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REVIEW PAPER

Protecting the Cerrado: where should we direct efforts for the conservation of bat-plant interactions?

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Abstract

Cerrado is a biodiversity hotspot composed of a vegetation mosaic landscape ranging from grasslands to forests. It holds a high endemicity of plants and vertebrate species suffering from high habitat destruction rates. We aimed at characterizing the mutualistic interactions between bats and the plant species present in their diet in the different habitats of the Cerrado to determine which habitats should be prioritized for the conservation of most bat-plant interactions. In order to do that, we assessed two datasets, one covering all interactions between bats and plants in Latin America and the other with the distribution of plant species across the 13 different Cerrado habitats and the Cerrado as a whole. Forests played the major role in the structure of the interactions as they hold the highest number of interactions, with a big percentage being unique to these habitats. The removal of forests in our simulations led to a high dissimilarity of the original structure of the interactions and the extinction of 1/3 of all bat species. Special attention must be given to key habitats such as gallery forests as they not only help connecting the landscape, but also hold a large proportion of the interactions between bats and plants in the Cerrado and play an important role on the network structure between bats and plants in the heterogeneous Cerrado landscapes.

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Introduction

The world is facing a high speed of species loss with extinction rates still accelerating (Barnosky et al. 2011). A decreasing species richness can bring as a consequence the loss of interactions and ecosystem function (Valiente-Banuet et al. 2015). Biodiversity hotspots cover a small percentage of Earth`s surface (1.4%), but comprise 44% of all vascular plant species and 35% of vertebrate species in four groups (Myers et al. 2000). They hold a large proportion of the world's vertebrate-plant interactions, but these interactions are also incredibly threatened by their high levels of habitat destruction rates and high endemicity of vertebrate and plant taxa (Myers et al. 2000). More than half of the world's threatened plant and vertebrates are hotspot endemics (Brooks et al. 2002). As such, biodiversity hotspots are one of the main priority areas for the conservation of species and interactions.

With an area of 2,116,000 km^2 covering almost 10% of South America, Cerrado is a biodiversity hotspot that contains a rich plant community (more than 12,000 species) (Sano et al. 2008) with a high endemicity level (44%) (Klink and Machado 2005), making it the richest savannah in the world in terms of plant species (Klink and Machado 2005). It is formed by a mosaic of different vegetation types ranging from open formations (grasslands) with sparse low trees to dense and forested formations (Ratter et al. 1997; Myers et al. 2000; Klink and Machado 2005). However, these different formations are not equally distributed across its area. While gallery forests, for example, cover only 5% of the Brazilian Cerrado area, savannah woodlands cover almost 70%, with each of these habitats holding very distinct plant communities (Ribeiro et al. 1998; Lenza et al. 2015).

Cerrado has been considered the last agricultural frontier of the planet (Borlaug 2002) and it has been suffering high habitat destruction rates (700,000 km^2/year) (Brasil 2011) that have already led to the loss of 80% of its original cover (Myers et al. 2000), with only 7.5% of it remaining inside protected areas (Strassburg et al. 2017). More than 4800 plant and vertebrate species are strictly endemic to the Cerrado (Strassburg et al. 2017) with at least 480 plant species predicted to be extinct in the following years due to habitat destruction in this neotropical savannah (Strassburg et al. 2017). Thus, habitat destruction caused by agriculture expansion and cattle ranching (some of the main causes of savanna loss in Brazil) are likely to provoke the loss of unique interactions that would not be formed anywhere else. This scenario makes it important to understand which habitats are more important to prioritize for conservation as they hold different plant species assemblages and levels of threats and protection, especially considering that savannah woodlands comprise most of the Cerrado area and it is extremely affected by Anthropogenic activities (Ribeiro et al. 1998; Lenza et al. 2015; Oliveira et al. 2017).

Cerrado has at least 268 mammal species, of which 118 are bats (~44%) (Paglia et al. 2012; Aguiar et al. 2016). The Phyllostomidae family comprises more than half of Cerrado bat species (65) (Paglia et al. 2012). Phyllostomids present a high diversity of feeding habits, with fruits and flower nectar representing some of their main food sources (Rojas et al. 2011). These bats play an important role in environmental dynamics (Kunz et al. 2011) as seed dispersers and pollinators of at least 549 and 360 species of Neotropical plants, respectively (Kunz et al. 2011). However, their mutualistic interactions are likely to not be evenly distributed across the Cerrado landscape. While in forested habitats, seed dispersal is mainly made by animals (zoochory) (Batalha and Mantovani 2000; Martins et al. 2007;

Stefanello et al. 2009), open areas tend to be dominated by wind seed dispersal (anemochory) (Howe and Smallwood 1982; Oliveira and Moreira 1992). However, few studies have analysed the importance of different habitats on bat mutualistic interactions in the Cerrado (Bizerril and Raw 1998; Ishara and Maimoni-Rodella 2011), and it is not known how environmental perturbations can affect interactions and the role of habitat heterogeneity in their maintenance.

