Article

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Biodiversity Research

Running header: Alien plants in plant-hummingbird networks

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

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ABSTRACT

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

Location Mainland and insular Americas.

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

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

Main conclusions Alien plants appear strongly integrated once incorporated into plant-hummingbird networks, and thus may have a large influence on network dynamics. Plant traits and floral abundance were generally poor predictors of how well alien species are integrated. Short-billed hummingbirds, often characterized as functionally generalized pollinators, facilitate the integration of alien plants. Our results show that plant-hummingbird networks are open for invasion.

Key-words

Abundance, exotic plants, generalization, invasion biology, network roles, ornithophily, specialization

INTRODUCTION

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

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

Richardson 2014). However, most of these studies have considered either temperate systems, which predominantly consist of functionally generalized insect pollinators (e.g. Aizen et al. 2008, Bartomeus et al. 2008), or focus on generalized island communities where the impact of invasive species might be most severe (e.g. Olesen et al. 2002, Traveset et al. 2013, Traveset & Richardson 2014, but see Kaiser-Bunbury et al. 2011). As an interaction network's stability may be more sensitive to the integration of alien species in specialized than in generalized systems (Kaiser-Bunbury et al. 2011), studies on specialized systems and over large geographical scales can contribute to our understanding of the general effects of alien species.

One such potential model system is the interaction networks between plants and hummingbirds across the Americas, which range from relatively specialized to generalized networks, and include both mainland and insular environments (Stiles 1981, Dalsgaard et al. 2011, Martín González et al. 2015). Hummingbirds are the most functionally specialized group of nectar-feeding birds and the most important vertebrate pollinators in the Americas (Stiles 1981, Bawa 1990, Cronk & Ojeda 2008). As specific floral phenotypes are often associated with hummingbird pollination (Cronk & Ojeda 2008, Ferreira et al. 2016), it could be expected that alien plants lacking a shared evolutionary history with hummingbirds would not be readily incorporated as important species in those networks (Richardson et al. 2000; Aizen et al. 2008). Conversely, Old World plants with convergent adaptations to bird pollination, notably to sunbirds and honeyeaters in Africa and South-east Asia (Cronk & Ojeda 2008, Fleming & Muchhala 2008, Ollerton et al. 2012, Janeček et al. 2015), could be well-integrated in novel plant-hummingbird communities in the Americas – at least more than alien plant species not previously pollinated by birds (see Johnson & Raguso 2015 for examples between specialized flowers and long tongued hawkmoths).

Given the increasing concerns over the effects of alien species on ecosystems (Davis et al. 2011, Richardson & Ricciardi 2013, Simberloff et al. 2013), community-wide studies on the role of alien plants across large geographic gradients could provide new insights into their potential threats to biodiversity. Here, we characterize the role of alien plants in 21 quantitative plant-hummingbird networks distributed broadly across the Neotropics, including both mainland and island environments (Fig. 1). We asked three questions: 1) whether an average alien plant is topologically more important than a native species, i.e. whether alien plants have a disproportionate large effect on plant-hummingbird networks; 2) whether alien plant traits, such as pre-adaptation to bird pollination in combination to the geographical setting of the network, i.e., insularity, affect the integration of plants into networks; 3) whether hummingbirds with short-bills, often characterized as functionally more generalized, facilitate the integration of alien plant species into networks.

METHODS

Plant-hummingbird networks and alien plants classification

In order to investigate the role of alien plant species in pollination networks, we compiled plant-hummingbird networks in which exotic plant species could be confidently identified (Figure 1). For this, we used an established database on quantitative plant-hummingbird interaction networks (see Dalsgaard et al. 2011 and Martín González et al. 2015 for previous versions of the database, updated details in Table S1-S3). We only considered legitimate interactions here, in which a hummingbird was observed contacting the reproductive structures of the flowers and with potential for pollination. For each network, plants were classified as either native or alien - taking into account the locality of a given network and the plant distribution range according to openly available databases, notably: Tropicos (http://www.tropicos.org/), GRIN Taxonomy for Plants for North America (http://www.ars-grin.gov/), Flora of the West Indies for the Caribbean (http://botany.si.edu/antilles/WestIndies/query.cfm), Brazilian Flora Checklist for networks from Brazil (http://floradobrasil.jbrj.gov.br/) and The Plant List (http://www.theplantlist.org/). Plant names used here followed The Plant List database. A total of 75 (19%) plant occurrences in the networks were not identified to species level, but to genus or family level only (Table S2); for these we adopted a conservative approach of only attributing "alien" status if the genus/family at the given locality was identified as alien in the databases. We note, however, that excluding these species did not affect the comparison between native and alien plants. Because the geographical origin of some plants is poorly known, the classification of these can be imprecise (Pyšek et al. 2004), and the use of a single general database has been argued for in order to standardize possible bias (Stouffer et al. 2014). However, our dataset is composed primarily of networks from the Neotropical region, which has relatively poor historical species records compared to North America and Europe (Pyšek et al. 2004). Since even for well recorded regions these general databases can fail to successfully classify species (see Stouffer et al. 2014), we preferred to use regional databases, which rely on local plant specialists, e.g. the Brazilian Flora Checklist. Whenever conflicts among databases appeared, or we were unsure of the classification, we contacted experts with working experience on the flora of the specific region (listed in the Acknowledgments). We refer to the plants considered here solely as alien, since to define these as invasive require more than distributional information e.g. ecological and demographic parameters that we currently lack (Colautti & MacIssac 2004). Moreover, all hummingbirds were considered as natives.

