



Tri-trophic networks of plants, gall-inducers, and micro-hymenopterans in tropical forests of the Peruvian Amazon

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Abstract

Interactions between host plants, insect herbivores, and parasitoids are fundamental to understanding ecosystem dynamics. In the present study, we describe the network structure of assemblages composed of host plants, galling insects, and micro-hymenopterans in four vegetation types in two protected areas in the Peruvian Amazon. In total, we recorded 13 host plant species, 20 species of galling insects and 31 taxa of micro-hymenopterans. The network of host plants and galling insects in the white sand-wet forest was very specialized, characterized by low connectance, low linkage density and higher modularity than expected based on the null model, compared to other vegetation types. The galling-micro-hymenopteran interactions in the *terra firme* and white-sand wet forest were characterized by lower connectance, lower linkage density and higher modularity than expected based on the null model. Our findings show that the high specialization in the plant-gall insect and gall insect-micro-hymenopteran networks reported in other biomes is also found in the Peruvian Amazon.

Keywords Diptera · Insect galls · Plant-galling interaction · Rainforest · Specialization

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Introduction

Gall-inducing insects have intimate associations with their host plants, manipulating plant tissues to create unique structures known as galls (Miller and Raman 2019). These galls serve as specialized habitats that provide shelter, nutrients, and protection for the developing insect larvae (Csóka et al. 2017). However, despite these benefits, gall-inducing insects face a suite of natural enemies, such as parasitoids (Costa-Resende et al. 2021). These parasitoids are organisms that exploit the gall insects as hosts for their own development, often resulting in significant impacts on gall insect populations and influencing the dynamics of their interactions with host plants (Leite et al. 2021). This interplay between gall-inducing insects, their host plants, and parasitoids underscores the complexity of ecological relationships in natural ecosystems.

The structure of interactions in plant-galling networks has been documented more in temperate regions (Cuevas-Reyes et al. 2007; Araújo et al. 2017; Araújo & Kollár 2019; Maldonado-López et al. 2022; Fang et al. 2024) than in Neotropical forests (Araújo and Maia 2021a,b). Studies on these networks have revealed a high degree of specificity, with many gall-inducing insects associated with a single host plant species (Cueva-Reyes et al. 2007; Oliveira et al. 2020; Tahar-Chaouche et al. 2021; Araújo and Maia 2021a). Furthermore, these networks are characterized by poorly connected and highly modular structure (Araújo et al. 2017). For instance, a previous study performed in a Brazilian restinga, has shown that plant-galling networks exhibit low values of connectivity and high modularity due to high level of monophagy of galling species (Araújo and Maia 2021b).

While plant-galling networks are characterized by high specialization, galling-parasitoid interactions are more connected (i.e., with a greater number of interactions), and less modular due to the presence of generalist parasitoids (Cuevas-Reyes et al. 2007; Araújo and Maia 2021b; Fang et al. 2024). Schönrogge and Crawley (2000) found that in cynipid-parasitoid food webs in temperate forests, the parasitoids were somewhat more polyphagous, resulting in slightly higher realized connectance. Similarly, Cueva-Reyes et al. (2007) found no specificity between parasitoid species and their host galling insect species in temperate forests in Mexico. In contrast, some studies show that galling-parasitoid interactions also exhibit high modularity and low connectivity in tropical ecosystems. For instance, Paniagua et al. (2009) found that galling-parasitoid network in the tropical rainforest of Panamá, most parasitoid species were host-specific, and the few polyphagous parasitoid species were restricted to the understory. Another study (Prauchner and Mendonça 2024) found that gall structure,

taxonomy of gall-inducers, host plant identity and gall-plant interaction are important factors shaping the modularity of galling insect-parasitoid networks. Among these, the taxonomy of gall-inducers and host plant identity were identified as the strongest determinants of parasitoid host selection. These findings highlight the complex nature of interactions in galling-parasitoid networks across various taxa and geographic regions, influencing the modularity and connectivity of these interaction networks.

Tritrophic networks display varying levels of modularity and specialization, depending on habitat characteristics and trophic level (Araújo and Maia 2021b; Maldonado-López et al. 2022; Zhang et al. 2023). The Peruvian Amazon is characterized by diverse vegetation types and habitats, influenced by factors such as topography, hydrology, and soil characteristics (Shepard et al. 2001). For instance, white-sand forests locally known as “varillales”, are unique ecosystems characterized by low species diversity and high endemism (Fine et al. 2010). These forests occur on nutrient-poor soil, with many endemic species adapted to the extreme edaphic conditions (Fine et al. 2010). White-sand forests are classified based on canopy height, drainage, and organic layer thickness, and can be categorized as wet or dry white-sand forests (García-Villacorta et al. 2003). Palm swamp forests are ecosystems adapted to seasonal flooding, which influences their soil properties and species composition (Myster 2017; Draper et al. 2018). Hydrological conditions, particularly flood levels and water table depth, play a crucial role in determining tree species (Llampazo et al. 2022). These forests have extremely low alpha-diversity compared to other Amazonian forest types (Draper et al. 2018), but they contribute to regional beta-diversity due to their unique species composition. *Terra firme* forests are characterized by high species richness and diversity, which is attributed to fertile soils, abundant habitat availability, and a diversity of climatic and edaphic conditions (Tuomisto et al. 2014). The combination of nutrient-rich soils and varied microenvironments supports a wide range of plant and insect species, contributing to the overall complexity and ecological interactions within these forests (Julião et al. 2014).

