calliandra guildingii</i>	Benth.	5
Leguminosae	<i>Calliandra purdiaei</i>	Benth.	7
Leguminosae	<i>Calliandra tweediei</i>	Benth.	21
Leguminosae	<i>Camptosema scarlatinum</i>	(Mart. Ex Benth.) Bukart	12
Leguminosae	<i>Clathrotropis brachypetala</i>	(Tul.) Kleinhoonte	5

Family	Plant species	Author	Network ID
Leguminosae	<i>Collaea speciosa</i>	(Loisel.) DC.	12
Leguminosae	<i>Dahlstedtia pentaphylla</i>	(Taub.) Burkart	19
Leguminosae	<i>Dahlstedtia pinnata</i>	(Benth.) Malme	15,16,17,18,19
Leguminosae	<i>Dioclea</i> sp.		18
Leguminosae	<i>Erythrina corallodendron</i>	L.	5
Leguminosae	<i>Erythrina crista-galli</i>	L.	21
Leguminosae	<i>Erythrina edulis</i>	Micheli	8
Leguminosae	<i>Erythrina fusca</i>	Lour.	5,11
Leguminosae	<i>Erythrina poeppigiana</i>	(Walp.) O.F. Cook	5
Leguminosae	<i>Erythrina rubrinervia</i>	Kunth	9
Leguminosae	<i>Erythrina</i> sp.		10
Leguminosae	<i>Erythrina speciosa</i>	Andrews	8,13,14,16,19,21
Leguminosae	<i>Inga densiflora</i>	Benth.	8
Leguminosae	<i>Inga edulis</i>	Mart.	14,19
Leguminosae	<i>Inga ingoides</i>	(Rich.) Willd.	5
Leguminosae	<i>Inga ingoides</i>	(Rich.) Willd.	8,9
Leguminosae	<i>Inga leiocalycina</i>	Benth.	11
Leguminosae	<i>Inga semialata</i>	(Vell.) C.Mart.	15,17
Leguminosae	<i>Inga sessilis</i>	(Vell.) Mart.	13
Leguminosae	<i>Inga</i> sp.1		18
Leguminosae	<i>Inga</i> sp.2		10
Leguminosae	<i>Inga</i> sp.3		5
Leguminosae	<i>Inga subnuda</i>	Benth.	14,16
Leguminosae	<i>Inga venosa</i>	Griseb.	5
Leguminosae	<i>Leguminosae</i> sp.		10
Leguminosae	<i>Lonchocarpus benthamianus</i>	Pittier	3
Leguminosae	<i>Lysiloma latisiliquum</i>	(L.) Benth.	1
Leguminosae	<i>Neorudolphia volubilis</i>	(Willd.) Britton	2
Leguminosae	<i>Phaseolus coccineus</i>	L.	6
Leguminosae	<i>Pithecellobium jupunba</i>	(Willd.) Urb.	5
Leguminosae	<i>Schizolobium parahyba</i>	(Vell.) S.F.Blake	19