Species-level network metrics

For each plant-hummingbird community, interactions were summarized as a bipartite matrix, with each cell filled with the frequency of the pairwise interaction between a plant and a hummingbird species. The role of each plant species within the networks was described by five distinct indices that capture distinct topological properties of a species: 1) the degree of a species (k_i) is computed as the number of partners a given species i is linked to in the network; 2) species strength (s_i) is the sum of dependencies across all interaction partners of a given species i; dependency is calculated as the proportion of interactions performed by species i to a specific partner (Bascompte et al. 2006); 3) complementary specialization, (d'_i) quantifies how interaction frequencies of a given species deviate in relation to the availability of interaction partners in the network, defined by their marginal totals; the higher the value of d', the more exclusive are the interactions of the species in relation to the other species in the network (Blüthgen et al. 2006). In addition, we calculated the level of quantitative modularity of each network, i.e. formation of distinct sub-communities within an ecological network characterized by high within-module prevalence over between-module interactions (Dormann & Strauss 2014). For each network, we estimated the module conformation using the QuanBiMo algorithm with the number of Markov Chain Monte Carlo (MCMC) moves to yield no improvement before the algorithm stops set to 10^7 steps (Dormann & Strauss 2014). From the module conformation with the highest modularity after 20 independent runs for each network (as in Maruyama et al. 2014), we calculated two species-level network indices: 4) between-module connectivity c and 5) within-module connectivity z. Whereas c_i describes how evenly the interactions of species i are distributed across modules in the network, z_i quantifies the importance of a given species i within its module (Dormann & Strauss 2014). Species-level network indices showed a positive correlation in some cases, indicating that species with high values for a given index tended to also have high values for another index (Table S4). The correlation was especially high between degree and species strength (Pearson's r = 0.68; Table S4), and between species strength and within module connectivity, i.e. z (Pearson's r = 0.70; Table S4). However, these indices complement each other and we therefore used all five indices when comparing alien vs. native plants. In order to compare the five species-level network indices across different networks, we transformed all network indices to z-scores, i.e., indices were standardized within each network by subtracting the mean value of each group (plants or hummingbirds) and dividing the results by its standard deviation (as in Vidal et al. 2014). Calculations of species-level network indices were conducted with the *bipartite* package (Dormann et al. 2008) in R (R Development Core Team 2014).

Question 1: Are alien plants topologically more important than native plants in the networks?

To test whether alien plant species differed from native species, we used a null model to contrast the observed difference of means of the species-level indices between native and alien plants to the differences of the means calculated from randomizations shuffling the alien or native status of the plants (the proportion of alien/natives was fixed; Vidal et al. 2014). The significance (*p*-values) was obtained by dividing the number of times the absolute differences generated from 10,000 randomizations were equal or larger than the observed difference of the means by the number of randomizations (Manly 1997). Whenever a plant species occurred in more than a single network (74 species, 19.3% of all plants), the average for each of the standardized indices was calculated and used for the null model analysis. We note that with the exception of the degree (*k*) which becomes non-significant, results were qualitatively similar if we consider the instances in which the same species occurred in different networks as distinct samples. Thus, we kept the same approach adopted in Vidal et al. (2014). To quantify the magnitude of the difference between native and alien plant species, we calculated Cohen's d effect size as the standardized mean difference between the indices of each group, i.e. the difference between means divided by the standard deviation of the respective index for all plants (Nakagawa & Cuthill 2007, Sullivan & Feinn 2012). For example, an effect size of around 0.5 is considered a medium effect, meaning that an average alien plant species has a higher index value than 69% of the natives (Nakagawa & Cuthill 2007, Sullivan & Feinn 2012).

Question 2: Do plant traits and insularity affect the network roles of alien plants?

For all alien plants identified in the 21 networks, we classified the species according to traits we hypothesized as relevant for their role in the networks. Trait information was gathered from the original sources of the network data (Table S1), as well as by a follow-up literature search using Google Scholar® with the species name as the search term. All alien plants were classified according to (a) the size of the plant, which potentially reflects their floral display (i.e. large or small, the former including trees and large herbs such as bananas, and the latter including shrubs, climbers and small herbs); (b) flower type (tubular, brush or other), (c) the length of the floral corolla or equivalent structures restricting the access to pollinator (mm), and (d) whether or not they are bird-pollinated in their native range (Tables S5-S6). To determine the latter, we used references from the plant-hummingbird network database as well as field based studies on the floral morphology and pollination biology of the plants, including information on the associated floral visitors and pollinators (Table S5-S6). Additionally, we classified whether an alien plant occurred on an island or on mainland communities. As we were only able to evaluate alien plant traits, and not the traits of the native plants, we asked whether particular characteristics of the aliens influence its integration into the networks.

We evaluated how plant traits and insularity related to plant species-level network indices with linear mixed effects models (LMM) using the *lme4* package (Bates 2014) in R (R Development Core Team. 2014). We used the plant traits (i.e. size, flower type, flower length and previous association to bird pollination) and insularity of the network as fixed factors. Here, we also included the plant family as a fixed factor to, at least partly, account for taxonomic relatedness. Alien plant species identity was included as a random effect to account for non-independence of the observations of the same species in different networks (Bolker et al. 2009, Zuur et al. 2009). We ran models separately for each of the five distinct species-level network indices. The full models included all predictors and were compared to reduced models using the function "dredge" in R package *MuMln* (Barton 2014), according to their Akaike information criteria (AIC) values, corrected for small sample sizes (AICc - Bolker *et al.* 2009, Zuur et al. 2009). Models with ΔAICc ≤ 2 were considered to be equivalent. We also estimated the proportion of variance explained by the fixed factors in the selected best model as marginal R^2, and the proportion of variance explained by fixed and random factors as conditional R^2 (Nakagawa & Schielzeth 2013, Barton 2014). For 12 of the networks (57.1% of the dataset), floral abundance data were available and thus we conducted additional analyses evaluating its role on species-level network indices. Following the same procedure to what was done for the entire dataset, we fitted LMMs to evaluate simultaneously the effect of alien plant traits, floral abundance and insularity on the species-level indices. Here, as for network indices, the floral abundances were standardized within each network.

Question 3: Do hummingbird traits relate to facilitation of alien plant integration?