In the present study, we describe the network structure involving host plants, galling insects, and micro-hymenopterans across four vegetation types in two protected areas of the Peruvian Amazon. To characterize the network structure, we used topological descriptors such as connectance, linkage density, and modularity (Dormann et al. 2009). Linkage density provides insight into the average number of connections maintained by each species and serves as an indicator of interaction intensity within the system. Connectance reflects how interconnected the network is (i.e., a greater number of realized interactions relative to the total possible), while modularity describes the extent to

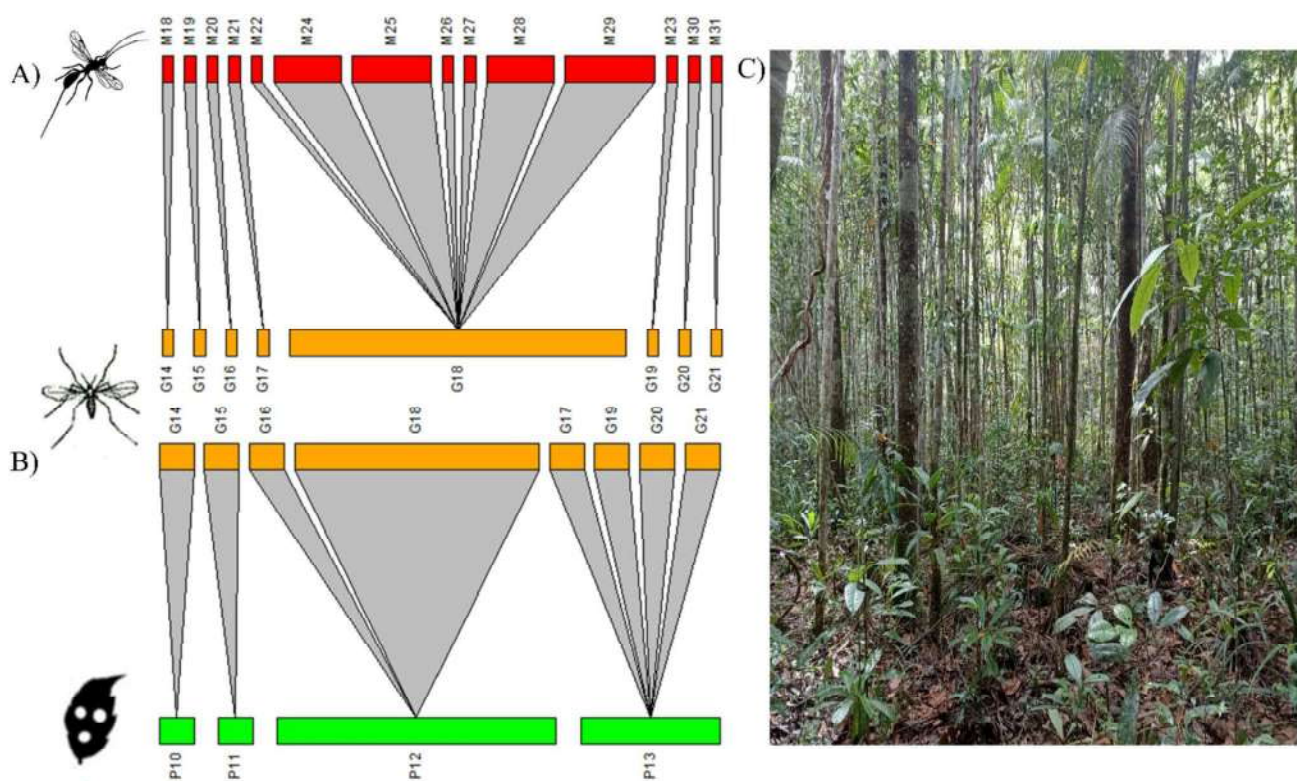


Fig. 1 Bipartite networks of (A) gall insect species (orange bars) and micro-hymenopteran (red bars), and (B) host plants (green bars) and gall-inducing species (orange bars) in the white-sand wet forest (C) in the Peruvian Amazon. The gray bars represent the number of interactions.

