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ARTICLE

Bird-plant interaction networks in native forests and eucalyptus plantations within a protected area

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Abstract. Frugivory is a plant-animal mutualistic interaction carried out mostly by birds. It consists in the bird consumption of fruits with later dispersion of the plants' seeds, helping in the vegetation regeneration. Frugivory can be affected by the habitat fragmentation and introduction of exotic species, which may alter the species interaction by extinction or competitor introduction. This study aimed to compare the structure of the network of frugivorous interactions between birds and plants in native forest and eucalyptus plantation. Birds were captured by mist nets and had their feces collected. Later, the seeds were identified in laboratory. The records of fruit consumption by birds in the zoochoric plant species present in the study area were also conducted. The data collected was used to build a network of interactions and identify the most important network metrics, species, and ecological functional groups in the studied environments. The results showed that the species composition, the connectivity of the relationships, the importance of the species for the interaction networks and the number of subgroups within the networks were highly similar between the native forest and the eucalyptus plantation. This could be explained by the favorable conditions that the studied eucalyptus plantations presented, such as the lack of anthropogenic activities, well-developed understory, and the presence of native surrounding vegetation, allowing practically the same seed dispersal capacity in both types of environments.

Keywords. Bird-plant interactions; Exotic species; Frugivory; Zoochory.

INTRODUCTION

Ecosystems with extensive plantations of non-native trees, such as the eucalyptus monocultures, can extinguish local species by replacing native vegetation and simplifying the forest heterogeneity, alter the regional water resources, and diminish soil fertility (Marsden *et al.,* 2001; Borsboom *et al.,* 2002; Kanowski *et al.,* 2005; Carnus *et al.,* 2006; Valduga *et al.,* 2016; Bayle, 2019). On the other hand, eucalyptus plantations can be used as fuelwood, replacing the use of indigenous species, and conserving native forests and wildlife, protecting soil from erosion, and help in habitat restoration by promoting the recruitment, establishment and succession of native woody species (Hobbs *et al.,* 2003; Barlow *et al.,* 2007; Brockerhoff *et al.,* 2008; Bremer & Farley, 2010; Brockerhoff *et al.,* 2013; Bayle, 2019). All these negative and positive effects have been much debated on whether they prevent forest regeneration (Altieri, 2009; Edwards *et al.,* 2014; Benton *et al.,* 2021). However, little is known about the consequences of eucalyptus plantations for seed dispersal.

Seed dispersal is considered the most important ecological process for the natural regeneration of vegetation (Bascompte & Jordano, 2007), occurring in most cases through frugivory (fruit consumption). Frugivory allow mutualistic animal-plant interactions in which more than two species are usually involved, that may form a complex network of interactions, capable of maintaining the resilience, and even the regeneration, of the ecosystem through the spread of propagules (Bascompte & Jordano, 2007). Mutualistic animal-plant interactions are influenced by environmental disturbances, such as habitat fragmentation and introduction of exotic species, by the exclusion or introduction of key species in the system, preventing pre-existing relationships in the interaction network (Markl *et al.,* 2012). To understand how a species becomes a key player in a network of mutualistic interactions, we need to

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assess the importance of the species in a complex context and through quantitative operational metrics (Mello *et al.,* 2015).

In South America, specifically in Brazil, eucalyptus is the most widespread exotic monoculture, which places the country as the second in the world with the largest area of native forest replaced by plantations of this tree (Ceccon, 2001). This fact led to changes in many ecosystems, such as the Atlantic Forest, considered one of the most fragmented domains in the Neotropics (Ceccon, 2001; FAO, 2016). This is the domain with the largest number of endemic species in Brazil (it is considered a biodiversity hotspot; Myers *et al.,* 2000; Rezende *et al.,* 2018). Because of this problem, some areas of the Atlantic Forest were converted into protected areas, such as the Itacolomi State Park (PEIT), located in southeastern Brazil, which include both native vegetation and a 30-year abandoned eucalyptus plantation. The PEIT is considered an important historical and geological natural park in the region (Tafuri, 2008; Messias *et al.,* 2017). Studies, such as those of Andrade (1998), Governo do Estado de Minas Gerais *et al.* (2007) and Pereira *et al.* (2015), highlighted the high bird diversity of the PEIT, indicating the probability of existence of a complex bird-plant interaction networks.

