

Changes in pollinator functional composition and plant –pollinator interaction networks in response to mangrove patch size and surrounding land use

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Abstract

Pollinators are declining worldwide as a result of land anthropization. However, several species have shown to be not affected or even benefited, since their responses depend on their functional traits that modulate their adaptability to particular environmental conditions. Pollinator responses may have important consequences on the structure of interaction networks, as the interacting species are sensitive to their counterparts. Despite the great importance that mangrove ecosystems have for human welfare, little is known about what is happening with pollinators' diversity and their interactions with mangrove species. This study investigates landscape effects on pollinator functional composition and their interactions with four dominant mangrove species in the Caribbean coast of Colombia. Pollinators of mangrove species *Avicennia germinans*, *Conocarpus erectus*, *Laguncularia racemosa*, and *Rhizophora mangle* were classified according to different functional traits and plant-pollinator interaction networks were created, with the aim to explore general patterns and to evaluate the effects of mangrove patch size and the surrounding land uses on pollinator functional composition and plant-pollinator interactions. Pollinator communities were mainly represented by wasps, flies, and bees, with the predominance of small and medium-sized predators, saprophagous, florivorous, no-social, and no-nesting species. Plant-pollinator interactions demonstrated a trend to niche differentiation in *C. erectus* and *R. mangle*, high number of interactions and pollinator species, as well as high values of interaction diversity and interaction evenness. Mangrove patch size decreased the richness of ground nesting wasps whereas increased network specialization, and urban size decreased the richness of predators, large-sized species, and ground-nesting wasps.

Introduction

Pollinator populations have been declining in the last decades worldwide in response to land use derived from human activities. Among the main drivers are habitat loss due to fragmentation, intensive use of herbicides and insecticides, pollution, introduction of exotic plants and pollinators, in addition to the global climate change (Winfree *et al.* 2011; Gonzalez-Varo *et al.* 2013; Goulson *et al.* 2015; Millard *et al.* 2021). Evidence about pollinator decline has been documented mainly for honeybees, bumblebees and butterflies in North America and Europe (Goulson *et al.* 2015). However, several pollinator species are still poorly known, and studies have found inconclusive or even positive effects of land use on various pollinators, including bees, wasps, butterflies, and birds (Winfree *et al.* 2011; Schuepp *et al.* 2012; Gonçalves *et al.* 2014; Steckel *et al.* 2014). Such differential responses occur because pollinators respond idiosyncratically to landscape changes according to their functional traits, i.e., morphological, physiological, and behavioral characteristics that modulate the species' adaptability to environmental conditions. Ground nesting wasps and bees, for example, have been found to increase in agricultural landscapes (Williams *et al.* 2010; Montoya-Pfeiffer *et al.* 2020; Szczepko *et al.* 2020), whereas cavity nesters benefited from urban landscapes (Fortel *et al.* 2014; Geslin *et al.* 2013; Wenzel *et al.* 2020). Responses among several functional traits also vary depending on their interactions with other traits (Williams *et al.* 2010; Winfree *et al.* 2011; Merckx *et al.* 2018; Montoya-Pfeiffer *et al.* 2020). Body size in

arthropods, for example, decreases in species with low dispersal ability such as ground spiders and beetles, but increases in species having a body size that correlates with dispersal ability like lepidopterans and orthopterans (Merckx *et al.* 2018). Pollinator responses may also depend on local diversity since the new matrices and cover types in anthropogenic landscapes sometimes provide resources for pollinators that are similar or alternative to those found in conserved areas (Matteson *et al.* 2013).

Pollinator responses to land use may have important consequences on the structure of interaction networks, as the interacting species are sensitive to the phenology, behavior, physiology, and relative abundances of their counterparts (Xiao *et al.* 2016). Changes in pollinator diversity may alter several network properties that are determinants of network maintenance. For example, habitat loss often leads to more generalized networks due to the extirpation of rare and less linked species, the increased influx of generalists, and the more generalist behavior of many pollinator species (Fontaine *et al.* 2008; Winfree *et al.* 2014; Xiao *et al.* 2016). The combined influence of pollinator extirpations, interaction losses, and diet breadth shifts (interaction rewiring) decreases the nestedness in the overall structure of the plant-pollinator interaction networks, increasing this way vulnerability of pollination services to future perturbations (Burkle *et al.* 2013). Changes in interaction networks have been shown to increase in urban environments compared to agricultural environments (Geslin *et al.* 2013), and are expected to be critical for less developed tropical regions where urbanization is increasing faster.

Understanding how pollinators and their interactions with plants respond to land anthropization in different environmental contexts is essential to make more accurate generalizations and to design more efficient strategies for ecosystem management, especially considering that land use will increase in the next few decades (Tilman *et al.* 2001; Seto *et al.* 2012). Neotropical mangroves are an ideal study system as these are naturally isolated ecosystems that are conformed by many endemic species with unique adaptations (Yates *et al.* 2014; Nagelkerken *et al.* 2018; Yeo *et al.* 2021); that there is evidence about plant genetic diversity loss associated with mangrove degradation (Salas-Leiva *et al.* 2009; Nettel-Hernanz *et al.* 2013; Millán Aguilar *et al.* 2016); that mangroves are prioritized ecosystems in world conservation strategies, given their critical role in carbon sequestration and storage, coastal erosion mitigation, and the provisioning of ecosystem goods (Lee *et al.* 2014); and finally, the poor level of knowledge about pollination systems in neotropical mangroves.