Species codes correspond to abbreviations of each host plant (P), gall-inducing species (G), and micro-hymenopteran (M) registered in this study (see Table 1SI)

which the network is organized into densely connected subsets of species (i.e., modules) (Olesen et al. 2007). In this context, we tested the following predictions: (1) Networks composed of host plants and gall-inducing insects are expected to exhibit lower connectance, lower linkage density, and higher modularity in the white-sand dry forest compared to other forests. This due to fact that white-sand dry forests have poorer soils and lower plant diversity, which limits the variety of plant species and consequently reduces potential interactions between plants and gall-inducing insects, (2) galling-parasitoid networks are predicted to have higher connectance, linkage density, and lower modularity in the *terra firme* forest compared to other forests, characterized by with soils rich in nutrients, and wide availability of niches and ecological resources.

Materials and methods

Study area

The study was carried out in both the Allpahuayo-Mishana National Reserve (3.967334° S, 73.418967° W) and the Quistococha Regional Reserve (3.829767° S, 73.322217°

W), located southwest of the city of Iquitos, in the department of Loreto in the Peruvian Amazon. The reserves have a tropical humid climate with a mean annual temperature and precipitation of 26 °C and 3,087 mm, respectively. High precipitation is frequent between January and April, and less frequent between June and September (Marengo 1998).

The Allpahuayo-Mishana National Reserve is characterized by an exceptionally diverse mosaic of soil types, ranging in texture from clay to mixed sandy/clay soils, and even nearly pure sand (Vásquez and Phillips 2000). This wide range of edaphic heterogeneity supports a highly diverse flora, with 1,729 plant species distributed in 61 plant families, the most representative being Fabaceae, Moraceae, Lauraceae, Annonaceae, and Burseraceae (Vásquez and Phillips 2000). In contrast, the Quistococha Regional Reserve features extensive palm swamp forests, locally known as “aguajales”. These forests occur on poorly drained soils that are often seasonally or intermittently inundated by the floodwaters of major rivers (Junk et al. 2011; Griffiths et al. 2020). The vegetation in this area is dominated by the arborescent palm *Mauritia flexuosa* (Arecaceae) and is surrounded by vegetation mainly composed of botanical families such as Bignoniaceae, Clusiaceae, and Euphorbiaceae (Roucoux et al. 2013; Bhomia et al. 2019).

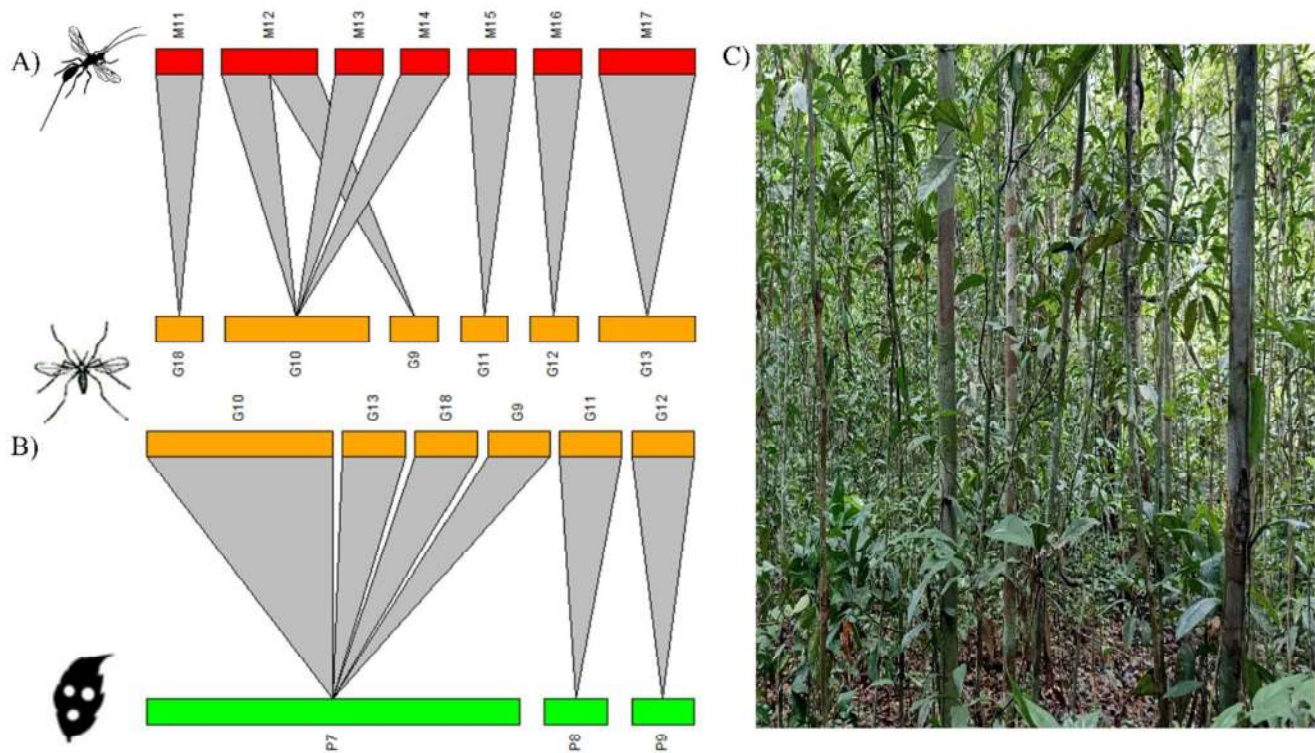


Fig. 2 Bipartite networks of (A) galling insect species (orange bars) and micro-hymenopteran (red bars), and (B) host plants (green bars) and gall species (orange bars) in the white-sand dry forest (C) in the Peruvian Amazon. The gray bars represent the number of interactions