Network analysis is a powerful tool for the study of species interactions (Memmot 2009) that has been gaining more attention in the last years (Ings et al. 2009), especially in the study of the dynamics of plant-animal mutualistic networks (Lewinsohn et al. 2006; Bascompte and Jordano 2007; Tylianakis et al. 2010; Nuismer et al. 2013). Many different network metrics can be used to understand interactions and prioritize conservation, such as nestedness, connectance, modularity and robustness (Tylianakis et al. 2010). It has already been shown that extinction risk and competition intensity depend on network topologies (Melián and Bascompte 2002). Nested networks, for example, reduce competition while increasing the biodiversity that is supported by the ecosystem (Thébault and Fontaine 2010), while in compartmentalized networks perturbation spread quickly within, but slowly between modules of interactions (Tylianakis et al. 2010). Thus, if a habitat is destructed, the impacts are more likely to be felt within the same module of interaction. Modules of interaction can also be used to infer niche segregation between species and landscape use. However, little attention has been given to mutualistic interactions in heterogeneous landscapes where the composition of plant species might play an important role in the determination and establishment of these interactions.

Our objective was to use a network analysis approach to describe the patterns of interactions between bats and the plant species in their diet in a highly heterogeneous landscape (the Cerrado) in order to understand which habitats should be prioritized for the conservation of most bat-plant interactions. The Cerrado biome present habitats that range from open to closed vegetation formations (Ribeiro and Walter 1998). Considering that forests are structurally complex environments offering a great variety of resources (e.g., food and shelter), generally contributing to an increased richness of fauna at a range of spatial scales (e.g., August 1983; Hansen 2000; Jung. et al. 2012) our predictions were the following: (1) forested habitats would hold most of the interactions and form a separate module of interactions from the savannahs and open vegetation formations (grasslands); (2) the loss of forested formations would lead to a higher number of bat species extinctions and a higher network dissimilarity in comparison to the original network of interactions; and (3) there will be a higher number of bat species in the module of interaction which includes forested formations in relation to the other modules of interactions.

Methods

Literature review

To account for bat–plant interactions (frugivory and nectarivory) in the Cerrado, we consulted the dataset present in the book "Plantas e Morcegos" (Bredt et al. 2012), which is a compilation for all records of interactions between bats and plants (frugivory and nectarivory) for Latin America. The book relies on 174 references from 1960 to 2010 containing data of bat-plant interactions. To account for plant species occurrence in the Cerrado habitats, we used the dataset present in the book "Cerrado: flora e fauna (Volume II)" (Ribeiro et al. 2008), which is a compilation of all Cerrado plants that occur in different habitats of grassland, savannah and forest formations. Therefore, for further analyses, we were able to obtain a dataset of plants with which bats interact, and determine to which vegetation formations these plants typically belong to. In total, we obtained data for 13 habitat types of the Cerrado and the Cerrado as a whole (see Supplementary Material for the full description of the characteristics of each habitat type).

Among grassland formations were dry grassland (campo limpo in Portuguese), wet grasslands (brejo), shrubland (campo sujo), murundu field (campo com murundus) and rupestrian grassland (campo rupestre). Among savannah formations were savannah woodland (cerrado *stricto* sensu) and swampy palm forest (vereda). Among forest formations were gallery forest (mata de galeria), riparian forest (mata ciliar), seasonal dry forest (mata seca) and dry woodland (cerradão). Additionally, we also obtained data of Cerrado vegetation formations that have influence from other biomes, such as Caatinga (a semiarid biome of the northeast Brazil) and Amazon Rainforest. They were represented respectively by dense woodlands (carrasco) and amazon savannahs (savanas amazônicas). We decided to include them in the analysis to evaluate the potential importance that they might have for bats diet since they have some structural and plant species composition similarities with the Cerrados because of the influences that they had during their formation (Ratter et al. 1973; Eiten 1984; Marques et al. 2019).

For some plant species, the specific habitat type to which they belonged were not available and they were assigned to a more generic habitat type called Cerrado. Amazon savannas are also a mosaic habitat, but references about the occurrence of plant species within it do not specify to which habitat type each plant species belongs to. Thus, plant species from the Amazon savannas were included in our analysis regardless of the habitat type to which they belonged.