This is the first study that investigates landscape effects on plant-pollinator interactions in mangrove forests on the Caribbean coast of Colombia. Pollinators of the dominant mangrove species *Avicennia germinans* (L.) L., *Conocarpus erectus* L., *Laguncularia racemosa* (L.) C. F. Gaertn., and *Rhizophora mangle* L. were classified according to different functional traits and plant-pollinator interaction networks were created, with the aim to explore general patterns and to evaluate the effects of mangrove patch size and the surrounding land use on pollinator functional composition and plant-pollinator interactions.

Methodology

Study area

The study was performed in the municipalities of Ciénaga and Santa Marta, Caribbean region of Colombia, Department of Magdalena (Fig. 1). Seven sampling sites were selected considering mangrove patch size and surrounding land use: two bigger patches dominated by dry forest vegetation (Chengue and Neguanje); two medium-sized patches mainly surrounded by fragmented dry forest, banana and mango plantations, as well as other smaller mixed-crops (Córdoba and Toribio); and three smaller patches mainly surrounded by a mixture of urban and disturbed areas (Cabo Tortuga, Gaira and Manzanares). Mangrove patches consisted on assemblages of *A. germinans*, *C. erectus*, *L. racemosa* and *R. mangle*. In the region the climate is warm and dry, The dry period occurs between December and April the annual precipitation mean varies between 1000 and 1500 mm, and the mean temperature ranges between 26 and 28°C. (IDEAM, 2020).

Pollinator data

Pollinator data were obtained during four sampling events on each mangrove patch. Sampling sessions were performed in October, November, and December 2020, and March 2021. Sampling was carried out between 08:00 h to 14:00 h, a total of six hours of collections per sampling session. Two blooming trees from the mangrove species *A. germinans*, *C. erectus*, *L. racemosa*, and *R. mangle* were selected for pollinator sampling in each mangrove patch. Pollinators were collected using an entomological net by one researcher during two intervals of 10 min on each tree, considering a time lag of at least one hour between the two sampling intervals. All flying flower visitors that touched the stigma and the anthers of flowers were collected and considered as pollinators. The specimens were identified to the lowest possible taxonomical level and deposited in the entomological collection of the Marine Natural History Museum Makuriwa - INVEMAR. The list of the identified specimens is available from the Zenodo Repository; see Data Availability.

Functional groups

Pollinator species were classified using five qualitative functional traits known to respond to habitat degradation (Williams *et al.* 2010; Merckx *et al.* 2018; Fenoglio *et al.* 2021; Török *et al.* 2022): pollinator guilds, body size, feeding preference, degree of sociality, and nesting site. Pollinator guilds were classified as bee, beetle, fly, lepidoptera, and wasp. Body size was classified based on measures of body area (intertegular distance * body length) as small-sized (< 20 mm²), medium-sized (20-40 mm²), or large-sized (> 40 mm²). Feeding preference was classified considering feeding habits during the larval stage as florivorous, phytophagous, predator (including parasites), and saprophagous. The degree of sociality was classified as no-social (solitaries and a few semi social) and social. Nesting site was classified as cavities, exposed, no-nest and ground. Information on functional traits was compiled from the literature by reviewing published works on each species or inferring trait data based on phylogeny. Species with incomplete information were dropped from the analysis (<5% of specimens).

Interaction networks

Quantitative interaction networks were constructed by site with the pollinator and the mangrove species. The following network metrics were calculated: number of interactions, number of pollinator species, interaction diversity (i.e., complexity of associations in networks), interaction evenness (i.e., variation in interaction frequencies indicating different ecological impacts), and network H_2 (i.e., deviation from a completely neutral network with the highest redundancy of interactions). Pollinator frequency was not standardized among networks, since variation in interaction frequencies is expected to reflect the effects of environmental change (Blüthgen, 2010). Interaction networks were constructed using the package *circlize* (Gu *et al.* 2014) and topological metrics were calculated using the package *bipartite* (Dormann *et al.* 2011) in R v.4.2.0 software (R Core Team, 2022).

Mangrove patch size and surrounding land use

Mangrove patch size and the surrounding land use areas (dry forest, degraded, urban, and croplands) were calculated by creating polygons in buffers of 1000 m around each mangrove patch, on Landsat images (scale 1:10 000) from Google (2021) using QGIS 3.22. (QGIS.org, 2022).

Data analysis

Prior to data analysis, a test for autocorrelation between mangrove patch size and the surrounding land use areas was performed and demonstrated a positive correlation between mangrove patch size and dry forest area (Pearson's $r = 0.78$, $p < 0.05$), as well as a negative correlation between mangrove patch size and degraded area (Pearson's $r = -0.81$, $p < 0.05$). Landscape heterogeneity was calculated with the Shannon index (H') by using the proportional land use areas, and demonstrated negative auto-correlation with mangrove patch size (Pearson's $r = -0.86$, $p < 0.05$). Therefore, dry forest area, degraded area, and landscape diversity were dropped from the analysis, and mangrove patch size was used as a proxy measure of landscape conservation and diversity.