	Family	Plant species	Author	Network ID
1				
2				
3				
4				
5	Leguminosae	<i>Tachigalia paniculata</i>	Aubl.	11
6	Leguminosae	<i>Tephrosia noctiflora</i>	Bojer ex Baker	3
7				
8	Loranthaceae	<i>Loranthaceae</i> sp.		18
9	Loranthaceae	<i>Psittacanthus cucularis</i>	(Lam.) G. Don	11
10	Loranthaceae	<i>Psittacanthus dichrous</i>	(Mart.) Mart.	13,14,16
11				
12	Lythraceae	<i>Cuphea melvilla</i>	Lindl.	11
13	Malvaceae	<i>Abutilon</i> aff. <i>regnellii</i>	Miq.	12
14	Malvaceae	<i>Abutilon darwinii</i>	Hook.f.	10
15	Malvaceae	<i>Abutilon</i> sp.1		13
16	Malvaceae	<i>Dombeya wallichii</i>	(Lindl.) Benth. & Hook.f.	14
17				
18	Malvaceae	<i>Eriotheca pentaphylla</i>	(Vell. & K.Schum.) A.Robyns	14,16
19	Malvaceae	<i>Guazuma ulmifolia</i>	Lam.	1
20	Malvaceae	<i>Hibiscus rosa-sinensis</i>	L.	10,14
21	Malvaceae	<i>Luehea divaricata</i>	Mart. & Zucc.	21
22	Malvaceae	<i>Malvaviscus arboreus</i>	Cav.	10
23	Malvaceae	<i>Quararibea lasiocalyx</i>	K.Schum.	11
24	Malvaceae	<i>Spirotheca rivieri</i>	(Decne.) Ulbr.	13
25	Malvaceae	<i>Talipariti tiliaceum</i>	(L.) Fryxell	14
26	Malvaceae	<i>Urena lobata</i>	L.	2
27				
28	Marantaceae	<i>Calathea capitata</i>	(Ruiz & Pav.) Lindl.	11
29	Marantaceae	<i>Ischnosiphon arouma</i>	(Aubl.) Korn.	5
30	Marantaceae	<i>Maranta furcata</i>	Nees & Mart.	14
31				
32	Marcgraviaceae	<i>Marcgravia myriostigma</i>	Triana & Planch.	14
33	Marcgraviaceae	<i>Marcgravia polyantha</i>	Delpino	18
34	Marcgraviaceae	<i>Marcgravia</i> sp.		5
35	Marcgraviaceae	<i>Norantea guianensis</i>	Aubl.	5
36	Marcgraviaceae	<i>Sarcopera</i> sp.		10
37				
38	Marcgraviaceae	<i>Schwartzia brasiliensis</i>	(Choisy) Bedell ex Gir.-Cañas	14,16,19
39	Melastomataceae	<i>Acinodendron sintenisii</i>	(Cogn.) Kuntze	2
40	Melastomataceae	<i>Melastomataceae</i> sp.		10
41				
42	Musaceae	<i>Musa balbisiana</i>	Colla	19
43				
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48				
49				

Family	Plant species	Author	Network ID
Musaceae	<i>Musa ornata</i>	Roxb.	15
Musaceae	<i>Musa sp.1</i>		7
Musaceae	<i>Musa sp.2</i>		10
Musaceae	<i>Musa velutina</i>	H.Wendl. & Drude	8,9
Musaceae	<i>Musa x paradisiaca</i>	L.	8
Myrtaceae	<i>Callistemon speciosus</i>	(Sims) Sweet	21
Myrtaceae	<i>Eucalyptus globulus</i>	Labill.	9
Myrtaceae	<i>Melaleuca leucadendra</i>	(L.) L.	21
Myrtaceae	<i>Syzygium malaccense</i>	(L.) Merr. & L.M.Perry	11
Myrtaceae	<i>Syzygium jambos</i>	(L.) Alston	4,5,7,14
Nyctaginaceae	<i>Bougainvillea sp.</i>		10
Onagraceae	<i>Fuchsia macrostigma</i>	Benth.	10
Onagraceae	<i>Fuchsia regia</i>	(Vell.) Munz	12,13,18,20
Orchidaceae	<i>Elleanthus aurantiacus</i>	(Lindl.) Rchb.f.	9
Orchidaceae	<i>Elleanthus smithii</i>	Schltr.	6
Orchidaceae	<i>Orchidaceae sp.</i>		10
Orobanchaceae	<i>Esterhazyia splendida</i>	J.C.Mikan	12
Passifloraceae	<i>Passiflora aff involucrata</i>	(Masters) A.Gentry	11
Passifloraceae	<i>Passiflora quadriglandulosa</i>	Rodschied	11
Passifloraceae	<i>Passiflora spinosa</i>	(Poeppig&Endlicher) Masters	11
Passifloraceae	<i>Passifloraceae sp.</i>		10
Passifloraceae	<i>Turnera ulmifolia</i>	L.	1,3
Polygonaceae	<i>Antigonon leptopus</i>	Hook. & Arn.	1
Rosaceae	<i>Rubus rosifolius</i>	Sm.	19
Rubiaceae	<i>Erithalis fruticosa</i>	L.	3
Rubiaceae	<i>Genipa americana</i>	L.	11
Rubiaceae	<i>Gonzalagunia hirsuta</i>	K.Schum.	4,5
Rubiaceae	<i>Hamelia patens</i>	Jacq.	5,7,8,9
Rubiaceae	<i>Isertia parviflora</i>	Vahl	5
Rubiaceae	<i>Manettia aff.sabiceoides</i>	Wernham	6,7
Rubiaceae	<i>Manettia cordifolia</i>	Mart.	13,18