Finally, we asked whether hummingbird bill length, a functional bird trait associated with flower choice (Dalsgaard et al. 2009, Maruyama et al. 2014, Maglianesi et al. 2014), was related to the probability of hummingbirds including alien plants in their array of interactions. Longer billed-hummingbirds are considered functionally more specialized (Dalsgaard et al. 2009, Maruyama et al. 2014, Maglianesi et al. 2014). For this, we compiled information on hummingbird bill lengths (Table S3) and assessed whether a given hummingbird species interacted with an alien plant across the networks. Then, we fitted a generalized linear model with binomial error distribution containing hummingbird bill length as predictor of the probability that a hummingbird species interacted with alien plant species (Zuur et al. 2009). This analysis was conducted at species level, contrasting each species' bill length to the presence of interaction with alien plants across all the networks in which a given hummingbird species occurred. We also conducted a similar analysis excluding hummingbird species occurring on Caribbean islands where networks are small (Dalsgaard et al. 2009), as well as using the body mass instead of the bill length. As bill length and body mass in hummingbirds show strong phylogenetic signal (Graham et al. 2012), we also included the hummingbird clades (McGuire et al. 2014) as another fixed factor in these analysis. The models with and without clade identity were compared by an analysis of deviance test and their AIC values (Zuur et al. 2009).

RESULTS

The 21 plant-hummingbird networks included a total of 74 hummingbird and 384 plant species, of which 32 plants were classified as being alien to the networks in which they occurred. Individual networks contained between seven and 65 plant species, with a mean of 10.8±8.2% (±sd) and up to 28.6% alien plant species (Figure 1, Table S7). Alien plants belonged to 16 plant families, with Musaceae and Myrtaceae constituting the most frequent families (Table S5-S6). Most alien plant species (~63%) had tubular flowers, and about half of them (~47%) had previous association with bird pollinators (Table S5-S6). Around 50% of alien species originated from Asia, about 19% originated from Africa and 19% from other regions of the Americas (Table S5).

Question 1: Are alien plants topologically more important than native plants in the networks?

Overall, alien plant species had higher values of species strength than native species (effect size, *k:* Cohen's d = 0.56; 95% Confidence Interval = 0.36-0.77; null model *p* = 0.003; Figure 2). Likewise, alien plants also had higher values of within module connectivity (*z:* Cohen's d = 0.49; 95% CI = 0.29-0.69; *p* = 0.006; Figure 2). For degree (*k*) and complementary specialization (*d'*), 95% CI of effect sizes did also not overlap zero and null models were significant (*k:* Cohen's d = 0.35; 95% CI = 0.15-0.56; *p* = 0.049; *d'*: Cohen's d = 0.35, 95% CI = 0.15-0.55; *p* = 0.050; Figure 2). However, alien plants did not differ from native species in connecting distinct modules (*c:* Cohen's d = 0.07; 95% CI = -0.12-0.27; *p* = 0.662). Hence, an average alien plant is more important for hummingbirds than an average native plant in terms of relative interaction frequency. There is also a tendency for alien plant species to have more partners and for some hummingbird species to interact more exclusively with alien plants than natives.

Question 2: Do plant traits and insularity affect the network roles of alien plants?

Alien plant traits did not relate to species-level network indices, except for between-module connectivity (*c*), since the model containing only the intercept was always included within the best models (Table S8). For *c,* the best two models included insularity and size of the alien plants; the model containing both terms had R^2 marginal = 0.22 and R^2 conditional = 0.33. Specifically, aliens on islands (estimate = 0.35, SE = 0.30) and larger alien plants (estimate = 0.75, SE = 0.27) had higher values for connectivity, i.e. were more important for interconnecting modules. Plant family was not included in any of the best models. Considering the subset of networks for which we had floral abundance data, this did not relate to species topological roles in any of the LMMs, as in all cases the intercept only model was as good as models including floral abundance (Table S9). Importantly, the results of LMMs for this reduced dataset were fairly consistent and we again have that insularity (estimate = 0.68, SE = 0.18) and plant size (estimate = 1.18, SE = 0.36) relate to *c* (R^2 marginal = 0.42 and R^2 conditional = 0.97).

Question 3: Do hummingbird traits relate to facilitation of alien plant integration?

We found that short-billed hummingbirds were more likely to interact with alien plants than were long-billed hummingbirds (slope: -0.10; $p < 0.01$; Figure 3). The model including the hummingbird clades did not differ from the one without (Deviance = 6.68, $p > 0.46$) and had higher value of AIC (ΔAIC = 9.32). Excluding the hummingbird species occurring in the Caribbean islands did not change our results (slope: -0.08; $p =$ 0.036; Figure S1) and body mass was found unrelated to the probability of using alien plants ($p = 0.091$).

DISCUSSION

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

The traits we hypothesized *a priori* to determine how alien plants would integrate into the networks showed little importance. For instance, convergent evolution to bird pollination has been suggested as an example of previous adaptation to specific pollinator types aiding the incorporation of aliens to novel plant-pollinator networks (Richardson et al. 2000, Ollerton et al. 2012). However, this pre-adaptation did not apply to network roles of alien plants in plant-hummingbird networks. Hummingbirds may favour specific floral traits (Cronk & Ojeda 2008, Ferreira et al. 2016), but they may also show opportunism in flower use by legitimately visiting plants that do not obviously conform to the bird pollination syndrome of ornithophily (e.g. Dalsgaard et al. 2009, Maruyama et al. 2013). Due to this opportunism, specialized floral traits may not relate to plant species roles in plant-hummingbird networks (Maruyama et al. 2013). Nevertheless, one possible limitation is the fact that we only considered plant species recorded as visited by hummingbirds, i.e., participating in the web of interactions. It is possible that other alien plants were present in the studied communities and that these were not visited by hummingbirds. If such non-participating alien species had been considered, plant traits, including the previous adaptation to bird-pollination, could have emerged as important for alien integration into the plant-hummingbird web. Likewise we did not include non-hummingbird pollinators and insects may overlap with hummingbirds on the phenotypically more generalised plant species (e.g. Dalsgaard et al. 2009, Maruyama et al. 2013); thus other pollinators may also influence alien plant integration.