Data were analyzed using generalized linear models (GLMs). The overall pollinator frequency and richness per site, the pollinator frequency and richness segregated according to functional groups per site, and the network metrics were taken as response variables. Pollinator frequency and richness were fitted to negative-binomial distributions. Interaction diversity was fitted to a normal distribution and interaction evenness and specialization were fitted to beta distributions. Mangrove species, mangrove patch size, urban size, and cropland size were taken as fixed effects in initial full models. Best models were selected based on significant differences in Akaike information criterion (AIC) values (Analysis of Variance ANOVA tests, significance level = 0.05). Residuals were inspected to assess model fit with the dispersion test proposed by Harting (2022). All analyses were performed in R v.4.2.0 software, using the packages *lme4* (Bates *et al.* 2015), *betareg* (Cribari-Neto and Zeileis, 2010), *DHARMa* (Harting, 2022), and *ggplot2* (Wickham, 2016).

Results

A total of 821 pollinator specimens, distributed in 152 morphospecies were collected in the study area. The pollinator community included several functional groups (Fig. 2). Wasps, bees, and flies were similar in frequency, whereas beetles and lepidopterans were significantly less frequent (GLM, explained deviance $D^2 = 61\%$, $p < 0.01$). All pollinator guilds differed in richness, with flies being the group with the highest richness, followed by wasps, bees, beetles, and lepidopterans (GLM, $D^2 = 76\%$, $p < 0.01$). Most pollinators were small and medium-sized (GLM, D^2 frequency = 55%, D^2 richness = 74%, $p < 0.01$). The frequencies of predators, florivorous, and saprophagous insects were similar, while phytophagous insects were less frequent (GLM, $D^2 = 64\%$, $p < 0.01$). The richness of predator and saprophagous pollinators were higher than the richness of florivorous and phytophagous pollinators (GLM, $D^2 = 65\%$, $p < 0.01$). Social and no-social pollinators did not differ in frequency, even though most species were no-social (GLM, $D^2 = 81\%$, $p < 0.01$). Regarding nesting site, the frequencies of the functional groups (ground, no-nest, exposed, and cavities) were similar but the richness of no-nest pollinators was higher (GLM, $D^2 = 75\%$, $p < 0.01$).

The frequency and richness of the majority of pollinator functional groups were lower in *R. mangle*, compared to other mangrove species (Fig. 3-4). *C. erectus* denoted lower frequencies of bees, big and medium-sized, florivorous and cavity-nesting pollinators, as well as a lower richness of cavity nesters. The lower frequencies in *C. erectus* were replaced by higher frequencies of beetles and saprophagous pollinators. *L. racemosa* also differed from *A. germinans* by the lower frequency of medium-sized pollinators (GLM results in Appendix Table 1).

Among interaction networks, the number of interactions varied between 63 and 156 ($\bar{X} = 111$), the number of pollinator species between 24 and 55 ($\bar{X} = 39$), interaction diversity between 2.48 and 3.74 ($\bar{X} = 3.05$), interaction evenness between 0.60 and 0.75 ($\bar{X} = 0.65$) and network specialization between 0.19 and 0.86 ($\bar{X} = 0.49$).

Mangrove patch size and surrounding land use effects

Several functional groups were affected by mangrove patch size and land use (Table 1). Mangrove patch size negatively affected the richness of wasps and ground-nesting pollinators. Urban size also showed negative effects on the richness of wasps, large-sized insects, predators, and ground-nesting pollinators, as well as on the frequency of large-sized pollinators. A positive effect of urban size on the frequency of exposed-nesting pollinators was additionally found. Cropland size was positively related to the frequency of beetles and saprophagous pollinators.

At the network level, the number of interactions and pollinator species, interaction diversity and interaction evenness were not affected by mangrove patch size or surrounding land use. However, network specialization was positively related to mangrove patch size (GLM, $p < 0.01$, Table 1).

Discussion

The mangrove pollinator communities comprised a variety of functional groups (Fig. 2). Considering pollinator guilds, these were mainly characterized by the higher frequencies of wasps, bees (mainly the exotic species *Apis mellifera* L.), and flies, including also higher richness of flies and wasps. Studies have found similar guild compositions in other neotropical mangroves (Landry and Rathcke, 2012; Sánchez-Núñez & Mancera-Pineda, 2012; Landry, 2013a-b; Nadia & Machado 2014a-b), however, such guild composition contrasts with that in other lowland tropical ecosystems where bees are the predominant pollinators (Ollerton 2017), probably because the low floral diversity of mangrove forests is not sufficient for sustaining bee populations (Heithaus 1979; Ollerton 2017). Mangrove pollinators were also predominantly small and medium-size, according to the small and medium-sized mangrove flowers. Regarding feeding preference, predator and saprophagous pollinators were predominant in frequency and richness. The prevalence of these functional groups demonstrates that the importance of mangrove pollinators is not only related to their pollination function, but also as they are involved in other ecological processes like biological control and decomposition, and therefore nutrient recycling. Pollinator groups with different levels of sociality and nesting sites were similar in frequency. However, there were higher proportions of no-social and no-nesting species due to the predominance of fly species in mangrove communities.