In total, 32 sampling plots were established, of which 24 were in the Allpahuayo-Mishana National Reserve (8 plots in terra firme forest, 8 plots in white-sand wet forest, 8 plots in white-sand dry forest) and 8 plots were in the Quistococha Regional Reserve (all in palm swamp forest).

Data sampling

Samples of host plants, galling insects, and micro-hymenopteran were collected bi-monthly from December 2021 to December 2022 across four vegetation types. For each vegetation type, we established 8 plots of 5 × 20 m, separated from one another by 20 m, totaling 800 m² sampled for each site (see more details in Grandez-Rios et al. 2023).

The host plants within each vegetation type, with a diameter at breast height (dbh, 1.3 m) equal to or greater than 10 cm were collected and identified to species as part of a previous floristic project. Their identifications were sourced from the ForestPlots.net online database (Lopez-Gonzalez et al. 2011; ForestPlots.net et al. 2021). We used gall morphotypes as surrogates for galling insect species. This approach is widely adopted in the literature, as gall-inducing insects typically produce distinct gall morphologies on specific host plant species, reflecting a high degree of host specificity (review in Araújo et al. 2021c). Gall morphotypes were

identified based on morphological characteristics, including shape, color, presence of trichomes, number of chambers, and the host plant organ attacked, following the methodology proposed by Isaias et al. (2013). Each gall morphotype were dissected using a stylet to observe the number of internal chambers and obtain the immature insects (larvae and pupae). Additionally, each gall morphotype was placed in a closed transparent plastic pot, labeled and with moistened paper at the bottom. These containers were monitored daily to record the emergence of adult insects, including both male and female gall-inducers as well as associated micro-hymenopterans. For micro-hymenopteran, only specimens identified to the genus level were considered. The data were obtained from Grandez-Rios et al. (2023). Prior to identification, the specimens were dried using the technique described by Pérez-Benavides et al. (2023), which involves treatment with amyl acetate. Taxonomy identification was carried out using a stereoscopic microscope and the following keys: Masner (1976) for the family Scelionidae, Masner and Huggert (1989) for the family Platygasteridae, Gibson et al. (1997) to subfamily Chalcidoidea, and Wharton et al. (1997) to the family Braconidae.

Data analyses

Quantitative trophic networks were constructed separately for each vegetation type using two bipartite networks. The first network analyzed the interactions between host plants and galling species based on frequency, while the second network examined the interactions between galling species and micro-hymenopteran based on abundance. In our analyses, we only considered host plants and galling species that had records of micro-hymenopterans.

To characterize the interaction structure of the networks, we used the following network descriptors: connectance, linkage density and modularity. Connectance (C) was calculated as the number of observed interactions divided by the number of possible interactions in the network (Dormann et al. 2009). Connectance ranges from 0 (no connected) to 1 (totally connected) (Dormann et al. 2009). Linkage density (L) is the average number of interactions per species in the network. Modularity (M) is a measure of the presence of modules that are more densely connected internally than with the rest of the network (Dormann et al. 2009). The modularity ranged from 0 (non-modular) to 1 (perfectly modular), and was calculated using the *computeModules* function of the *bipartite* package (Dormann et al. 2008).

To test the significance of network descriptors for the different bipartite networks, we use null models with 999 repetitions generated by the *r2dtable* algorithm (Dormann

et al. 2009). The values generated by the null models for each bipartite network are presented as mean $\pm$ SD (standard deviation). The probability of observed values occurring within the distribution of null values was used to determine the P -value for each descriptor. The values for each descriptor in the two bipartite networks, as well as all null models, were calculated using *bipartite* and *vegan* packages (Dormann et al. 2008) in the R software version 4.4.0 (R Development Core Team 2024).

Results

In total, we recorded 13 host plant species, 20 galling insect species (gall morphotypes), and 31 micro-hymenopteran taxa (Table 1SI). *Caraipa utilis* and *Micrandra elata* hosted the highest number of gall morphotypes, with four each. Eulophidae and Eurytomidae were the most diverse micro-hymenopteran families, with 11 and 5 species. The most abundant taxa were Tetrastichinae sp. 1 (24 individuals) and *Allorhogas* sp. 1 (8 individuals) (Table 1SI).