Family	Plant species	Author	Network ID
Rubiaceae	<i>Manettia luteorubra</i>	(Vell.) Benth.	19
Rubiaceae	<i>Manettia pubescens</i>	Cham. & Schltld.	12
Rubiaceae	<i>Morinda citrifolia</i>	L.	3
Rubiaceae	<i>Palicourea acetosoides</i>	Wernham	9
Rubiaceae	<i>Palicourea aff lasiantha</i>	K.Krause	11
Rubiaceae	<i>Palicourea anderssoniana</i>	C.M.Taylor	10
Rubiaceae	<i>Palicourea cf.vagans</i>	Wernham	6
Rubiaceae	<i>Palicourea crocea</i>	(Sw.) Roem. & Schult.	2,4,5,11
Rubiaceae	<i>Palicourea demissa</i>	Standl.	6,10
Rubiaceae	<i>Palicourea fastigiata</i>	Kunth	11
Rubiaceae	<i>Palicourea sodiroi</i>	Standl.	10
Rubiaceae	<i>Palicourea sp.1</i>		6
Rubiaceae	<i>Palicourea sp.2</i>		11
Rubiaceae	<i>Posoqueria sp.</i>		6
Rubiaceae	<i>Psychotria berteroana</i>	DC.	2
Rubiaceae	<i>Psychotria leiocarpa</i>	Cham. & Schltld.	13
Rubiaceae	<i>Psychotria mapourioides</i>	DC.	5
Rubiaceae	<i>Psychotria muscosa</i>	(Jacq.) Steyerem.	5
Rubiaceae	<i>Psychotria nuda</i>	(Cham. & Schltld.) Wawra	14,15,16,17,19
Rubiaceae	<i>Psychotria sp.</i>		5
Rubiaceae	<i>Psychotria suterella</i>	Mull. Arg.	19,20
Rubiaceae	<i>Rubiaceae sp.</i>		10
Rubiaceae	<i>Sabicea grisea</i>	Cham. & Schltld.	14,15,16
Rubiaceae	<i>Schradera exotica</i>	(J.F.Gmel.) Standl.	2
Rubiaceae	<i>Warszewiczia coccinea</i>	(Vahl) Klotzsch	5
Rutaceae	<i>Citrus sp.</i>	L.	5
Rutaceae	<i>Rutaceae sp.</i>		10
Salicaceae	<i>Ryania speciosa</i>	M. Vahl	5
Schlegeliaceae	<i>Schlegelia brachyantha</i>	Griseb.	2
Scrophulariaceae	<i>Buddleja brasiliensis</i>	J.Jacq.	12,18
Scrophulariaceae	<i>Castilleja scorzonerifolia</i>	Kunth	7