It has been suggested that invasive plants, i.e. widespread and abundant alien plants, may become core components of plant-insect pollinator networks due to their high abundance in invaded communities (Lopezaraiza-Mikel et al. 2007, Aizen et al. 2008, Albrecht et al. 2014). However, recent studies have shown that abundance has minor importance in structuring interactions among plants and hummingbirds, in contrast to more generalized insect pollination systems (Maruyama et al. 2014, Vizentin-Bugoni et al. 2014, 2016). In accordance, analyses conducted with the subset of the networks for which we have floral abundance data show that there is no association between floral abundance and their species-level indices. Thus, for plant-hummingbird networks, floral abundance is a poor predictor of alien topological importance. Instead, we suggest that other plant traits that we lack in our dataset, such as the temporal availability of alien flowers in relation to native plants (i.e. phenology), or higher nectar secretion rates, could be important for explaining the integration of alien species in these networks (see Chittka & Schürkens 2001, Godoy et al. 2009).

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

From the hummingbird perspective, we show that shorter billed hummingbirds have higher probabilities of incorporating alien plant species in their web of interactions. Although there is variation in this trend, since some longer-billed hummingbirds used alien plants (Figure 3), this result is consistent to the setting in which longer-billed hummingbirds avoid interacting with more generalised flowers due competition with shorter-billed hummingbirds (Maglianesi et al. 2015). Studies have suggested that generalist insect pollinators facilitate alien plant establishment, since these often include alien plants in their interactions (Richardson et al. 2000, Memmott & Waser 2002, Olesen et al. 2002, Lopezaraiza-Mikel et al. 2007, Aizen et al. 2008, Bartomeus et al. 2008, Traveset et al. 2013, Stouffer et al. 2014). In previous studies, however, "generalists" were defined based in their roles in networks, e.g., number of partners. Here, we show a link between integration of alien plants and a functional trait of the pollinators, i.e. bill length of hummingbirds.

CONCLUSION

Invasive plants are regarded as one of the major current threats to biodiversity. One of the key components for alien plants to establish in novel ecosystems is their successful integration into mutualistic networks (Richardson et al. 2000, Traveset & Richardson

2014). Although examples of successful integration of alien species in temperate and insular insect-plant systems are common (e.g. Olesen et al. 2002, Aizen et al. 2008, Bartomeus et al. 2008, Vilà et al. 2009, Stouffer et al. 2014), here we show that alien plants are strongly integrated into the web of interactions even for more specialized tropical pollination systems, such as hummingbird pollination. Further research incorporating complementary data, such as interspecific pollen deposition or the contribution of hummingbirds to alien plant reproduction, are essential next steps to fully assess the impact and integration of alien plants in this system (Richardson et al. 2000, Lopezaraiza-Mikel et al. 2007, Bufford & Daehler 2014, Traveset & Richardson 2014). By acting as core generalist species in the networks, these plants may impact the entire plant-pollinator network (Traveset et al. 2013) and even modify their eco-evolutionary dynamics (Guimarães et al. 2011). In sum, our results here show that plant-hummingbird networks are dynamic and open for invasion, emulating what happens in other plant-pollinator systems.

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SUPPORTING INFORMATION:

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

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

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

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

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

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

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

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

Table S8 Model selection results for linear mixed effect models explaining network indices of the alien plant species.

Table S9 Model selection results for the subset of 12 networks with floral abundance data.

BIOSKETCH

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

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

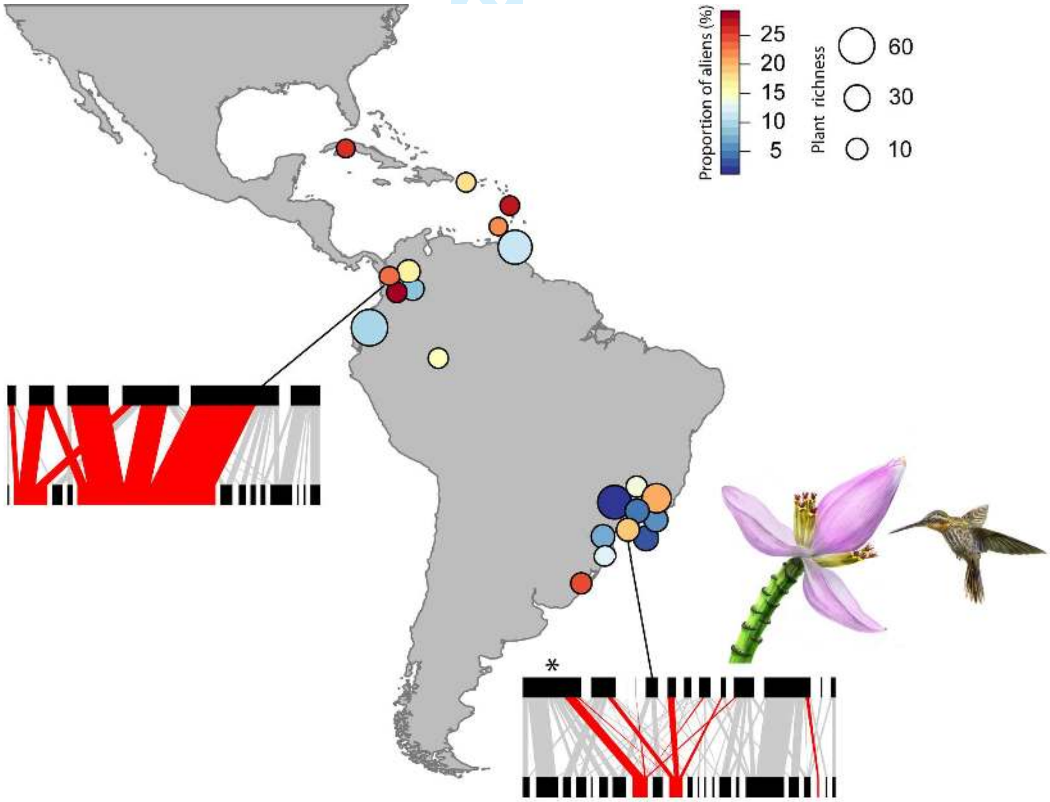

Figure 2 Species-level network indices for 352 native and 32 alien plant species across 21 plant-hummingbird networks. On the left, we show the effect sizes (Cohen's d) comparing alien and native plant species for various network indices; an effect size is considered significant if the 95% CI of the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