Vegetation characterisation of habitats in Cerrado

The habitat types presented on this study are characterized by different canopy cover, tree densities and tree heights. Grasslands are open formations with only few scattered trees present in the landscape and the great majority of plant species formed by grass. Savannah formations present a higher density of scattered trees than grasslands, and the landscape is dominated by shrubs and grasses with low canopy cover. On the other hand, forested habitats are composed mostly by a high density of trees that form a dense canopy cover (Fig. 1). An additional description of the vegetation of each habitat type with more details and photos can be found in the supplementary material.

Interaction networks

We compiled the recorded interactions from the literature into interaction frequency matrices where each cell value represents the number of plant species that a bat species interacts within each habitat. We considered one realized interaction when a plant species was registered in the literature as part of a bat species diet. We pooled together the interactions where bats consumed fruits (frugivory) and nectar (nectarivory). We constructed the following matrices: (1) the whole network of interactions for bat and plant species; and (2) a network of interactions between bat species and the Cerrado habitats.

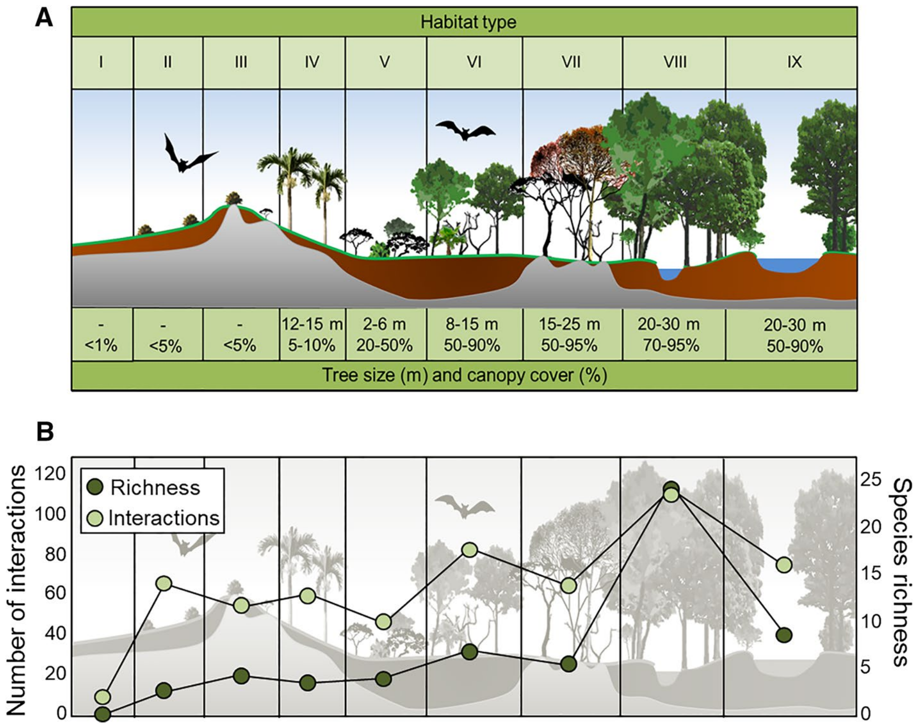

Fig. 1 Representation of variations in tree size and canopy cover (**a**), and bat species richness and number of interactions across the different habitat types in the Brazilian savannah (Cerrado) (**b**). *I* grassland (campo limpo in Portuguese), *II* shrubland (campo sujo), *III* rupestrian grassland (campo rupestre), *IV* swampy palm forest (vereda), *V* savannah woodland (cerrado sensu stricto), *VI* dry woodland (cerradão), *VII* seasonal dry forest (mata seca), *VIII* gallery forest (mata de glaeria), *IX* riparian forest (mata ciliar). For the description of each habitat type, see supplementary material