The pollinator functional composition varied between the mangrove species. The interaction frequency of the different functional groups was much smaller in *R. mangle*, since it is mainly wind pollinated and potentially less rewarding to visitor insects (Sánchez-Núñez and Mancera-Pineda 2012; Nadia and Machado, 2014b). *C. erectus* also differentiated by lower frequencies of bees, medium and large-sized insects, cavity nesters, social and florivorous pollinators (Fig. 3). Conversely, this species interacted more frequently with saprophagous beetle pollinators (given the overabundance of *Oxacis* beetles in the Cordoba site, Fig. 4), and fly species, although not significantly (Fig. 3B). Nadia and Machado (2014a) also observed in Brazil, that *C. erectus* was much less visited by bees than *L. racemosa*. However, in that region, *C. erectus* did not interact with beetles, but did with a fly species that performed around 70% of interactions. The lower visitation from bees in *C. erectus* might be attributed to the small nectar amounts offered by its tiny flowers, which were probably enough for small beetles and flies but not for food-storing insects like bees (Nadia and Machado 2014a).

The differences in pollinator functional composition of *R. mangle* and *C. erectus* suggest niche partitioning that could be driven by competition for pollinators, probably because of their larger flowering periods that overlap with those of other species (Nadia et al., 2012; Nadia and Machado 2014a-b). In contrast, *A. germinans* and *L. racemosa* exhibited more similarity in their pollinators, as they probably avoid competition by flowering in different periods throughout the year (Landry, 2013a). Despite this, *A. germinans* differentiated from *L. racemosa*, in that this species interacted more frequently with medium-sized pollinators (mainly *A. mellifera*), probably because of its larger nectar amounts. Ayala-Viloria and Fiorenzano-Camacho (2003) also recorded two hummingbird species that were strongly related to the flowering periods of *A. germinans*.

Interaction networks showed relatively high numbers of interactions and pollinator species, in spite of the low floral diversity of mangroves. This result contradicts the global correlation between plant and pollinator diversity (Olerton 2017), and the lower number of interactions per plant species toward the tropics (Olesen & Jordano 2002; Vizentin-Bugoni *et al.* 2018). Mangrove pollinators were diverse probably because many important pollinators rely on resources different from plants, such as decomposing materials and preys, which are abundant in mangrove ecosystems (Yeo *et al.* 2021). Interaction diversity and interaction evenness were also high, demonstrating that the interaction networks were relatively complex and symmetric, with more or less similar interaction frequencies between species pairs (Blüthgen, 2010). These results seem to reflect high connectivity and niche overlap between the interacting species, which may be due to the low floral diversity that probably forced pollinators to similarly exploit the available mangrove resources. Network specialization, however, denoted an intermediate mean value and varied more locally in response to the landscape variables (see discussion below).

Effects of mangrove patch size and surrounding land use

The overall frequency and richness of mangrove pollinators did not vary in response to habitat patch size or land use. However, their functional composition did vary, showing species turnover at the regional scale. In the first place, mangrove patch size was negatively related to the richness of wasps and ground-nesting pollinators (Table 1). Such effects were probably due to the autocorrelation between landscape heterogeneity and mangrove patch size (Pearson's $r = -0.86$, $p < 0.05$). Landscape heterogeneity surrounding small-sized mangrove patches may have benefited ground-nesting pollinators through higher availability of other ground substrates in closed environments (e.g. Williams *et al.* 2010; Szczepko *et al.* 2020) since these species probably could not nest in unstable mangrove substrates that are exposed to tidal waves and flood events. The mangrove patch size effect on wasps is explained by their correlation with ground-nesting, since other wasps that nest in different substrates were not significantly affected (GLM, $p > 0.05$), and 78% of the ground-nesting group corresponded to wasp species.

Urban size negatively affected the richness of wasps, large-sized insects, predators, and ground-nesting pollinators, as well as the frequency of large-sized pollinators. Urban size drove ground-nesting pollinator richness, maybe due to the increasing pavement that makes nesting sites inaccessible for them (Zanette *et al.* 2005; Geslin *et al.* 2013; Wenzel *et al.* 2020; Fenoglio *et al.* 2021). Ground-nesting responses were mainly reflected on wasps given the correlation between these functional groups. The negative effect on predator pollinators might be explained by their reliance on several food resources (prey for the larvae, floral resources for the imagoes), and on the dynamics of their preys (Holt *et al.* 1999; Burkle *et al.* 2013; Burkman and Gardiner 2014; Burks and Philpott 2017; Corcos *et al.* 2019; Fenoglio *et al.* 2021).