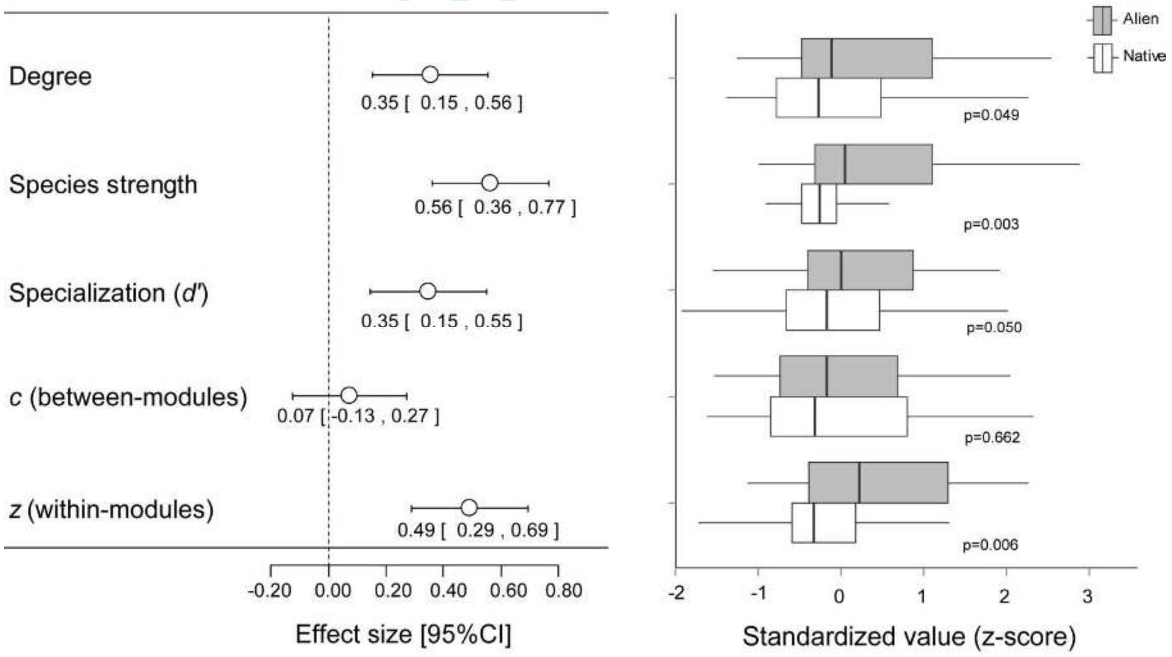

Figure 3 Probability of hummingbird species incorporating alien plant species into their interactions in relation to their bill length. Each circle illustrates whether a given hummingbird species incorporates alien plants (1), or not (0). The fitted line reflects the modelled probability of hummingbird 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. A Mann-Whitney test likewise shows significant difference between the bill length of those hummingbirds incorporating and those not incorporating alien plants in their interactions (*p* = 0.004).

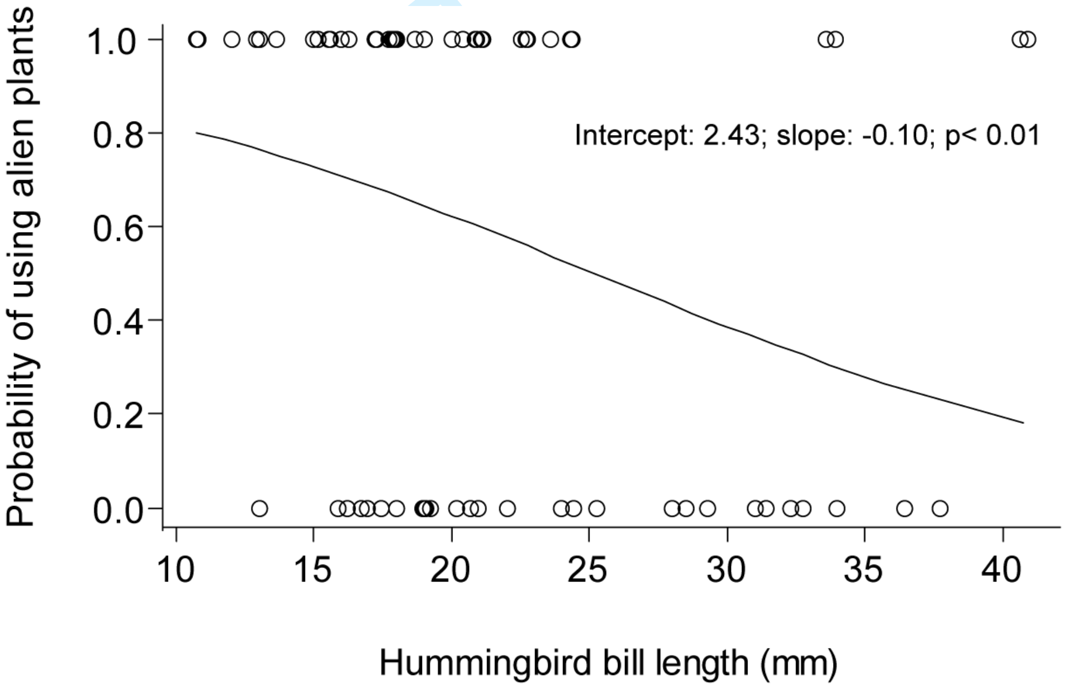

Figure S1. Probability of hummingbird species incorporating alien plant species into their interactions in relation to their bill length, here species occuring at Caribbean islands networks were excluded. Each circle illustrates whether a given hummingbird species incorporates alien plants (1), or not (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.