Descriptors of network structure

We considered five metrics that describe the plant-bat network interactions: number of compartments, modularity, nestedness, connectance, and robustness. (1) Number of compartments are defined as isolated sub-sets of nodes interacting with each other that do not have any connection with another compartment in the network (Dormann et al. 2008). Thus, we were able to identify whether there is fragmentation of interactions in the plant-bat network. (2) For modularity, we used the QuanBiMo algorithm which is an approach based on simulated annealing and more specifically designed for weighted bipartite networks (Dormann and Strauss 2014). These metrics identify the degree to which networks are structured in weakly interconnected subnetworks (i.e., modules) that present strong interactions (Dormann and Strauss 2014). This approach evaluates whether the network presents more interactions within a module than between modules. (3) In order to evaluate nestedness, we used the weighted NODF, which is a measure that uses overlap and decreasing fill in the weighted matrix (Almeida-Neto and Ulrich 2011). These metrics identify the degree to which species with few links have a sub-set of the links of more connected species. (4) Weighted connectance was obtained by dividing linkage density by the number of species in the network (Tylianakis et al. 2007), which reveals the number of links in the network given a total number of links. (5) For the calculation of robustness, it was considered the area below the curve of secondary extinction of bats when primary extinction of plant species was simulated according to the random extinction of plant species. This metric measures the robustness of a network in relation to the co-extinctions in one trophic level triggered by extinctions in the other trophic level. The more robust a network is, the more extinctions in one level have to occur for a significant decrease in species of the other level due to co-extinctions.

Data analysis

For the calculation of the different network metrics, we used the function networklevel from the R package Bipartite (Dormann et al. 2008) to determine network structure and resilience of the Cerrado network of interactions to the loss of forested, savannic or open formations (grasslands) in the landscape. For that, we calculated each metric for four networks: I—one network including all habitat types (Cerrado); II—one network after excluding all interactions from forested vegetation formations (forests); III—one network after excluding all interactions from savannic vegetation formations (savannic); and IV—one network after excluding all interactions from open vegetation formations (grasslands). Apart from robustness, all metrics chosen have little or no biases to sampling completeness and network size (Fründ et al. 2015). Additionally, we also assessed the dissimilarity of the networks comparing the Cerrado landscape with all possible interactions with the network structure after the exclusion of interactions from each of the vegetation formations separately (forested, savannic and grasslands) using the R package betalink (Poisot et al. 2012). We calculated the dissimilarity indices based on the dissimilarity of species composition in the network (β_S) and the dissimilarity between interactions of both networks (β_{WN}).

In order to better understand the role of interaction similarity between habitats and among different bat species to determine the network structure within the mosaic of the Cerrado landscape, we combined a cluster dendrogram with the network of interactions of the habitats. We used a cluster dendrogram with the Jaccard index of similarity and the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method, where similarity of interactions for bat species are represented by the number plant species that every species pair have in common on its diet. The interaction similarity for Cerrado habitats were represented by the number of common plant species present on each pair of habitats that were present on bats diet.

All statistical analysis and network drawings were performed using R (version 3.1.2, Core Team 2014).

Results

There were a total of 416 unique interactions between 28 bat species (66.67% of all plantivorous bat species in the Cerrado (42)) and 71 plant species (21.58% of all plant species registered to be present on bats diet in Brazil (329)) present in 13 habitat types and the Cerrado as a whole. Five plants species (7.04%) were not assigned to any specific habitat type and thus were included in the Cerrado as a whole. There was a clear distinction between the interaction types of the plant species with 14 plants being only bat pollinated, while 57 plants were only seed dispersed. However, most bat species that acted as pollinators were also seed dispersers. Only *Anoura caudifer* was strictly a pollinator in the network. When taking into account interactions between bat species and the habitats where plant species present on bats diet occur, gallery forests had the highest amount of interactions (115 plant species present in the diet of the bats). This forest formation represented almost three times the number of interactions in riparian forests (N = 40), the second habitat with the highest amount of plant species for bats diet (Figs. 2, 3), with 24 shared bat species. Gallery forests also held the highest distinctiveness of interactions forming a separated branch from other habitats in the cluster dendrogram (Fig. 3). While *Artibeus lituratus, Sturnira lilium*, and *Carollia perspicillata* showed a very distinct plant species composition in their diet in relation to other bat species, the rest of the bat species were clustered together in the same block of interactions.

There were four modules of interactions in our network (Fig. 4) with a low value of modularity (0.164). Additionally, we found that each cluster of interactions was mainly formed by the same types of vegetation in the landscape (savannahs, grasslands or forests). Most nectarivorous species (*Lonchophylla mordax*, *Hsunycteris thomasi*, *Anoura geoffroyi*, *Lionycteris spurreli*) were contained in the module with grassland—savannic formations (swampy palm forest, dry woodland and amazon savannah) (Fig. 3). This module had the highest bat species richness (11 species).

Forest formations removal had the highest impact on the network, provoking the extinction of nine bat species, the increase in network dissimilarity considering species composition ($\beta_S = 0.206$) and interactions ($\beta_{WN} = 0.414$) and the decrease in nestedness of the habitats (Weighted NODF). The removal of savannahs and grasslands in our simulations had little impact on network structure with the extinction of one and none bat species, respectively (Table 1).