Family	Plant species	Author	Network ID
Solanaceae	<i>Acnistus arborescens</i>	(L.) Schltld.	15,19
Solanaceae	<i>Brugmansia arborea</i>	(L.) Steud.	10
Solanaceae	<i>Cestrum corymbosum</i>	Schltld.	12
Solanaceae	<i>Cestrum macrophyllum</i>	Vent.	2
Solanaceae	<i>Cestrum</i> sp.		10
Tropaeolaceae	<i>Tropaeolum pentaphyllum</i>	Lam.	21
Verbenaceae	<i>Citharexylum spinosum</i>	L.	3
Verbenaceae	<i>Lantana camara</i>	L.	5,13,15
Verbenaceae	<i>Lantana nivea</i>	Vent.	14
Verbenaceae	<i>Stachytarpheta cayennensis</i>	(Rich.) Vahl	15,16
Verbenaceae	<i>Stachytarpheta jamaicensis</i>	(L.) Vahl	3
Verbenaceae	<i>Stachytarpheta maximiliani</i>	Schauer	19
Verbenaceae	<i>Stachytarpheta</i> sp.		14
Xanthorrhoeaceae	<i>Phormium tenax</i>	J.R.Forst. & G.Forst.	18
Zingiberaceae	<i>Hedychium coronarium</i>	J.Koenig	14,15,20
Zingiberaceae	<i>Renealmia alpinia</i>	(Rottb.) Maas	2
Zingiberaceae	<i>Renealmia sessilifolia</i>	Gagnep.	10
Zingiberaceae	<i>Renealmia</i> sp.		5

Table S3. List of hummingbird species found across 21 plant-hummingbird networks. References for hummingbird bill length data are also listed.

Species	Clades	Network ID	Bill length (mm)	Data sources
<i>Orthorhyncus cristatus</i>	Emerald		3,4	10.7 Brown and Bowers 1985
<i>Mellisuga helenae</i>	Bee		1	10.8 Andrea Baquero, unpublished
<i>Lophornis chalybeus</i>	Coquette	13,14,16,19		12.0 Vizentin-Bugoni et al. 2014
<i>Ocreatus underwoodii</i>	Brilliant		6,9,10	12.9 Graham et al. 2012
<i>Calliphlox amethystina</i>	Emerald		15	13.0 Grantsau 1989
<i>Chrysolampis mosquitus</i>	Mango		5	13.0 Snow & Snow 1972
<i>Chlorostilbon maugaeus</i>	Emerald		2	13.6 Brown and Bowers 1985
<i>Adelomyia melanogenys</i>	Coquette		6,9,10	15.0 Graham et al. 2012
<i>Stephanoxis lalandi</i>	Emerald		12,13	15.0 Vizentin-Bugoni et al. 2014
<i>Stephanoxis lodigessi</i>	Emerald		21	15.9 Jeferson Vizentin-Bugoni, unpublished
<i>Chlorostilbon mellisugus</i>	Coquette		8,11	15.1 Graham et al. 2012
<i>Agelaiocercus kingi</i>	Emerald		6,9	15.5 Graham et al. 2012
<i>Amazilia versicolor</i>	Emerald	13,15,16,17,18,19,20		15.6 Snow & Snow 1986
<i>Hylocharis cyanus</i>	Emerald		14,15,16	16.0 Araujo 1996
<i>Chlorostilbon gibsoni</i>	Emerald		7	16.2 Snow & Snow 1980
<i>Agelaiocercus coelestis</i>	Coquette		10	16.2 Graham et al. 2012
<i>Chaetocercus mulsant</i>	Bee		6	16.7 Snow & Snow 1980
<i>Boissonneaua flavescens</i>	Brilliant		6,9,10	17.0 Graham et al. 2012
<i>Chlorostilbon ricordii</i>	Emerald		1	17.2 Andrea Baquero
<i>Chlorostilbon poortmani</i>	Emerald		6	17.3 Graham et al. 2012
<i>Colibri delphinae</i>	Mango		10	17.4 Graham et al. 2012
<i>Calliphlox mitchellii</i>	Emerald		10	17.7 Walther & Brieschke 2001
<i>Amazilia cyanifrons</i>	Emerald		7	17.8 Snow & Snow 1980
<i>Thalurania glaucopis</i>	Emerald	13,14,15,16,17,18,19,20,21		17.9 Araujo 1996
<i>Amazilia saucerrottei</i>	Emerald		8,9	17.9 Oscar Humberto Marin-Gomez, unpublished
<i>Amazilia tobaci</i>	Emerald		5	18.0 Snow & Snow 1972
<i>Chlorestes notatus</i>	Emerald		5,11	18.0 Snow & Snow 1972
<i>Chlorostilbon lucidus</i>	Emerald		12,19,21	18.0 Grantsau 1989
<i>Helianthus amethysticollis</i>	Coquette		6	18.0 Snow & Snow 1980