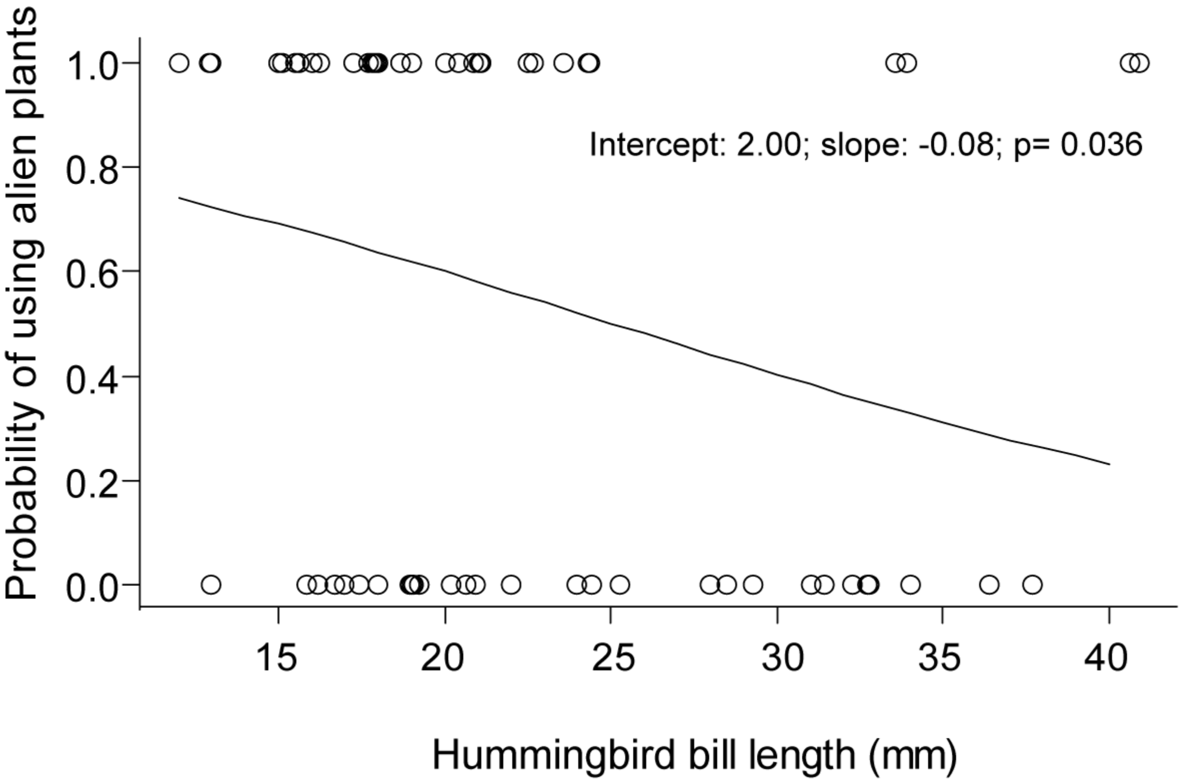

Table S1. Coordinates, description, location and data references for each studied plant-hummingbird network.

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. *MSc Thesis.* 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. *Oecologia,* **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. *Oecologia,* **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. *Oecologia,* **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. *Journal of Animal Ecology*, **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. *Bulletin of the British Museum of Natural History (Zoology),* **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. *Bulletin of the British Museum of Natural History (Zoology),* **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. *BSc Thesis.* Universidad del Quindío, Colombia.
9	4.50	-75.60	Andean second growth humid forest, Colombia	Marín-Gómez, O.H. *Unpublished data*.
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. *International Journal of Ornithology*, **4**, 115–135.
11	-3.82	-70.27	Amazonian rainforest, SE Colombia	Cotton, P.A. (1998) The hummingbird community of a lowland Amazonian rainforest. *Ibis*, **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. *Botanica Acta,* **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. *Proceedings of the Royal Society of London B,* **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 planicie costeira do litoral norte de São Paulo, sudeste do Brasil. *MSc. Thesis*. 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. *Oecologia*, 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. *Oecologia*, 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. *Oecologia*, 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. *Hornero,* **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. *MSc. Thesis*. 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. *MSc. Thesis*. Universidade Federal do Paraná, Brazil.
21	-31.80	-52.42	Pampa, S Brazil	Vizentin-Bugoni, J. & Rui, A.M. *Unpublished data*.

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

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

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

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

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

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

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

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

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

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

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Leguminosae	*Tachigalia paniculata*	Aubl.	11
Leguminosae	*Tephrosia noctiflora*	Bojer ex Baker	3
Loranthaceae	*Loranthaceae* sp.		18
Loranthaceae	*Psittacanthus cucularis*	(Lam.) G. Don	11
Loranthaceae	*Psittacanthus dichrous*	(Mart.) Mart.	13,14,16
Lythraceae	*Cuphea melvilla*	Lindl.	11
Malvaceae	*Abutilon* aff. *regnellii*	Miq.	12
Malvaceae	*Abutilon darwinii*	Hook.f.	10
Malvaceae	*Abutilon* sp.*1*		13
Malvaceae	*Dombeya wallichii*	(Lindl.) Benth. & Hook.f.	14
Malvaceae	*Eriotheca pentaphylla*	(Vell. & K.Schum.) A.Robyns	14,16
Malvaceae	*Guazuma ulmifolia*	Lam.	1
Malvaceae	*Hibiscus rosa-sinensis*	L.	10,14
Malvaceae	*Luehea divaricata*	Mart. & Zucc.	21
Malvaceae	*Malvaviscus arboreus*	Cav.	10
Malvaceae	*Quararibea lasiocalyx*	K.Schum.	11
Malvaceae	*Spirotheca rivieri*	(Decne.) Ulbr.	13
Malvaceae	*Talipariti tiliaceum*	(L.) Fryxell	14
Malvaceae	*Urena lobata*	L.	2
Marantaceae	*Calathea capitata*	(Ruiz & Pav.) Lindl.	11
Marantaceae	*Ischnosiphon arouma*	(Aubl.) Korn.	5
Marantaceae	*Maranta furcata*	Nees & Mart.	14
Marcgraviaceae	*Marcgravia myriostigma*	Triana & Planch.	14
Marcgraviaceae	*Marcgravia polyantha*	Delpino	18
Marcgraviaceae	*Marcgravia* sp.		5
Marcgraviaceae	*Norantea guianensis*	Aubl.	5
Marcgraviaceae	*Sarcopera* sp.		10
Marcgraviaceae	*Schwartzia brasiliensis*	(Choisy) Bedell ex Gir.-Cañas	14,16,19
Melastomataceae	*Acinodendron sintenisii*	(Cogn.) Kuntze	2
Melastomataceae	*Melastomataceae* sp.		10
Musaceae	*Musa balbisiana*	Colla	19