Discussion

Similar to African landscapes, where riparian forests support a higher species richness and abundance of frugivorous bats than savannic environments due to their higher fruit availability (Monadjem and Reside 2008), forests in the Cerrado have revealed a massive importance to support not only a high bat species richness, but also a high number of unique interactions. Additionally, our results showed that most of these interactions are linked with gallery forests. This forest formation holds a unique community of mammals in relation to other Cerrado habitat types which is in part due to its distinct plant species composition (Johnson et al. 1999) and varying vegetation structures. However, contrary to what was found by Jonhson et al. (1999), where the mammal composition of gallery forests was more closely related with savannah woodland (cerrado s.s.), gallery forests in our study formed a separated branch in the dendrogram of interaction similarity, being very distantly related from any other habitat type. Gallery forests are important environments for frugivorous vertebrates, being responsible for the survival of more than 80% of Cerrado bat and bird species (Marinho-Filho and Reis 1989; Silva and Bates 2002) with simulations of the removal of forests in our study leading to the extinction of 1/3 of all plantivorous bat species.

Although the importance of gallery forests for bat-plant interactions, they cover only 5% of the total area of the Cerrado (Ribeiro et al. 1998) while savannahs dominate 72%, with the remnant parts formed by savannah-forest transitions (24%) and dry forests (4%) (Silva and Bates 2002). However, gallery forests comprise 33% of all phanerogamic species of all other habitat types of the Cerrado (Felfili et al. 2001). They occur across most of the