Species	Clades	Network ID	Bill length (mm)	Data sources
<i>Amazilia chionopectus</i>	Emerald		5,14	18.7 Araujo 1996
<i>Heliodoxa aurescens</i>	Brilliant		11	19.0 Graham et al. 2012
<i>Clytolaema rubricauda</i>	Brilliant	12,13,15,18,20		19.0 Vizentin-Bugoni et al. 2014
<i>Eupetomena macroura</i>	Emerald		13,14,16	19.0 Grantsau 1989
<i>Florisuga mellivora</i>	Topazes		5,9,10,11	19.0 Snow & Snow 1972
<i>Hylocharis chrysurus</i>	Emerald		21	19.0 Jefferson Vizentin-Bugoni, unpublished
<i>Urosticte benjamini</i>	Brilliant		10	19.1 Graham et al. 2012
<i>Thalurania fannyi</i>	Emerald		10	19.2 Graham et al. 2012
<i>Leucochloris albicollis</i>	Emerald	12,13,14,15,18,21		20.0 Vizentin-Bugoni et al. 2014
<i>Amazilia tzacatl</i>	Emerald		7,8,9,10	20.0 Graham et al. 2012
<i>Aphantochroa cirrochloris</i>	Emerald		19	20.2 Grantsau 1989
<i>Phaethornis ruber</i>	Hermit	11,14,15,16		20.4 Araujo 1996
<i>Thalurania furcata</i>	Emerald		11	20.6 Graham et al. 2012
<i>Chrysuronia oenone</i>	Emerald		11	20.9 Graham 2012
<i>Amazilia fimbriata</i>	Emerald	11,14,15,16,17,19,20		20.9 Araujo 1996
<i>Colibri thalassinus</i>	Mango		6,10	20.9 Graham et al. 2012
<i>Phaethornis longuemareus</i>	Hermit		5	20.9 Graham et al. 2012
<i>Heliodoxa rubinoides</i>	Brilliant		10	21.1 Graham et al. 2012
<i>Florisuga fusca</i>	Topazes	13,14,15,16,18,19,21		21.1 Snow & Snow 1986
<i>Colibri serrirostris</i>	Mango		12	22.0 Grantsau 1989
<i>Boissonneaua jardini</i>	Brilliant		10	22.5 Walther & Brieschke 2001
<i>Amazilia franciae</i>	Emerald		7,9,10	22.7 Graham et al. 2012
<i>Eulampis holosericeus</i>	Mango		3,4	22.7 Brown and Bowers 1985
<i>Anthracothorax nigricollis</i>	Mango	5,7,8,9,11,14,21		23.6 Graham et al. 2012
<i>Phaethornis squalidus</i>	Hermit	15,16,17,19		24.0 Grantsau 1989
<i>Heliodoxa imperatrix</i>	Brilliant		10	24.3 Graham et al. 2012
<i>Colibri coruscans</i>	Mango		6,9,10	24.3 Graham et al. 2012
<i>Anthracothorax viridis</i>	Mango		2	24.4 Kodric-Brown et al. 1984
<i>Campylopterus largipennis</i>	Emerald		11	25.3 Graham et al. 2012
<i>Coeligena prunellei</i>	Brilliant		6	28.0 Graham et al. 2012
<i>Threnetes leucurus</i>	Hermit		11	28.5 Cotton 1998