The white-sand wet network (Fig. 1B) was the most representative, featuring eight galling species and four host plant species, followed by white-sand dry (Fig. 2B), *terra firme* (Fig. 3B), and palm swamp (Fig. 4B) networks (Table 1). The observed connectance did not differ from the null model for *terra firme* ($C=0.25$), white sand-dry ($C=0.333$) and

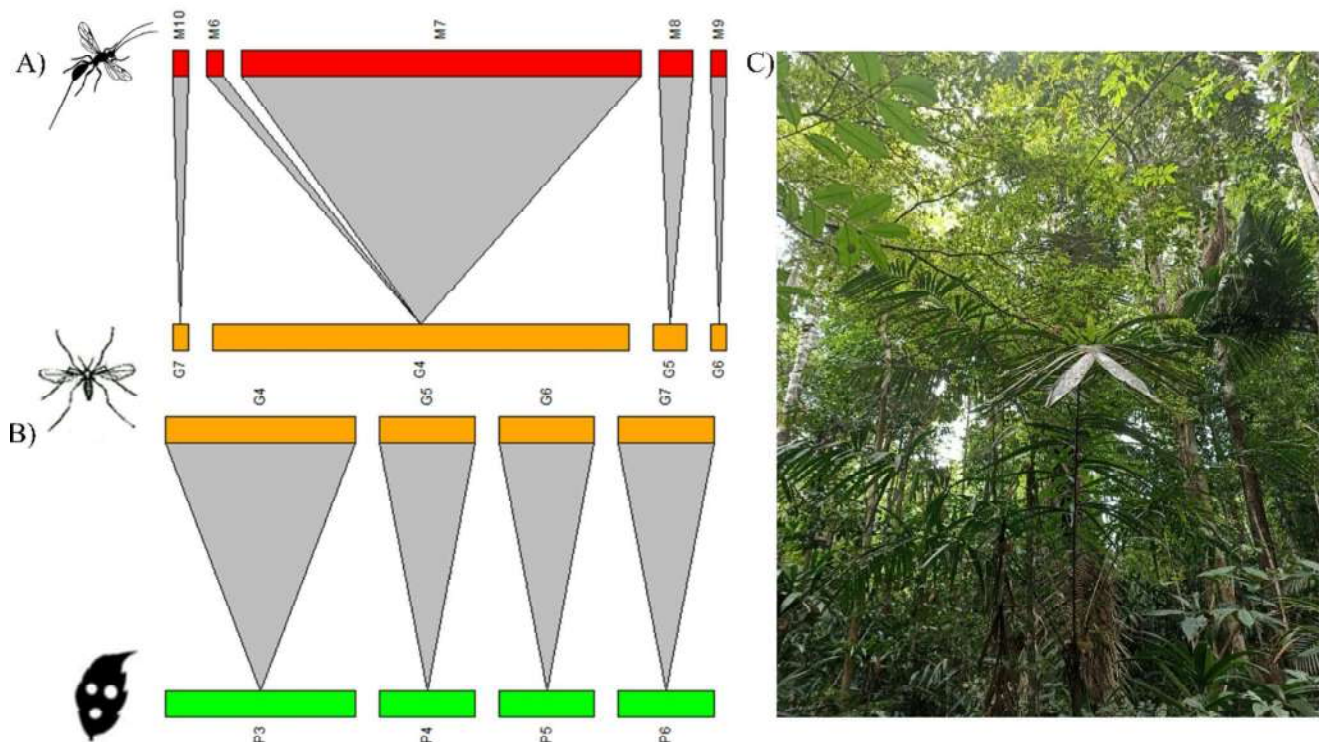


Fig. 3 Bipartite networks of (A) galling insect species (orange bars) and micro-hymenopteran (red bars), and (B) host plants (green bars) and galling species (orange bars) in the terra firme forest (C) in the Peruvian Amazon. In both figures, gray bars represent the number of interactions