The negative response from large-sized pollinators supports the general trend toward smaller-sized insects in the warmer climates of urban areas, i.e., urban heat island effect (Merckx *et al.* 2018; Fenoglio *et al.* 2021). Large-sized ectotherms are expected to be more vulnerable to overheating in warmer areas

due to higher metabolic rates (Gardner *et al.* 2011). However, large insects with higher dispersal capacity are presumed to respond the opposite to urbanization, since only they would be able to fly long distances to reach the small forest fragments in urban areas (Fortel *et al.* 2014; Harrison and Winfree, 2015; Merckx *et al.* 2018). In the present study, the larger species were negatively affected by urban size despite their higher flying capacity. Other likely causes could be, the greater space and food requirements of large pollinators, their probable higher specialization on larger preys and flowers, and the presence of local urban barriers that impede long-distance dispersal (Warren and Lawton 1987; Reynolds, 2003; Corcos *et al.* 2019; Eggenberger *et al.* 2019; Fenoglio *et al.* 2021; Raiol *et al.* 2021).

Urban size positively affected the frequency of an exposed-nesting wasp (*Polybia occidentalis venezuelana*) which is known for its adaptability to disturbed environments (Zanette *et al.* 2005; Hernandez *et al.* 2009). Cropland size also increased the frequency of two saprophagous beetle species (genus *Oxaxis*) in one study site (Cordoba, Figs. 1, 4). These land use effects increased the overall frequency of the exposed-nesting, beetle and saprophagous functional groups (Table 1). However, since these effects were specific to the named species, they cannot be generalized to their functional groups.

The structure of the interaction networks little varied between sites in spite of changes in pollinator functional composition. The number of interactions and pollinator species, interaction diversity, and interaction evenness were not affected by mangrove patch size or land use. However, while the number of interactions and pollinator species considerably varied independently from landscape variables, interaction diversity and interaction evenness were rather stable between sites. This was probably because the strongest interactors were maintained, or the remaining species switched their interaction partners, this way recovering lost interactions and conserving network structure (Kaiser-Bumbury *et al.* 2010).

In contrast, network specialization was negatively affected by mangrove patch size. A lower specialization in smaller mangroves might be explained by the loss of rare specialist species, or the diet breadth expansion in some pollinators due to faster resource depletion (Fontaine *et al.* 2008; Weiner *et al.* 2014; Winfree *et al.* 2014). Additionally, the more heterogeneous landscapes surrounding smaller mangroves could have promoted the arrival of generalist species (Geslin *et al.* 2013; Moreira *et al.* 2015). The higher richness of ground nesting wasps that was observed in smaller mangroves may have contributed to increasing network generalization, considering that ground nesting pollinator interactions were not segregated towards any mangrove species (Fig. 3).

Conclusions

The pollinator communities in these Neotropical mangrove forests were found to be functionally diverse assemblages of species, which are important for preserving the functionality of these threatened ecosystems. Their functional composition differed from other lowland tropical ecosystems, being in line with the unique functions and processes that characterize mangrove ecosystems. Plant-pollinator

interactions demonstrated a trend to niche differentiation in *C. erectus* and *R. mangle*, an unexpected high pollinator: mangrove species ratio, as well as high interaction diversity and evenness.

Pollinator functional composition was affected by the studied landscape variables. Mangrove patch size decreased the richness of ground nesting wasps, whereas urban size decreased the richness of predators, large-sized species, and ground-nesting wasps. These effects, however, were little reflected on the interaction network structure, since the number of interactions and pollinator species, interaction diversity and interaction evenness were not affected by mangrove patch size or land use. However, an increase in network specialization with mangrove patch size was observed, which was probably related to the higher ground nesting wasp richness in smaller mangroves.

Our results revealed the importance of landscape connectivity, and highlight urban size, rather than cropland size, as the main threat to pollinator functional composition and plant-pollinator interaction networks in mangrove ecosystems. To offer practical solutions to sustainable, inclusive and nature-positive urban development, and at the same time enhance the pollination function in remnant mangroves at the cities, conservation and restoration strategies should focus on the mitigation of warming climates and the provisioning of soil nesting substrates and food resources for predator and large-sized pollinators in urban areas. Further research should consider the study of the cascade effects of changes in pollinator functional composition and interaction networks on the reproductive fitness and the genetic diversity of mangrove species.

Declarations

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Table 1

Table 1. Land use effects on the frequency and richness of pollinators in overall and segregated into different functional groups, and on the interaction networks. Only coefficients with significant effects ($p <$

0.05) in the generalized linear models are presented. Coefficients out of parenthesis indicate significant effects on pollinator frequency and coefficients within parenthesis indicate significant effects on pollinator richness. R^2/D^2 : Explained variance/deviance.