Species	Clades	Network ID	Bill length (mm)	Data sources
<i>Phaethornis bourcierii</i>	Hermit		11	29.3 Graham et al. 2012
<i>Glaucis hirsutus</i>	Hermit	4,5,11,14,15,16		31.0 Snow & Snow1972
<i>Heliomaster squamosus</i>	Gem		15	31.0 Grantsau 1989
<i>Coeligena coeligena</i>	Brilliant		9	31.4 Oscar Humberto Marin-Gomez, unpublished
<i>Coeligena torquata</i>	Brilliant		6	32.3 Graham et al. 2012
<i>Doryfera ludoviciae</i>	Mango		6,9,10	32.7 Graham et al. 2012
<i>Phaethornis hispidus</i>	Hermit		11	32.8 Graham et al. 2012
<i>Coeligena wilsoni</i>	Brilliant		10	33.6 Graham et al. 2012
<i>Ramphodon naevius</i>	Hermit	14,15,16,17,19,20		33.9 Araujo 1996
<i>Phaethornis eurynome</i>	Hermit	12,13,18,19,20		34.0 Vizentin-Bugoni et al. 2014
<i>Heliomaster longirostris</i>	Gem		8	36.4 Oscar Humberto Marin-Gomez, unpublished
<i>Phaethornis superciliosus</i>	Hermit		11	37.7 Cotton 1998
<i>Phaethornis syrmatophorus</i>	Hermit		10	40.6 Graham et al. 2012
<i>Phaethornis guy</i>	Hermit	5,7,8,9		40.9 Graham et al. 2012

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Table S4. Pearson correlation r among distinct species-level network indices calculated across 21 quantitative plant-hummingbird networks. For hummingbirds, indices related to species roles in modules were not included as many modules within networks contained only one hummingbird species, rendering these indices less meaningful. Moreover, the correlation of the indices in relation to hummingbird bill length is also shown. Strong correlations ($r > 0.6$) are in bold.

Plants	Strength	Specialization (d')	c	z
Degree	0.68	-0.01	0.62	0.53
Strength		0.30	0.23	0.70
Specialization (d')			-0.33	0.31
c				0.14

Hummingbirds	Strength	Specialization (d')	Bill length
Degree	0.92	-0.05	0.17
Strength		0.14	0.22
Specialization (d')			0.38

Table S5. List of the 32 alien plant species found across 21 plant-hummingbird networks. See Table S6 for references and details on the assessment of pollination systems for the plants.

Family	Plant species	Bird pollination	Country	Network ID	Origin	Size	Flower	
							Type	Length (mm)
Acanthaceae	<i>Dicliptera squarrosa</i>	Yes	Colombia	8	America	small	tube	27.90
Acanthaceae	<i>Sanchezia nobilis</i>	Yes	SE Brazil	17	America	small	tube	46.60
Balsaminaceae	<i>Impatiens</i> sp.	Unknown	Ecuador	10	Africa	small	tube	-
Balsaminaceae	<i>Impatiens walleriana</i>	No	Puerto Rico, SE Brazil	2,15,16	Africa	small	tube	14.30
Bignoniaceae	<i>Campsis grandiflora</i>	Yes	S Brazil	21	Asia	small	tube	32.10
Bignoniaceae	<i>Spathodea campanulata</i>	Yes	Colombia	8	Africa	large	other	102.90
Caprifoliaceae	<i>Lonicera japonica</i>	No	SE Brazil	12	Asia	small	tube	28.00
Iridaceae	<i>Crocasmia x crocosmiiflora</i>	Yes	SE Brazil	13	Africa	small	tube	14.10
Lamiaceae	<i>Leonotis nepetifolia</i>	Yes	Dominica	3	Africa	small	tube	11.09
Leguminosae	<i>Albizia saman</i>	No	Cuba	1,5	America	large	brush	9.95
Leguminosae	<i>Phaseolus coccineus</i>	No	Colombia	6	America	small	other	4.38
Leguminosae	<i>Tephrosia noctiflora</i>	No	Dominica	3	Africa	small	other	5.38
Malvaceae	<i>Dombeya wallichii</i>	No	SE Brazil	14	Asia/Africa?	small	other	10.00
Malvaceae	<i>Hibiscus rosa-sinensis</i>	Yes	Ecuador, SE Brazil	10,14	Asia	small	tube	24.50
Malvaceae	<i>Talipariti tiliaceum</i>	No	SE Brazil	14	Asia	small	tube	57.20
Musaceae	<i>Musa ornata</i>	Yes	SE Brazil	15	Asia	large	tube	39.50
Musaceae	<i>Musa rosacea</i>	Yes	S Brazil	19	Asia	large	tube	38.44
Musaceae	<i>Musa</i> sp.	Unknown	Colombia	7	Asia	large	tube	35.00
Musaceae	<i>Musa</i> sp.	Unknown	Ecuador	10	Asia	large	tube	-
Musaceae	<i>Musa velutina</i>	Yes	Colombia	8,9	Asia	large	tube	32.10
Musaceae	<i>Musa x paradisiaca</i>	No	Colombia	9	Asia	large	tube	31.80
Myrtaceae	<i>Callistemon speciosus</i>	Yes	S Brazil	21	Oceania	small	brush	3.10
Myrtaceae	<i>Eucalyptus globulus</i>	Yes	Colombia	9	Oceania	large	brush	13.20
Myrtaceae	<i>Melaleuca leucadendra</i>	No	S Brazil	21	Oceania	large	brush	2.90
Myrtaceae	<i>Syzygium jambos</i>	Yes	Colombia, Grenada, Trinidad, SE Brazil	4,5,7,14	Asia	large	brush	2.69
Myrtaceae	<i>Syzygium malaccens</i>	Yes	Colombia	11	Asia	large	brush	20.00