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

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

Family	Plant species	Author	Network ID
Solanaceae	*Acnistus arborescens*	(L.) Schltdl.	15,19
Solanaceae	*Brugmansia arborea*	(L.) Steud.	10
Solanaceae	*Cestrum corymbosum*	Schltdl.	12
Solanaceae	*Cestrum macrophyllum*	Vent.	2
Solanaceae	*Cestrum* sp.		10
Tropaeolaceae	*Tropaeolum pentaphylum*	Lam.	21
Verbenaceae	*Citharexylum spinosum*	L.	3
Verbenaceae	*Lantana camara*	L.	5,13,15
Verbenaceae	*Lantana nivea*	Vent.	14
Verbenaceae	*Stachytarpheta cayennensis*	(Rich.) Vahl	15,16
Verbenaceae	*Stachytarpheta jamaicensis*	(L.) Vahl	3
Verbenaceae	*Stachytarpheta maximiliani*	Schauer	19
Verbenaceae	*Stachytarpheta* sp.		14
Xanthorrhoeaceae	*Phormium tenax*	J.R.Forst. & G.Forst.	18
Zingiberaceae	*Hedychium coronarium*	J.Koenig	14,15,20
Zingiberaceae	*Renealmia alpinia*	(Rottb.) Maas	2
Zingiberaceae	*Renealmia sessilifolia*	Gagnep.	10
Zingiberaceae	*Renealmia* 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
Orthorhyncus cristatus	Emerald	3,4	10.7	Brown and Bowers 1985
Mellisuga helenae	Bee	1	10.8	Andrea Baquero, unpublished
Lophornis chalybeus	Coquette	13,14,16,19	12.0	Vizentin-Bugoni et al. 2014
Ocreatus underwoodii	Brilliant	6,9,10	12.9	Graham et al. 2012
Calliphlox amethystina	Emerald	15	13.0	Grantsau 1989
Chrysolampis mosquitus	Mango	5	13.0	Snow & Snow 1972
Chlorostilbon maugaeaus	Emerald	2	13.6	Brown and Bowers 1985
Adelomyia melanogenys	Coquette	6,9,10	15.0	Graham et al. 2012
Stephanoxis lalandi	Emerald	12,13	15.0	Vizentin-Bugoni et al. 2014
Stephanoxis lodigessi	Emerald	21	15.9	Jeferson Vizentin-Bugoni, unpublished
Chlorostilbon mellisugus	Coquette	8,11	15.1	Graham et al. 2012
Aglaiocercus kingi	Emerald	6,9	15.5	Graham et al. 2012
Amazilia versicolor	Emerald	13,15,16,17,18,19,20	15.6	Snow & Snow 1986
Hylocharis cyanus	Emerald	14,15,16	16.0	Araujo 1996
Chlorostilbon gibsoni	Emerald	7	16.2	Snow & Snow 1980
Aglaiocercus coelestis	Coquette	10	16.2	Graham et al. 2012
Chaetocercus mulsant	Bee	6	16.7	Snow & Snow 1980
Boissonneaua flavescens	Brilliant	6,9,10	17.0	Graham et al. 2012
Chlorostilbon ricordii	Emerald	1	17.2	Andrea Baquero
Chlorostilbon poortmani	Emerald	6	17.3	Graham et al. 2012
Colibri delphinae	Mango	10	17.4	Graham et al. 2012
Calliphlox mitchellii	Emerald	10	17.7	Walther & Brieschke 2001
Amazilia cyanifrons	Emerald	7	17.8	Snow & Snow 1980
Thalurania glaucopis	Emerald	13,14,15,16,17,18,19,20,21	17.9	Araujo 1996
Amazilia saucerrottei	Emerald	8,9	17.9	Oscar Humberto Marin-Gomez, unpublished
Amazilia tobaci	Emerald	5	18.0	Snow & Snow 1972
Chlorestes notatus	Emerald	5,11	18.0	Snow & Snow 1972
Chlorostilbon lucidus	Emerald	12,19,21	18.0	Grantsau 1989
Heliangelus amethysticollis	Coquette	6	18.0	Snow & Snow 1980

Species	Clades	Network ID	Bill length (mm)	Data sources
Amazilia chionopectus	Emerald	5,14	18.7	Araujo 1996
Heliodoxa aurescens	Brilliant	11	19.0	Graham et al. 2012
Clytolaema rubricauda	Brilliant	12,13,15,18,20	19.0	Vizentin-Bugoni et al. 2014
Eupetomena macroura	Emerald	13,14,16	19.0	Grantsau 1989
Florisuga mellivora	Topazes	5,9,10,11	19.0	Snow & Snow1972
Hylocharis chrysura	Emerald	21	19.0	Jeferson Vizentin-Bugoni, unpublished
Urosticte benjamini	Brilliant	10	19.1	Graham et al. 2012
Thalurania fannyi	Emerald	10	19.2	Graham et al. 2012
Leucochloris albicollis	Emerald	12,13,14,15,18,21	20.0	Vizentin-Bugoni et al. 2014
Amazilia tzacatl	Emerald	7,8,9,10	20.0	Graham et al. 2012
Aphantochroa cirrochloris	Emerald	19	20.2	Grantsau 1989
Phaethornis ruber	Hermit	11,14,15,16	20.4	Araujo 1996
Thalurania furcata	Emerald	11	20.6	Graham et al. 2012
Chrysuronia oenone	Emerald	11	20.9	Graham 2012
Amazilia fimbriata	Emerald	11,14,15,16,17,19,20	20.9	Araujo 1996
Colibri thalassinus	Mango	6,10	20.9	Graham et al. 2012
Phaethornis longuemareus	Hermit	5	20.9	Graham et al. 2012
Heliodoxa rubinoides	Brilliant	10	21.1	Graham et al. 2012
Florisuga fusca	Topazes	13,14,15,16,18,19,21	21.1	Snow & Snow 1986
Colibri serrirostris	Mango	12	22.0	Grantsau 1989
Boissonneaua jardini	Brilliant	10	22.5	Walther & Brieschke 2001
Amazilia franciae	Emerald	7,9,10	22.7	Graham et al. 2012
Eulampis holosericeus	Mango	3,4	22.7	Brown and Bowers 1985
Anthracothorax nigricollis	Mango	5,7,8,9,11,14,21	23.6	Graham et al. 2012
Phaethornis squalidus	Hermit	15,16,17,19	24.0	Grantsau 1989
Heliodoxa imperatrix	Brilliant	10	24.3	Graham et al. 2012
Colibri coruscans	Mango	6,9,10	24.3	Graham et al. 2012
Anthracothorax viridis	Mango	2	24.4	Kodric-Brown et al. 1984
Campylopterus largipennis	Emerald	11	25.3	Graham et al. 2012
Coeligena prunellei	Brilliant	6	28.0	Graham et al. 2012
Threnetes leucurus	Hermit	11	28.5	Cotton 1998