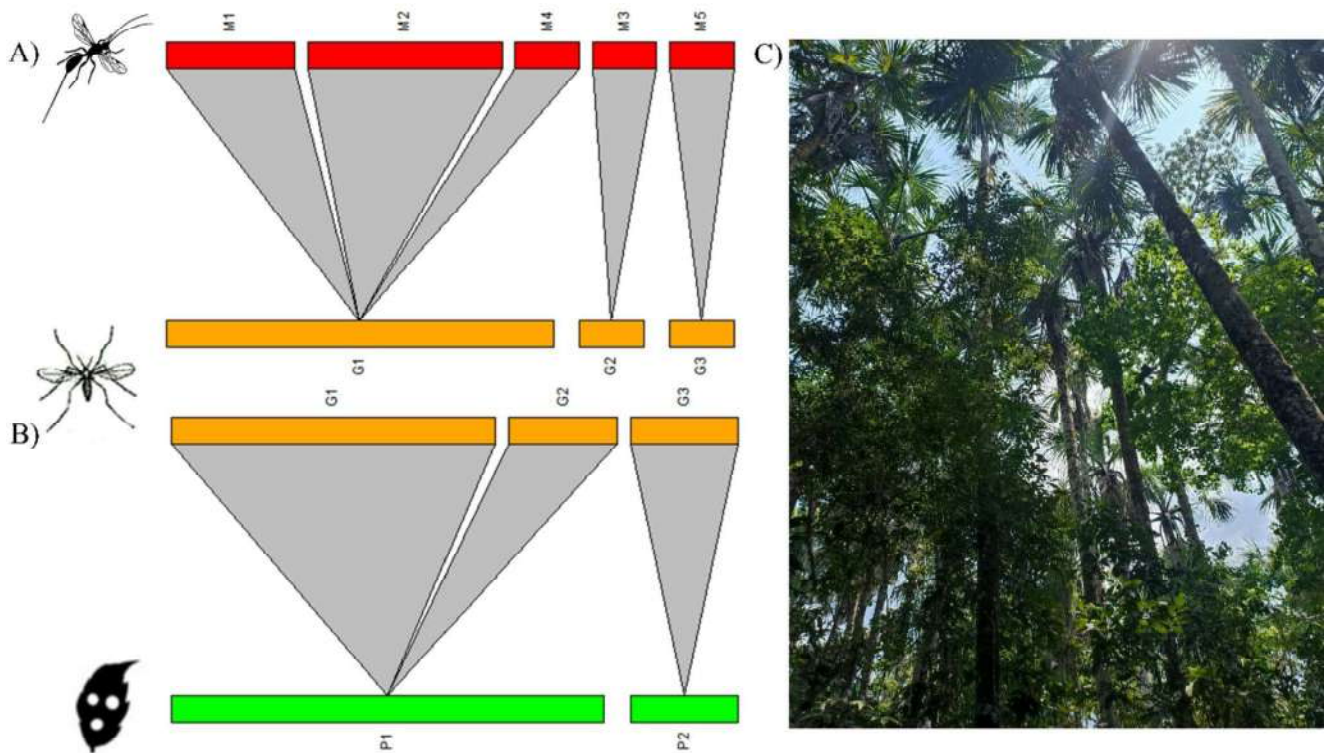


Fig. 4 Bipartite networks of (A) gall insect species (orange bars) and micro-hymenopteran (red bars), and (B) host plants (green bars) and galling species (orange bars) in the palm swamp forest (C) in the Peruvian Amazon. The gray bars represent the number of interactions

Table 1 Species richness at higher and lower trophic levels in host plant-galling and galling-micro-hymenoptera networks, across four vegetation types in the Peruvian Amazon

Networks	Vegetation type	Higher trophic level richness	Lower trophic level richness
Plant-galling networks	Terra Firme	4	4
	White-sand dry	6	3
	White-sand wet	8	4
	Palm swamp	3	2
	Terra Firme	5	4
Galling-micro-hymenoptera networks	White-sand dry	7	6
	White-sand wet	14	8
	Palm swamp	5	3

palm swamp ($C=0.50$) forests. However, the white sand-wet forest had a lower connectance ($C=0.25$) than expected based on the null model values (Table 2). Similarly, the observed linkage density was also lower for white sand-wet ($L=1.495$) than expected by chance, while the other vegetation types did not differ from the null model (Table 2). The observed values of modularity for the host plant-galling networks were higher for all vegetation types ($M=0.72$, *terra firme*; $M=0.406$, white-sand dry; $M=0.539$, white-sand wet; and $M=0.32$, palm swamp), than expected from the null model values (Table 2).

For the networks of galling species and micro-hymenopterans consisted of 31 micro-hymenoptera taxa and 20 galling species, with a total of 32 distinct interactions (Table 1SI). The white-sand wet network (Fig. 1A) was the most representative with 14 micro-hymenoptera species and eight gall morphotype species, followed by white sand-dry (Fig. 2A), *terra firme* (Fig. 3A) and palm swamp (Fig. 4A) networks (Table 1). Both the observed values of connectance and linkage density were lower for *terra firme* ($C=0.25$, $L=1.079$) and white-sand wet ($C=0.125$, $L=2.761$), than expected by the null models (Table 2). However, the observed values for the other vegetation types did not differ from the null models. Modularity of gall morphotype-micro-hymenopteran interactions was higher for *terra firme* ($M=0.25$), white-sand wet ($M=0.337$), and palm swamp ($M=0.406$) than expected by the null models (Table 2). In contrast, modularity for white-sand dry did not differ from the null models.