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Family	Plant species	Bird pollination	Country	Network ID	Origin	Size	Flower	
							Type	Length (mm)
Polygonaceae	<i>Antigonon leptopus</i>	No	Cuba	1	America	small	other	3.11
Rubiaceae	<i>Morinda citrifolia</i>	No	Dominica	3	Asia	large	tube	9.29
Rutaceae	<i>Citrus</i> sp.	No	Trinidad	5	Asia	large	other	-
Verbenaceae	<i>Lantana nivea</i>	No	SE Brazil	14	America?	small	tube	11.60
Xanthorrhoeaceae	<i>Phormium tenax</i>	Yes	SE Brazil	18	Oceania	small	tube	29.00
Zingiberaceae	<i>Hedychium coronarium</i>	No	SE, S Brazil	14,15,20	Asia	small	tube	60.90

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Table S6. Alien plant species across 21 plant-hummingbird networks and details on the assessment of their pollination system.

Plant species	Pollinators			Network ID
	Birds	Bats	Insects	
<i>Dicliptera squarrosa</i>	x			1
<i>Sanchezia nobilis</i>	x			2,*
<i>Impatiens walleriana</i>			x	3
<i>Campsis grandiflora</i>	x		x	4,5
<i>Spathodea campanulata</i>	x			6,7,8,9,10
<i>Lonicera japonica</i>			x	11
<i>Crococsmia x crocosmiiflora</i>	x		x	12
<i>Leonotis nepetifolia</i>	x		x	13,14
<i>Albizia saman</i>			x	15,16
<i>Phaseolus coccineus</i>			x	17,18
<i>Tephrosia noctiflora</i>			x	19,20
<i>Dombeya wallichii</i>			x	21,22
<i>Hibiscus rosa.sinensis</i>	x			23,24
<i>Talipariti tiliaceum</i>			x	25,26
<i>Musa ornata</i>	x		x	27,28,29,30
<i>Musa rosacea</i>		x		27,28,29,30
<i>Musa velutina</i>	x			27,28,29,30
<i>Musa x paradisiaca</i>	x	x	x	27,28,29,30
<i>Callistemon speciosus</i>	x		x	31,32,33
<i>Eucalyptus globulus</i>	x			34
<i>Melaleuca leucadendra</i>			x	31,35
<i>Syzygium jambos</i>	x	x		36,37,38
<i>Syzygium malaccens</i>	x	x	x	36,37,38
<i>Antigonon leptopus</i>			x	39
<i>Morinda citrifolia</i>			x	40, 41, 42
<i>Citrus sp.</i>			x	43
<i>Lantana nivea</i>			x	44

Plant species	Pollinators			Network ID
	Birds	Bats	Insects	
<i>Phormium tenax</i>	x		x	45
<i>Hedychium coronarium</i>			x	46

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Table S7. Proportion of alien plant species and alien plant species interactions across 21 plant-hummingbird networks in Americas.