Birds play a fundamental role in the establishment and evolution of native vegetation, with many species that consume and potentially disperse seeds, hence contributing to the forest restoration in degraded areas (Fleming & Kress, 2011). In addition, birds have the largest number of frugivorous species in the Neotropics, with some families being dependent or highly dependent on eating fruits (Fadini & De Marco, 2004; Hernández-Ladrón de Guevara *et al.,* 2012). For these reasons, it would be important to evaluate the contribution of birds to seed dispersal inside the PEIT, evaluating if the replacement of native vegetation by eucalyptus plantations interfere with birds-plant interaction network. This study aimed to compare the relationships between frugivorous birds and zoochoric plants in the forests of the PEIT, by comparing bird-plant interaction networks in an area of native forest with an area of eucalyptus plantation. We hypothesized that the richness of seed dispersing birds would be lower in the eucalyptus plantation than in native forest areas due to the replacement of native vegetation by the monoculture. Also, we hypothesized that the interaction network would be more connected in the native forest than in the eucalyptus plantation, due to the exclusion of frugivorous birds and their mutualistic native plant species by the eucalyptus trees (Valduga *et al.,* 2016).

MATERIAL AND METHODS

Study Area

The study was carried out at the Itacolomi State Park (PEIT), a protected area located in the southeast of the state of Minas Gerais, between the municipalities of Ouro Preto and Mariana (43°32′30″W, 20°22′30″S). The PEIT has an area of 7,543 ha, with altitudes varying between 700 to 1,772 m.a.s.l. The region's climate, according to the Koeppen classification, is dry-winter subtropical highland climate (CWb), as temperatures can vary from 4 to 33°C, with an annual average of 20°C. Precipitation is concentrated between the months of October and March, with a notorious wet season during summer and another dry season in winter (Tafuri, 2008). In the PEIT, rupestrian grasslands occupy 51% of its territory (3,846.93 ha), 40% is covered by montane Atlantic Forest (3,017.2 ha), and 9% is occupied by a 30-years abandoned eucalyptus plantation (two blocks totaling 678.87 ha), placed in an area previously occupied by the native Atlantic Forest, as long as abandoned tea plantations and human constructions (Messias *et al.,* 2017). In this protected area, have being recorded 1,623 plant species, 251 birds, 43 mammal species, 37 amphibians and 22 reptiles, showing its high biodiversity (Governo do Estado de Minas Gerais *et al.,* 2007; Messias *et al.,* 2017).

The study was conducted in two different habitats: native Atlantic forests and abandoned eucalyptus plantations. In each habitat, three sample units were set. In each sampling unit, six 30 m^2 transects were placed, equidistant 200 m (Cullen *et al.,* 2006), for data collection. The native forest sample units were located in 1 (20°25′44.3″S, 43°30′50.4″W) and 3 (20°25′37.9″S, 43°30′36.7″W) were set in an Atlantic Forest fragment comprising 0.65 km^2, while the native forest sample unit 2 (20°25′33″S, 43°30′22″W) was set in an Atlantic Forest fragment of 0.21 km^2. The Atlantic Forest fragments were 800 m distant from each other. The eucalyptus plantation sample units 1 (20°26′06.6″S, 43°30′14.2″W) and 2 (20°26′16.9″S, 43°31′14.6″W) were set in an abandoned eucalyptus plantation fragment comprising 1.62 km^2, while the sample unit 3 (20°26′17.4″S, 43°31′07.2″W) was set in an abandoned eucalyptus plantation of 0.4 km^2. Both eucalyptus plantations were 1 km distant from each other. The sampled units of the abandoned eucalyptus plantations were distant at least 1 km from the sampled units of the native vegetation.

Eucalyptus grandis W. Hill ex Maiden formed the abandoned eucalyptus plantations, with trees reaching heights up to 45 m. A developed understory, formed by native plant species with up to 15 m height, could be observed in the abandoned eucalyptus plantation. Common native plant species such as *Schinus terebinthifolius* Raddi and *Drimys brasiliensis* Miers are found in native forest. A dense understory, with plants measuring from 15 to 18 m is present in the native vegetation area.

Fecal Samples

Sets of 10 mist nets (35 mm mesh, 12 m length x and 2.5 m width) were installed in the three sampling units of both the native forest and the eucalyptus plantation. The nets remained open for sampling between 06:00 h until 12:00 h, totaling 180 hours in each habitat, for 10-month samplings. Each net was inspected at 30 min intervals during the sampling period. Once a bird was captured, the species was identified using a field guide (Sigrist, 2014). Then, each captured bird was placed in a cloth bag with filter paper for 15 or 30 minutes until it defecated, and the feces were preserved in 70% alcohol for later laboratory analysis (León, 2010; Hernández-Ladrón de Guevara *et al.,* 2012).