Discussion

Our findings show that in the Peruvian Amazon, there is a high level of specialization in the interactions between host plants, galling insects, and micro-hymenopterans. We found that the host plant-galling and galling-micro-hymenopteran

Table 2 Network topology analysis results for host plant-galling and galling-micro-hymenopteran networks across four vegetation types in the Peruvian Amazon

Networks	Vegetation type	Topological descriptor	Observed value	Null value	Null SD	P-value
Plant-galling networks	Terra Firme	Connectance	0.25	0.306	0.018	0.096
	Terra Firme	Modularity	0.72	0.60	0.055	<0.001
	Terra Firme	Linkage density	1.0	1.356	0.126	0.111
	White-sand dry	Connectance	0.333	0.374	0.034	0.353
	White-sand dry	Modularity	0.406	0.348	0.045	<0.001
	White-sand dry	Linkage density	1.924	2.421	0.420	0.352
	White-sand wet	Connectance	0.25	0.316	0.021	<0.001
	White-sand wet	Modularity	0.539	0.304	0.04	<0.001
	White-sand wet	Linkage density	1.495	2.503	0.401	<0.001
	Palm swamp	Connectance	0.50	0.60	0.082	0.397
	Palm swamp	Modularity	0.32	0.224	0.078	<0.001
	Palm swamp	Linkage density	1.301	1.725	0.340	0.392
Galling-micro-hymenopteran networks	Terra Firme	Connectance	0.25	0.395	0.028	<0.001
	Terra Firme	Modularity	0.25	0.066	0.026	<0.001
	Terra Firme	Linkage density	1.079	1.724	0.140	<0.001
	White-sand dry	Connectance	0.190	0.209	0.010	0.216
	White-sand dry	Modularity	0.716	0.680	0.042	0.154
	White-sand dry	Linkage density	1.444	1.604	0.121	0.221
	White-sand wet	Connectance	0.125	0.171	0.009	<0.001
	White-sand wet	Modularity	0.337	0.235	0.022	<0.001
	White-sand wet	Linkage density	2.761	4.386	0.398	<0.001
	Palm swamp	Connectance	0.333	0.413	0.041	0.110
	Palm swamp	Modularity	0.406	0.324	0.043	<0.001
	Palm swamp	Linkage density	1.656	2.293	0.345	0.091

networks have a low linkage density and are not highly connected, but it is very modular. These modules may be formed by plants with similar ecological traits and phylogenetic relatedness (i.e., closely related taxa), which tend to group specific species and their interactions. This pattern suggests significant ecological and phylogenetic constraints that shaping the structure of interactions within the networks. Our results showed that, for the host plant-galling networks, the connectance and linkage density in the white-sand wet forest were lower than expected by the null models. This was not the case for the other vegetation types. Modularity was higher for all vegetation types than expected by the null models, with the highest observed modularity for the *terra firme* forest compared to the other vegetation types.

Networks comprising host plants and galling insects tend to exhibit lower connectance compared to networks involving other groups of herbivorous insects (Oliveira et al. 2020). This is largely attributed to a high incidence of specialist species (i.e., monophagous) within the network (Araújo and Maia 2021a). Our study revealed that the observed connectance in the white-sand wet forest ($C=0.25$) was lower compared to other vegetation types. However, compared to previous studies of networks of host plants and galling insects, the observed value here was higher than those reported by Araújo and Maia (2021a, b) ($C=0.028$ and $C=0.022$, respectively) in a Brazilian restinga, as well as

in temperate forests in Mexico ($C=0.164$) by Maldonado-López et al. (2022). This higher connectance in our results can be attributed to the fact that our network is smaller, as we only included identified interactions between gall-inducing insects and their host plants, as well as micro-hymenopteran. In this context, smaller networks tend to exhibit greater connectance values because the limited number of nodes increases the proportion of realized interactions (e.g., Dunne et al. 2002). Additionally, micro-hymenopterans were identified only to the genus level, which may have further influenced connectance by reducing the number of distinct nodes. While this may limit the generalizability of our findings, we prioritized taxonomic accuracy and consistency across all interaction records, which strengthens the reliability of the observed patterns.

Additionally, our research also showed that white-sand wet forests have low linkage density ($L=1.495$), supporting the pattern observed in other host plants and gall morphotypes networks (Araújo and Maia 2021a,b). These results corroborate with other studies indicating that networks involving host plants and galling species are highly specialized and intimate, resulting in specific plant-galling interactions (Cuevas-Reyes et al. 2007; Araújo et al. 2017). Contrary to expectations, our study showed lower connectance in the white-sand wet forest. This may be attributed to the fact that white-sand forests have poorer soils and

lower plant diversity in the Peruvian Amazon (Fine et al. 2010). The limited variety of plant species in the white-sand forest restricts potential interactions between plants and gall-inducing insects. With fewer plant species available, there are also fewer niches for gall-inducing insects, leading to less diverse communities of galling insects and, consequently, a less dense network of interactions.

On the other hand, unexpectedly, our study observed high modularity in the network of *terra firme* forest ($M=0.72$). This elevated modularity likely stems from the composition and diversity of plant species, which contribute to a heightened degree of modular interactions. Different plant species may support distinct communities of gall-inducing insects with specialized behaviors and adaptations (Cuevas-Reyes et al. 2004). Furthermore, the pattern of high modularity in plant-gall morphotype networks has been documented in other studies (Araújo et al. 2017; Araújo and Maia 2021a,b).