Response Variable		Mangrove	Urban	Cropland	R^2/D^2
Guilds	Wasps	(-0.9)	(-1.0)	-	(12%)
	Flies	-	-	-	-
	Bees	-	-	-	-
	Beetles	-	-	1.0	20%
	Lepidopterans	-	-	-	-
Body size	large	-	-1.0 (-1.0)	-	18% (18%)
	medium	-	-	-	-
	small	-	-	-	-
Feeding preference	predator	-	(-1.0)	-	(4%)
	saprophagous	-	-	1.0	9%
	florivorous	-	-	-	-
	phytophagous	-	-	-	-
Sociality	social	-	-	-	-
	no-social	-	-	-	-
Nesting site	ground	(-0.8)	(-1.0)	-	(27%)
	cavities	-	-	-	-
	exposed	-	1.0	-	12%
	no nest	-	-	-	-
Interaction networks	Number of interactions	-	-	-	-
	Number of pollinator species	-	-	-	-
	interaction diversity	-	-	-	-
	interaction evenness	-	-	-	-
	specialization H2	0.1	-	-	74%

Figures

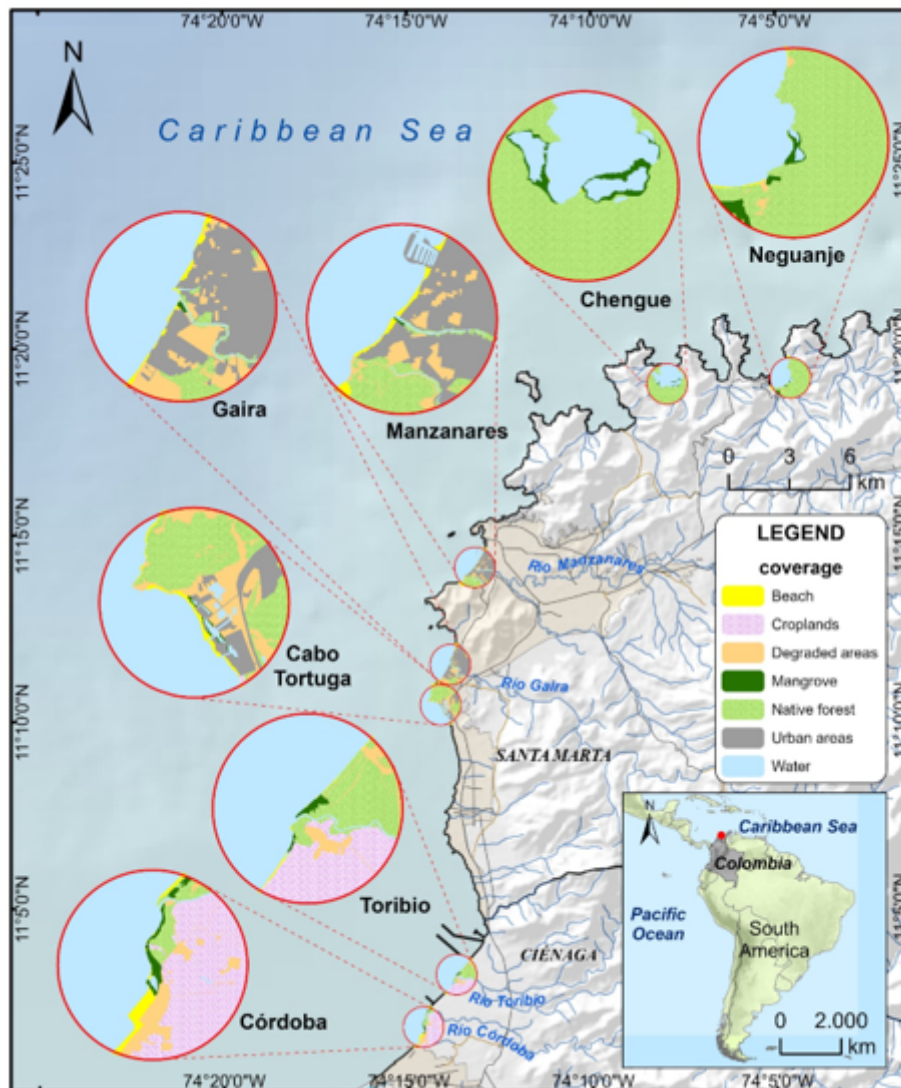


Figure 1

Map of the study area showing the location of the sampled mangrove patches in the Caribbean coast of Colombia. The figure shows the distribution of vegetation cover types in 1000 m radii landscapes around the mangrove patches.