Network ID	Plant richness		Number of interactions	
	Total	Aliens (Prop.)	Total	Aliens (Prop.)
1	8	0.25	133	0.65
2	11	0.09	246	<0.01
3	11	0.27	1348	0.56
4	7	0.14	500	0.12
5	57	0.05	1417	0.07
6	13	0.15	257	0.68
7	22	0.05	343	0.05
8	14	0.29	1376	0.20
9	23	0.09	2957	0.03
10	65	0.05	2162	0.02
11	13	0.08	1203	0.14
12	25	0.04	482	0.01
13	56	0.02	2804	<0.01
14	42	0.14	8450	0.01
15	22	0.14	330	0.16
16	28	0.04	721	0.01
17	16	0.06	173	0.16
18	25	0.04	250	0.19
19	24	0.04	451	0.21
20	18	0.06	562	<0.01
21	16	0.19	481	0.23

Table S8. Comparison of linear mixed effect models explaining network indices of the alien plant species across 21 plant-hummingbird networks. We included plant traits (plant size, flower type, flower length and previous association to bird pollinators) as well as insularity of the network as fixed factors. Alien plant species identity was included as a random effect to account for plant species occurring in several networks. We only show the best models defined by $\Delta AICc < 2$. Note that with the exception of *c*, for all network indices the intercept only “model” was among the best models.

Network index	Model description	AICc	$\Delta AICc$	Weight
Degree	Size	116.9	-	0.173
	~intercept only	117.9	1.02	0.104
	Bird pollination+Size	118.2	1.33	0.089
	Bird pollination	118.6	1.71	0.074
	Insularity+Size	118.7	1.77	0.072
Species strength	~intercept only	127.3	-	0.268
	Bird pollination	129	1.72	0.114
	Size	129.1	1.75	0.112
	Insularity	129.2	1.89	0.104
<i>d'</i>	Size	119.7	-	0.262
	~intercept only	121.6	1.84	0.105
<i>c</i> (between module)	Size	105.3	-	0.305
	Size+Insularity	106.6	1.34	0.156
<i>z</i> (within module)	~intercept only	125.6	-	0.264
	Bird pollination	127.1	1.57	0.121
	Insularity	127.4	1.81	0.107

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Table S9. Comparison of linear mixed effect models explaining network indices of the alien plant species across 12 plant-hummingbird networks for which we had floral abundance data. We included plant traits (plant size, flower type, flower length and previous association to bird pollinators) insularity of the network and floral abundances as fixed factors. Alien plant species identity was included as a random effect to account for plant species occurring in several networks. We only show the best models defined by $\Delta AICc < 2$. Note that with the exception of c, for all network indices the intercept only “model” was among the best models.

Network index	Model description	AICc	$\Delta AICc$	Weight
Degree	Insularity	62.3	-	0.132
	-intercept only	62.4	0.06	0.127
	Insularity+Size	62.7	0.34	0.111
	Size	62.9	0.59	0.098
	Insularity+Abundance	63.6	1.29	0.069
Species strength	-intercept only	66.9	-	0.346
d'	-intercept only	70.5	-	0.307
	Size	71.9	1.41	0.152
c (between module)	Insularity+Size	55.0	-	0.464
z (within module)	-Abundance	61.1	-	0.327
	-intercept only	63.0	1.88	0.128



The illustration depicts a interaction between the Saw-billed hermit *Ramphodon naevius* and the Flowering banana *Musa ornata* originally from Southeast Asia (credit: Pedro Lorenzo).
338x253mm (300 x 300 DPI)