For galling-micro-hymenopteran networks, the connectance and linkage density in the *terra firme* and white-sand wet forest were lower than expected by the null models compared to other vegetation types. Furthermore, the observed modularity was higher in palm swamp forest than expected based on null models, in comparison to other vegetation types. Gall-inducing species and their interactions with micro-hymenoptera are host-specific and highly specialized, with low connectance and high modularity in the tropical forests (Paniagua et al. 2009). In the present study, we found that observed connectance in the *terra firme* ($C=0.25$) and white-sand wet ($C=0.125$) forests were higher than that reported by Araújo and Maia (2021b) (0.049) and Prauchner and Mendonça (2024) (0.079), who sampled networks in Brazilian restingas and subtropical forests, respectively. This high connectance is also due to the inclusion of only those micro-hymenoptera species identified in the interaction networks, as mentioned earlier. However, the linkage density in *terra firme* ($L=1.079$) and white-sand wet ($L=2.761$) forests was lower than that observed by Araújo and Maia (2021b) ($L=8.694$). This low connectance in the gall morphotypes-micro-hymenoptera network in white-sand wet forest may be due to fact that plant species in these ecosystems tend to be more sclerophyllous, with hard leaves, long life spans, low nutrient status and high levels of chemical defenses; particularly tannins (Coley et al. 1985; Fagundes et al. 2018; Turner 1994; Turner et al. 1993). These traits affect plant quality, providing protection against natural enemies (e.g., parasitoids). Thus, due to these physical and chemical characteristics, micro-hymenoptera species are not able to parasitize gall-inducers in these ecosystems, thereby leading to lower connectance in these interaction networks. On the other hand, contrary to expectations, *terra firme* forests exhibit lower connectance in the gall morphotypes-micro-hymenoptera network. One

possible explanation for this could be related to vertical stratification in food web structure (Paniagua et al. 2009). *Terra firme* forests have a complex vertical structure with multiple canopy layers in the Amazon forest (Santos et al. 2018), which might cause a spatial separation between gall-inducing insects and their parasitoids (Paniagua et al. 2009). For instance, Paniagua et al. (2009) examined the structure of galling-parasitoid networks across different vertical strata in tropical forests in Panama. They discovered that both the understorey and canopy had networks with few galling-parasitoid connections, with connectivity values of 13.8% and 11.1%, respectively. This vertical stratification could limit the interactions between these groups, as parasitoids may not effectively reach or locate gall-inducers distributed across different forest strata, thereby leading to lower connectivity in these interaction networks.

In our study, the modularity of the galling-micro-hymenoptera network was higher in the palm swamp forest ($M=0.406$) compared to other vegetation types. This is consistent with the findings of Araújo and Maia (2021b), who reported a modularity of $M=0.486$ in a Brazilian restinga, and Prauchner and Mendonça (2024), who observed a modularity of $M=0.411$ in the subtropical forest. This high modularity in the gall morphotype-micro-hymenoptera networks in palm swamp forests can be influenced by the specific structure of the galls (Prauchner and Mendonça 2024). Galls, formed by plants in response to the activity of gall-inducing insects, exhibit a wide variety of shapes and sizes that can affect the interaction between the gall-inducing insects and their parasitoids (Joseph et al. 2011). Complex and well-structured galls can provide a specific and protected microhabitat, allowing certain gall-inducing insects to avoid generalist predators and parasitoids, thereby promoting specialization and, consequently, modularity in these networks (Prauchner and Mendonça 2024). Moreover, galls can develop specific characteristics that only certain specialized parasitoids can overcome (Zhang et al. 2022). These additional physical and chemical barriers within the galls force parasitoids to develop particular adaptations to access the gall-inducing insects, fostering greater specialization in these interactions (Prauchner and Mendonça 2024). This highly specific relationship between the structure of the galls, the insects that induce them, and the parasitoids that attack them significantly contributes to the high modularity observed in palm swamp forests.

Conclusion

Our results indicate that both the host plant-galling and galling-micro-hymenoptera networks exhibit high specialization. The host plant-galling network displays lower

connectance in the white-sand wet forest and greater modularity in the *terra firme* forest. In contrast, the galling-microhymenoptera network shows lower connectance in both *terra firme* and white-sand wet forests but is more modular in the palm swamp forests in the Peruvian Amazon. These findings underscore the irreplaceable nature of species interactions within each unique vegetation type of the Peruvian Amazon, characterized by distinct assemblies of host plants, galling species, and parasitoid species.

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Author contributions JMGR — Conceptualization, Data curation, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing; JMGR and WSA — Formal Analysis; WSA and VCM — Conceptualization, Methodology, Supervision, Writing – review & editing; APB, ENHC, TRB, RVM, AMM, RGV, GFL, JRH and MAPA — Data collection.

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Declarations

Conflict of interest The authors declare there are no conflicts of interest.

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