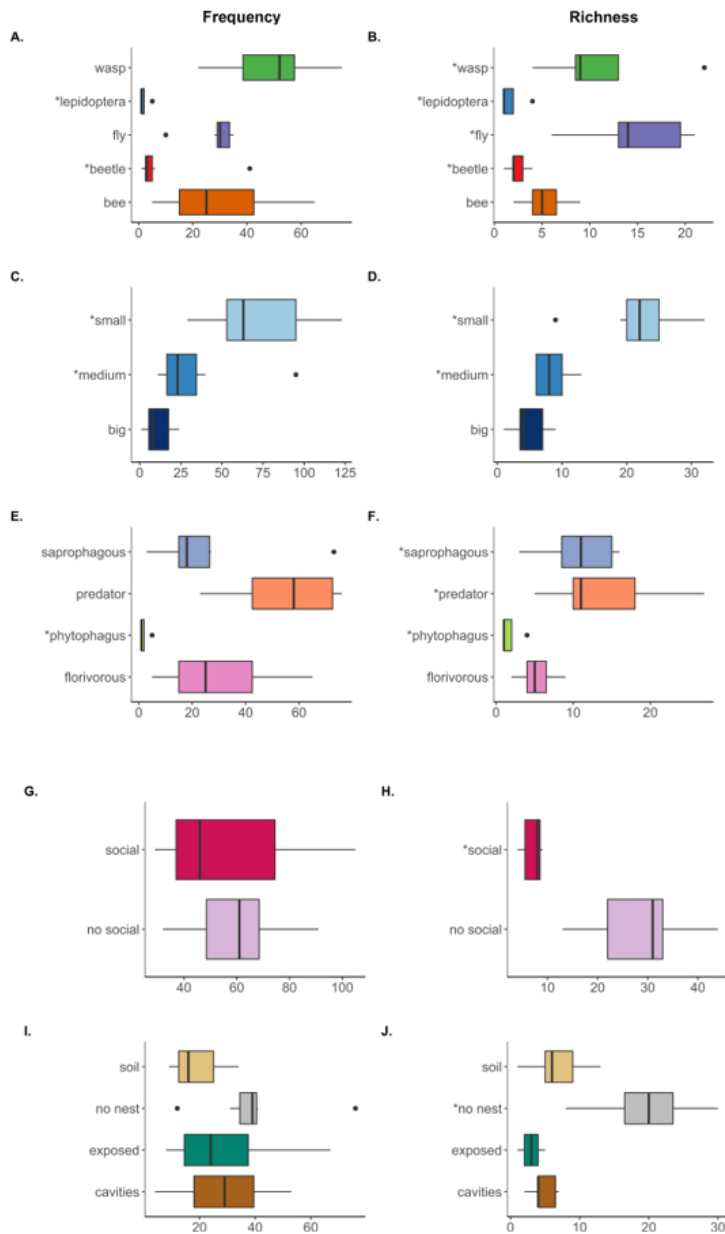


Figure 2

Frequency and richness of pollinator functional groups from the mangrove patches sampled in the Caribbean coast of Colombia. Central boxes span the first quartile to the third quartile (the inter-quartile range or IQR). Segments inside the boxes show the mean, respectively, while whiskers show the location of the smallest and the largest values no further than 1.5 x IQR from the first and the third quartiles. Black dots indicate outliers, data beyond the whiskers. Asterisks (*) in y-axis labels denote significant

differences in frequency or richness between functional groups in the generalized linear models ($p < 0.05$).