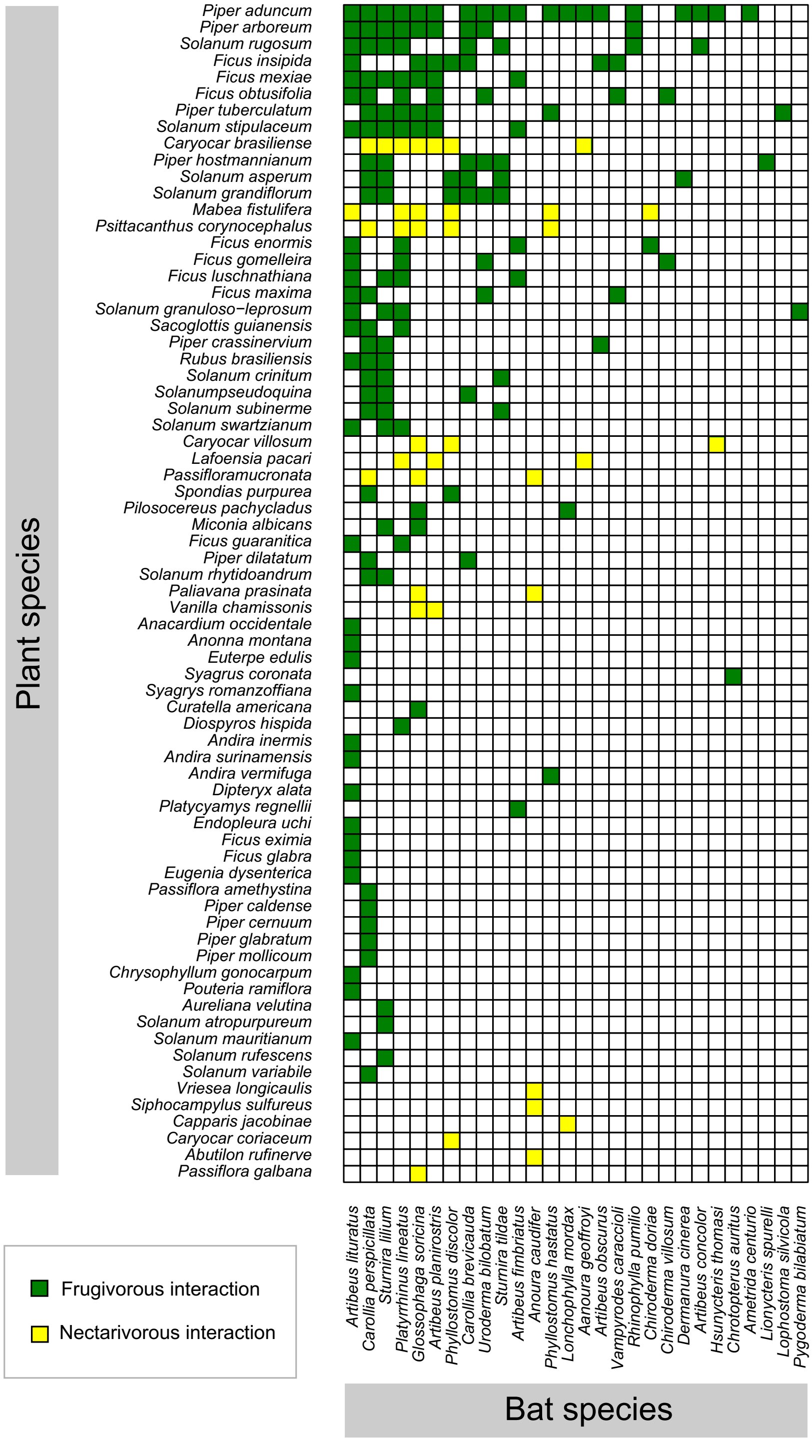

Fig. 2 Frugivorous and nectarivorous interactions between phyllostomid bat species and the plant species registered for their diet in the Brazilian savannah (Cerrado)

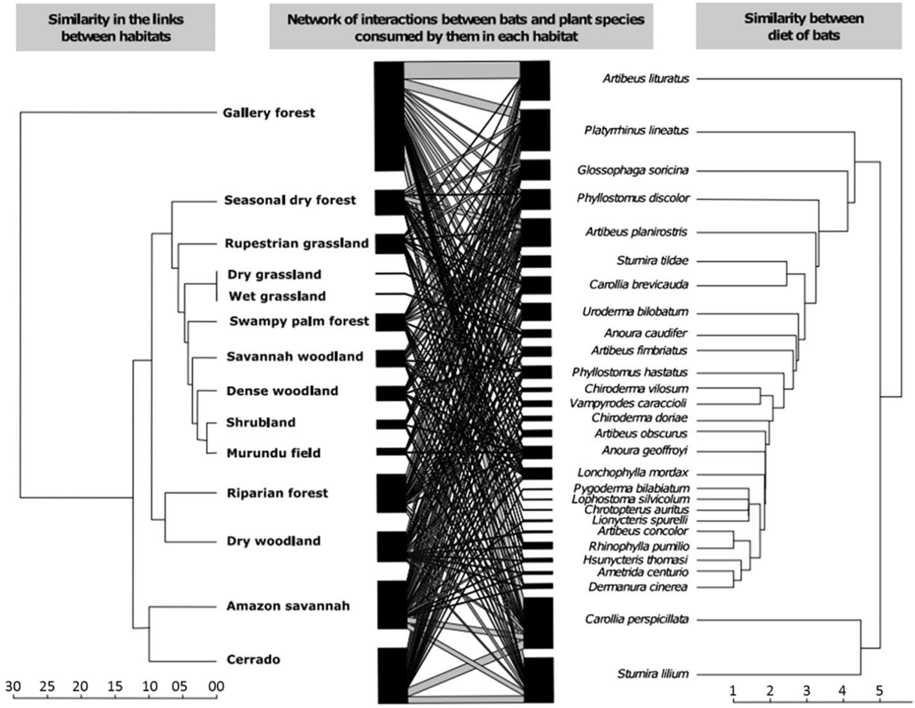

Fig. 3 Network of interactions between bats and the plants registered for their diet in different vegetation formations of the Brazilian savannah (Cerrado). Cluster dendrograms represent the similarity of links on bats' diet and similarity of plant species present on bats diet between differen vegetation types. For the description of each habitat type, see supplementary material

Cerrado landscape and help to connect different habitats, possibly acting as corridors for bat species (Oliveira et al. 2017). This is extremely important as biodiversity loss and ecosystem flux changes are mitigated when habitats have corridors connecting them (Staddon et al. 2010).

The diversity of habitats within the landscape helps to sustain a high diversity of plant species in the Cerrado. Beta diversity is very high with as much as 30% of plant species occurring in single localities while only 5% of plant species occurring at more than 50% of different sites (Ratter 1986). Alpha diversity of tree and shrub species per hectare can range from 10 to 120 species (Ratter et al. 1997). This diversity is more concentrated on the ground layer where the richness of plant species can be four to seven times higher than species richness of trees and large shrubs (Pereira et al. 1993; Ratter et al. 1997). The high beta diversity makes it important to conserve a range of different habitats to maintain populations and landscape connectivity. Thus, it also makes it important to maintain a high diversity of habitat types in the landscape and not just those with a high uniqueness of interactions, such as savanna woodlands and gallery forests, respectively, to conserve plant species for bats diet on a broader scale.