All fecal samples were placed in petri dishes and diluted with 70% alcohol to separate intact seeds using a stereoscopic microscope in the laboratory. The seed identification in feces was carried out using seed identification guides (Kuhlmann, 2012; Frigieri *et al.,* 2016) and by comparison with collections of fruits and seeds of exsiccates present at the Herbário Professor Jose Badini of the Federal University of Ouro Preto (OUPR). Interaction data were collected from each fecal sample, and an interaction record was considered valid whenever a fecal sample of a bird species contained intact seeds (seeds not broken during gut passage) from a given plant species. The number of seeds within fecal samples was not recorded due to the difficulties that would lead to an underestimation of some species with very tiny and numerous seeds, such as those of the Melastomataceae family.

Visual Recordings

Focal observations of the plants whose fruits were consumed by frugivorous birds were conducted in the six transects of each sampling areas, from 06:00 h to 11:00 h and from 15:00 h to 18:00 h (Pizo & Galetti, 2010), for 10 months, totaling 240 hours of observation in each type of habitat. The number of bird-plant interactions per species was recorded, considering an interaction when a bird species consumed fruits of a plant species, in a way that every plant species may have numerous/many interactions when fruits were consumed by several bird species, and a bird species could have multiple interactions when consuming fruits of several plant species (Silva *et al.,* 2002; Pizo & Galetti, 2010; Cullen *et al.,* 2004). In each transect, the plant species with fleshy fruits were sampled, and the fruits were placed in alcohol 70% and taken to the laboratory for later identification (Caziani, 1996; Amico & Aizen, 2005).

Data Analysis

An interaction network is the graphic representation of a complex system of multiple potentially connected elements, in which the connection may be a mutualistic relationship, and the elements are the plants and birds (Bascompte & Jordano, 2014). To identify the importance of species and groups of species in the interaction network in the sampled habitats, the following network metrics were calculated following Mello *et al.* (2015), Costa *et al.* (2016) and Mello *et al.* (2016). The degree of connection or connectivity, which is used to compare the pair of species that interact the most within the network, thus showing the strongest bird-plant relationships in the community. The degree of centrality, which points out the species with greater number of interactions. The centrality by proximity or closeness centrality, that estimates which species are more likely to interact with others within the network, in other words, showing the species with the greatest indirect relationship with other species in the network. The centrality by intermediate or betweenness centrality, which indicates the species that are mediating the interaction between two other species within the community. Finally, the Louvain modularity (Q) was used to assess if the relationships are equally distributed between birds and plants or if they are separated into subgroups (modules) within the community.

All metrics were calculated using the software Pajek 4.09 (Batagelj & Mrvar, 1998) and non-parametrical Mann-Whitney tests were used to compare the resulting metrics between the two types of sampled habitats using the software R 3.5.0. (R Development Team, 2018). Complementarily, the Sorensen Index for similarity between communities, the Index of dispersion importance, and the Index of importance for plants were calculated for each habitat. The Sorensen Index for similarity between communities (IS) indicates the similarity in the species composition of the compared communities was calculated using the formula $IS = 2c / a + b - c$, where "c" represents the number of species recorded in both environments, "a" the number of species in the first environment (native forest), and "b" the number of species in the second environment (eucalyptus plantation) (Rabinovich, 1981). The Dispersion Importance Index (DII) indicates the importance of each bird species as a seed-disperser in the studied habitats and it was calculated using the formula $DII = (S * B) / 1000)$, where S represents the relative abundance of each captured species, and B represents the percentage of fecal samples with seeds of each species; DII values ranges from 0 to 10, where 0 represents no seeds found on the feces and 10 represents a unique bird species dispersing all seeds (Galindo *et al.,* 2000). Finally, the Index of importance for plants (IVIP), which represents the importance of a bird species for seed dispersal of a given plant, was calculated using the formula $IVIP = \Sigma (r / R)$, where r represents the number of times a bird species presented seeds of a plant species in its feces and R represents the total number of plant species consumed by a bird species (Galindo *et al.,* 2000; León, 2010). Then, after testing data normality using the Lilliefors test, we used paired t-tests to evaluate if the total richness of seed dispersing birds were higher in the native forests than in the eucalyptus forests.

RESULTS

A total of 419 individuals from 21 bird species were captured with mist nets, from which 318 samples of feces were obtained. The intact seeds found in the feces belong to 17 species of plants (one seed type was identified to genus, two to family, and three remained as morphospecies). In the native forest area, 42 species of birds were recorded, with 17 captured by the mist nets and 35 registered through focal observations. On the other hand, 36 species of birds were recorded in the eucalyptus plantation, with 13 captured by the mist nets and 30 registered by the focal method (Table 1). In both native forest and eucalyptus plantation, the most common plant genus found in bird droppings was *Miconia* (Melastomataceae), followed by *Leandra* (Melastomataceae) and *Myrsine* (Primulaceae), the first two are undergrowth shrubs in the studied area, and the third being arboreal. No differences in seed dispersing by birds were found between native forests and eucalyptus plantations ($t = 1.20$, $p = 0.25$).