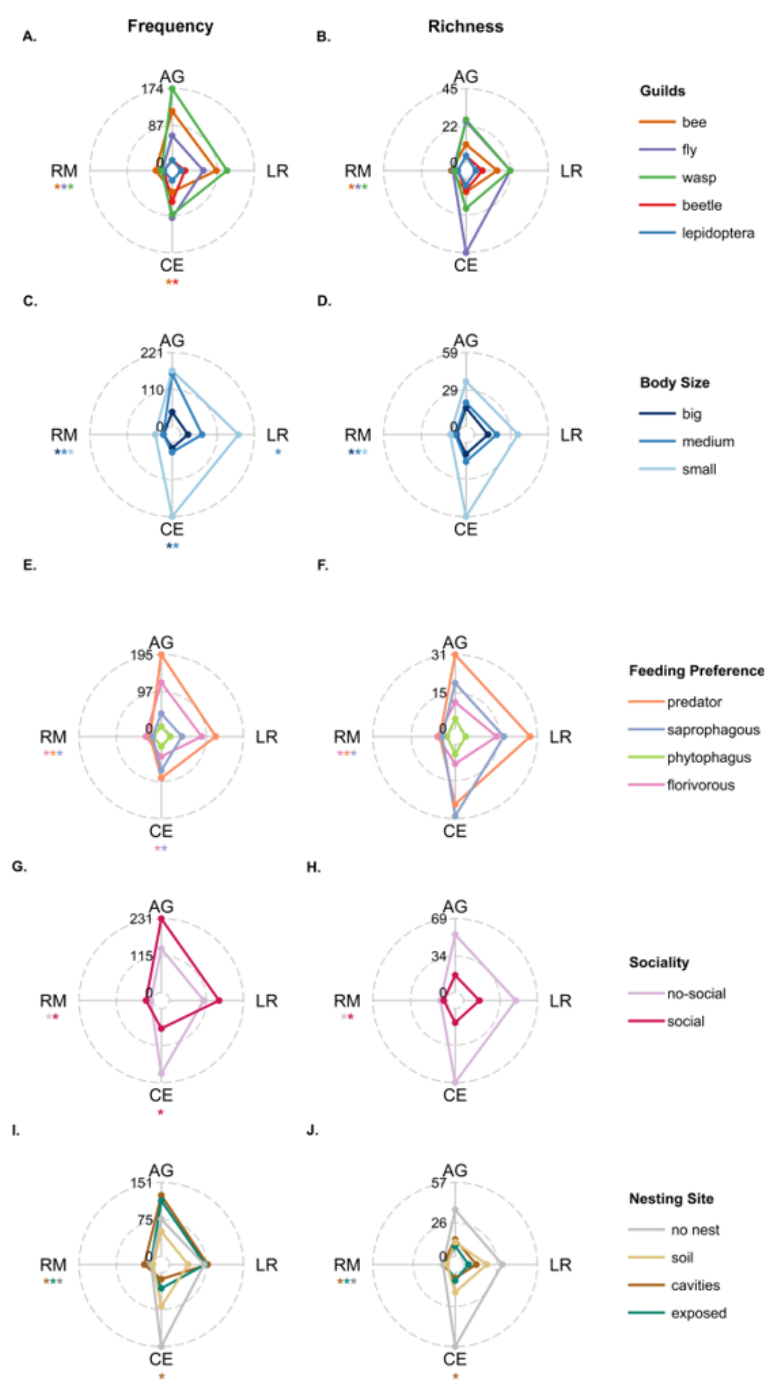


Figure 3

Frequency and richness of the pollinator functional groups that visited the mangrove species, *Avicennia germinans* (AV), *Laguncularia racemosa* (LR), *Conocarpus erectus* (CE), and *Rhizophora mangle* (RM).

Asterisks (*) denote significant differences in frequency and richness of pollinator groups between mangrove species in the generalized linear models ($p < 0.05$).

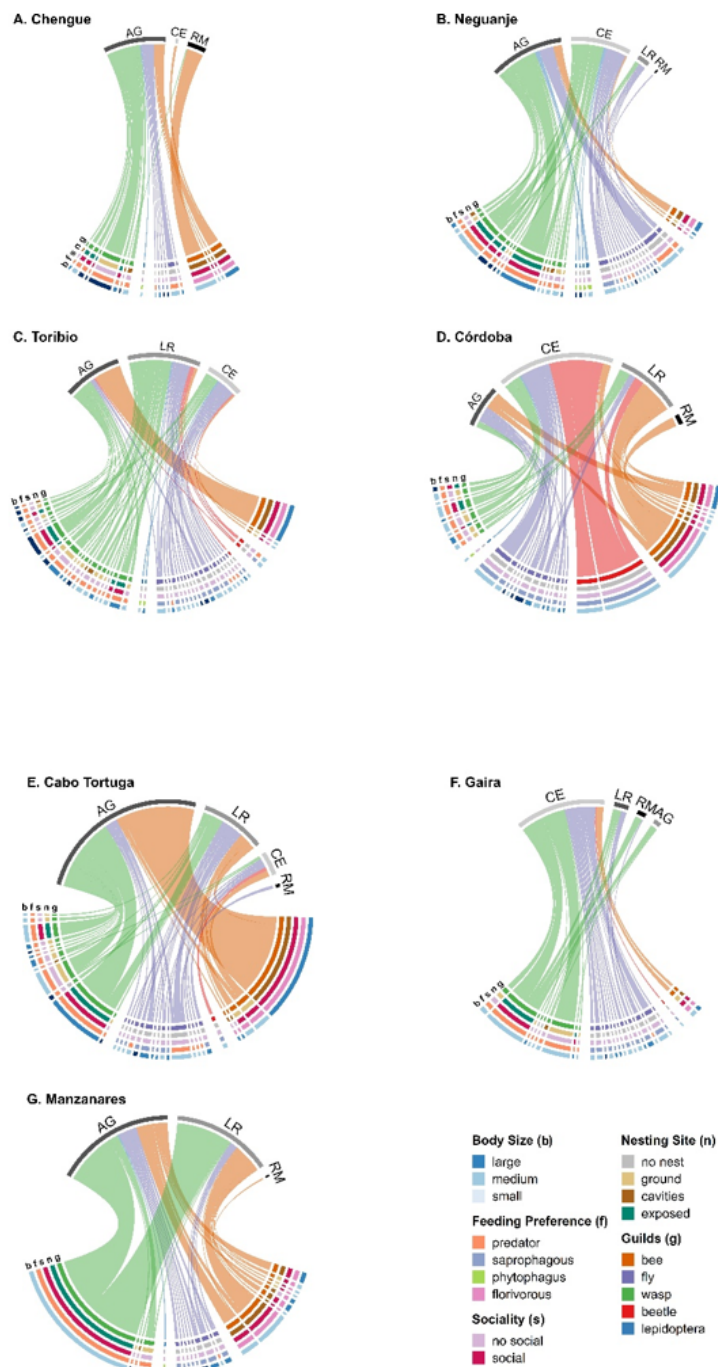


Figure 4

Plant-pollinator interaction networks in the mangrove patches sampled in the Caribbean coast of Colombia. Subtitles correspond to site location in figure 1. The colored grids at the lower side of the

networks illustrate the distribution of functional attributes among the pollinators that interacted with the mangrove species: *Avicennia germinans* (AV), *Laguncularia racemosa* (LR), *Conocarpus erectus* (CE), and *Rhizophora mangle* (RM). The number of compartments represents the number of pollinator and mangrove species in each network. The compartment length represents the pollinator frequency.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [AppendixTable1.docx](#)