A good mechanism to help in finding the priority of conservation for habitat preservation is to understand how interactions are distributed across these habitats. Our analysis has showed that interactions are not randomly distributed, but instead, are clustered

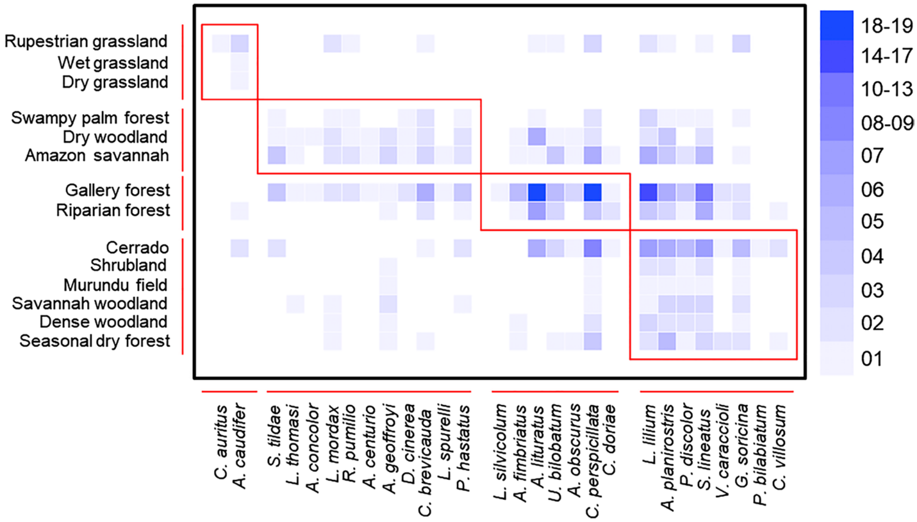

Fig. 4 Modules of interactions (represented by red polygons) calculated using the QuanBiMo algorithm, between bat species and vegetation formations of the Brazilian savannah (Cerrado). Links between vegetation formations and bat species used for the calculation were used to assess the interactions between bat and plant species present in each habitat. Numbers indicate the number of interactions between bats and plants according to the color intensity. For the description of each habitat type, see supplementary material

Table 1 Network metrics for the interactions of bats and plant species of the Cerrado biome as a whole, and after the exclusion of the interactions from different Cerrado habitats: forests, savannahs and grassy fields

Network metrics	Cerrado	Excluding		
		Forests	Savannahs	Grasslands
Species richness	28	19	28	27
Number of interactions	288	74	243	259
β_S	–	0.206	0.041	0.07
β_{WN}	–	0.414	0.139	0.093
Weighted nestedness (NODF)	44.515	26.378	46.347	50.191
Weighted connectance	0.237	0.258	0.246	0.267
Number of compartments	1	1	1	1
Robustness (lower)	0.857	0.800	0.825	0.946

β_S represent the dissimilarity of species and β_{WN} the dissimilarity of interactions. Robustness (lower) represents the tolerance of bat species to the exclusion of the different habitat types

into four modules of interactions formed by similar vegetation types that are weakly separated from each other and from other bat species and habitats. In modular networks, the effects of perturbation are more likely to stay contained within members of the same module than between members of different modules (Tylianakis et al. 2010). This means that the removal of one habitat within a module is more likely to affect other habitats of the same module (grassland, savannah or forest). This would happen due to increased competition for food resources in the other habitats within the same module due to bat species exploring other habitats in search for food.

When simulating the extinction of different vegetation formations to the network of interactions, only the removal of forested formations led to a significant change in the number of bat species and interactions supported by the environment. It has also led to a higher dissimilarity in species composition in the network as well as higher interaction dissimilarity, decreased nestedness and robustness of the network to extinction of habitat types at random. The decreased nestedness after the removal of forests indicate that the remaining landscapes are less resistance to further habitat loss. Considering habitat loss, forests in the Cerrado are the only habitat type that actually matter for sustaining high richness of bats (Muylaert et al. 2016). Therefore, forests need to be carefully managed and preserved as bats can show a low tolerance to habitat loss with landscapes that have less than 47% of habitat remaining, for example, showing a sharp decrease in bat species richness (Muylaert et al. 2016). Thus, the conservation focus should be put not only on forest conservation, but in the amount of habitat left for bats (Muylaert et al. 2016) with landscape composition playing an important role in sustaining biodiversity in these landscapes (Fahrig et al. 2003). Management at the landscape level can provide a better alternative for the conservation of bat assemblages than a focus on local habitat features (Mendes et al. 2017).