Species	**Clades**	**Network ID**	**Bill length (mm)**	**Data sources**
Phaethornis bourcieri	Hermit	11	29.3	Graham et al. 2012
Glaucis hirsutus	Hermit	4,5,11,14,15,16	31.0	Snow & Snow1972
Heliomaster squamosus	Gem	15	31.0	Grantsau 1989
Coeligena coeligena	Brilliant	9	31.4	Oscar Humberto Marin-Gomez, unpublished
Coeligena torquata	Brilliant	6	32.3	Graham et al. 2012
Doryfera ludoviciae	Mango	6,9,10	32.7	Graham et al. 2012
Phaethornis hispidus	Hermit	11	32.8	Graham et al. 2012
Coeligena wilsoni	Brilliant	10	33.6	Graham et al. 2012
Ramphodon naevius	Hermit	14,15,16,17,19,20	33.9	Araujo 1996
Phaethornis eurynome	Hermit	12,13,18,19,20	34.0	Vizentin-Bugoni et al. 2014
Heliomaster longirostris	Gem	8	36.4	Oscar Humberto Marin-Gomez, unpublished
Phaethornis superciliosus	Hermit	11	37.7	Cotton 1998
Phaethornis syrmatophorus	Hermit	10	40.6	Graham et al. 2012
Phaethornis guy	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	*Dicliptera squarrosa*	Yes	Colombia	8	America	small	tube	27.90
Acanthaceae	*Sanchezia nobilis*	Yes	SE Brazil	17	America	small	tube	46.60
Balsaminaceae	*Impatiens* sp.	Unknown	Ecuador	10	Africa	small	tube	-
Balsaminaceae	*Impatiens walleriana*	No	Puerto Rico, SE Brazil	2,15,16	Africa	small	tube	14.30
Bignoniaceae	*Campsis grandiflora*	Yes	S Brazil	21	Asia	small	tube	32.10
Bignoniaceae	*Spathodea campanulata*	Yes	Colombia	8	Africa	large	other	102.90
Caprifoliaceae	*Lonicera japonica*	No	SE Brazil	12	Asia	small	tube	28.00
Iridaceae	*Crocosmia x crocosmiiflora*	Yes	SE Brazil	13	Africa	small	tube	14.10
Lamiaceae	*Leonotis nepetifolia*	Yes	Dominica	3	Africa	small	tube	11.09
Leguminosae	*Albizia saman*	No	Cuba	1,5	America	large	brush	9.95
Leguminosae	*Phaseolus coccineus*	No	Colombia	6	America	small	other	4.38
Leguminosae	*Tephrosia noctiflora*	No	Dominica	3	Africa	small	other	5.38
Malvaceae	*Dombeya wallichii*	No	SE Brazil	14	Asia/Africa?	small	other	10.00
Malvaceae	*Hibiscus rosa-sinensis*	Yes	Ecuador, SE Brazil	10,14	Asia	small	tube	24.50
Malvaceae	*Talipariti tiliaceum*	No	SE Brazil	14	Asia	small	tube	57.20
Musaceae	*Musa ornata*	Yes	SE Brazil	15	Asia	large	tube	39.50
Musaceae	*Musa rosacea*	Yes	S Brazil	19	Asia	large	tube	38.44
Musaceae	*Musa* sp.	Unknown	Colombia	7	Asia	large	tube	35.00
Musaceae	*Musa* sp.	Unknown	Ecuador	10	Asia	large	tube	-
Musaceae	*Musa velutina*	Yes	Colombia	8,9	Asia	large	tube	32.10
Musaceae	*Musa x paradisiaca*	No	Colombia	9	Asia	large	tube	31.80
Myrtaceae	*Callistemon speciosus*	Yes	S Brazil	21	Oceania	small	brush	3.10
Myrtaceae	*Eucalyptus globulus*	Yes	Colombia	9	Oceania	large	brush	13.20
Myrtaceae	*Melaleuca leucadendra*	No	S Brazil	21	Oceania	large	brush	2.90
Myrtaceae	*Syzygium jambos*	Yes	Colombia, Grenada, Trinidad, SE Brazil	4,5,7,14	Asia	large	brush	2.69
Myrtaceae	*Syzygium malaccens*	Yes	Colombia	11	Asia	large	brush	20.00

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

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

Plant species	Pollinators			Network ID
	Birds	Bats	Insects	
Phormium tenax	x		x	45
Hedychium coronarium			x	46

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* Personal observations

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 ΔAICc < 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**	**ΔAICc**	**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
d'	Size	119.7	-	0.262
	~intercept only	121.6	1.84	0.105
c (between module)	Size	105.3	-	0.305
	Size+Insularity	106.6	1.34	0.156
z (witthin module)	~intercept only	125.6	-	0.264
	Bird pollination	127.1	1.57	0.121
	Insularity	127.4	1.81	0.107

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 abudances 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 ΔAICc < 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**	**ΔAICc**	**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 (witthin 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)