No simulations of habitat removals have led to an increase in the number of compartments in the networks. This probably has happened because some species in real communities have high diversity in species degree (Jordano et al. 2003), which make them more connected than expected by chance, and help to link habitats. One-third of the bat species of our studies have links with more than half of the total habitats. These species are critically important to be conserved in the landscape as they can act as important process linkers and help in the recovery of ecosystems via seed dispersal and pollination following perturbation and fragmentation (Staddon et al. 2010; Kunz et al. 2011). However, this will depend on landscape configuration and species dispersal abilities.

Although the removal of savannic habitats did not have a strong effect on the landscape structure of the interactions in our simulation models, the conversion of savannahs is likely to reduce the abundance of nectarivorous species due to the reduction in their food sources (Oliveira et al. 2017). In fact, our results showed that most nectarivorous bats composed the module with savannah formations (savannas). Even though only one bat species of our analysis is considered threatened (*L. mordax* = near threatened), it is a nectarivorous species that is specialized in savanna habitats. Thus, the protection of habitat types within savannas is likely to play a big role on its conservation.

The habitat destruction of savannahs while leaving only few scattered trees on the landscape, which is the most common type of deforestation of savannas, is likely to increase the difference in bat abundance and species richness between both landscapes (Galindo-Gonzalez and Sosa 2003). The increase in the isolation of habitat destructed landscapes from protected areas are also likely to play an important role in the formation of the realized interactions as they promote a decrease in the abundance of frugivorous bats (Galindo-Gonzalez and Sosa 2003; Oliveira et al. 2017). Mutualistic interactions are also very sensitive to habitat loss and scenarios where more than 50% of the habitat is lost is likely to be unsuitable to sustain metapopulations and mutualistic networks (Hanski and Ovaskainen 2002; Gonzalez et al. 2011).

Forests associated with watercourses in the Cerrado are legally protected under the law 12.651/12, which regulates Brazilian forest code and establishes that at least 30 meters of riparian forest from each side of the river need to be protected. In rural areas, 35% of the areas of properties located in the Cerrado should be dedicated to conservation. This puts the Cerrado in a very good position for forested and other habitats in terms of legal protection. However, in most cases this legislation is disrespected, with no area designated to protection in rural areas and riparian forests being destructed and cleared for cattle ranching and agriculture.

Although amazon savannahs are geographically isolated from the rest of the Cerrado and have a lower species richness, they still share a lot of common plant species with the Cerrado (Kubitsky 1979, 1983; Eiten 1984). Thus, if they are removed from the landscape in the amazon forests, it is likely that most of their interactions will disappear on that landscape. Although bats are one of the animal groups that have received most of the studies in the amazon savannahs (Carvalho and Mustin 2017), there are still few studies characterizing their diets and interactions in this landscape. Similar to other regions of the Cerrado, they are also suffering from high habitat destruction rates due low protection and the advances of soy bean plantations (Carvalho and Mustin 2017).

Cerrado holds a rich bat assemblage (118 species) for which at least 42 phyllostomid species would be expected to include fruits or nectar on their diet (Aguiar et al. 2016). Our literature review include 2/3 of plantivorous bat species of the Cerrado, which highlights the lack of knowledge and the need for more studies to characterize bats diet in this domain. More specifically, the description of bat-plant interactions in other habitats than forests should be done to better understand if these relationships remain true. Phyllostomidae bats have a plastic diet (Barros et al. 2013; Heithaus et al. 1975; Zortéa 2003; Tschapka 2005) and even species that are more morphologically specialized for the consumption of fruits and nectar are likely to include other food times, such as arthropods, in their diet (Willig et al. 1993). This plasticity might also help on species persistence during fragmentation processes where interactions remain restricted to a compressed area (McCann et al. 2005).

Conclusions

With a modular network where modules are formed mainly by habitat formations from the same type, the maintenance of a heterogeneous landscape with a range of different habitat types is likely to help sustaining a higher diversity of bat species. However, forests (especially gallery forests) are some of the most important habitats to preserve for the conservation of bat-plant interactions as they sustain not only a high, but also a unique set of interactions, and are responsible for connecting the landscape. They form an important part of the core diet for most bat species that can be complemented by interactions in other landscapes. Although Brazilian legislation protects a substantial portion of the Cerrado landscape, the high habitat destruction rates are likely to remain high in the next years due to city growth together with agriculture and cattle ranching expansion, which poses a big threat for the conservation of interactions in the Cerrado. Thus, special attention should be given for the conservation of gallery forests in the Cerrado, as well as the composition of the landscape to allow bat movement and the sustainability of mutualistic interactions.

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