Within the native forest fragments, 50 interactions between 17 bird species and 20 plant species were recorded through fecal analysis (Fig. 1A); while, in the eucalyptus plantation fragments 41 interactions, between 13 species of birds and 19 species of plants were recorded (Fig. 1B). On the other hand, with focal observation sam-

Table 1. Bird and plant species recorded in the two types of sampled habitats of the Itacolomi State Park (PEIT) with each used methodology: cap = Bird captured in mist nets, fe = plant recorded in fecal samples, obs = species recorded by focal observation.

Bird Species	Native	Eucalyptus	Plant Species	Native	Eucalyptus
Basileuterus culicivorus	cap	obs	*Aegiphila integrifolia*	fe/obs	obs
Chiroxiphia caudata	cap/obs	cap/obs	*Cupania vernalis*	obs	
Coereba flaveola	obs	obs	*Fuchsia regia*	fe/obs	fe/obs
Conopophaga lineata		cap	*Leandra australis*	fe	fe
Dacnis cayana	obs		*Leandra glabrata*	fe	fe
Elaenia flavogaster		obs	*Leandra melastomoides*	fe	fe
Elaenia mesoleuca	obs	obs	*Myrcia excoriata*	obs	
Elaenia obscura	cap/obs	cap/obs	*Miconia chamissois*	fe	fe
Elaenia sp.	obs	obs	*Miconia flammea*		obs
Euphonia chlorotica		obs	*Miconia corallina*	fe	obs
Hemithraupis ruficapilla	obs		*Miconia elegans*	fe	fe
Hylophilus poicilotis	obs		*Miconia paniculata*	fe	
Ilicura militaris	cap/obs	cap/obs	*Miconia rimalis*	fe/obs	fe/obs
Knipolegus cyanirostris	obs	obs	*Miconia theaezans*	fe/obs	fe/obs
Manacus manacus	cap/obs	cap	*Miconia valtheri*		fe/obs
Mionectes rufiventris	cap/obs	cap/obs	*Morphospecies* 1	fe	fe
Myiarchus ferox	obs		*Morphospecies* 2	fe	fe
Myiophobus fasciatus		obs	*Morphospecies* 3	fe	fe
Myiothlypis leucoblephara	cap		*Myrcia splendens*	obs	
Myiozetetes similis	obs	obs	*Myrcia vauthiereana*	obs	obs
Neopelma chrysolophum	cap	cap	*Myrsine coriacea*	fe	fe
Pachyramphus viridis	obs	obs	*Myrsine umbellata*	fe/obs	fe/obs
Penelope obscura	cap/obs		*Phoradendron undulatum*	fe	fe
Phaeomyias murina		obs	*Piper* sp.		fe
Phibalura flavirostris	obs		*Poaceae* 1		fe
Phyllomyias fasciatus		cap/obs	*Poaceae* 2	fe	fe
Piranga flava	obs		*Rudgea sessilis*	obs	obs
Pyriglena leucoptera	cap		*Schinus terebinthifolius*	fe/obs	obs
Saltator similis	obs	obs	*Struthanthus concinnus*	fe/obs	fe/obs
Schiffornis virescens	cap		*Vismia parviflora*	obs	
Schistochlamys ruficapillus	obs				
Synallaxis ruficapilla	cap				
Tachyphonus coronatus	cap/obs	cap/obs			
Tangara cayana	obs	cap/obs			
Tangara cyanoventris	obs	obs			
Tangara desmaresti	obs	obs			
Tangara ornata	obs	obs			
Tangara sayaca	obs	obs			
Tersina viridis	obs				
Thamnophilus caerulescens	cap/obs	obs			
Todirostrum poliocephalum	obs	obs			
Tolmomyias sulphurescens		obs			
Trichothraupis melanops	cap/obs	cap/obs			
Turdus albicollis	cap/obs	obs			
Turdus amaurochalinus	cap	obs			
Turdus leucomelas	cap				
Turdus rufiventris	cap/obs	obs			
Zonotrichia capensis	obs	cap			

pling, 92 interactions were recorded in native fragments among 36 bird species and 14 plants (Fig. 2A); while in eucalyptus fragments, 70 interactions among 32 birds and 11 plants were registered (Fig. 2B). Statistically, there was no differences in the number of interactions between the two types of habitats for the fecal analysis (W = 4.0, P-value = 0.99) or for the focal observations (W = 3.5, P-value = 0.83) (Fig. 3). Almost all bird species were recorded in both types of habitats, with some exceptions such as *Phibalura flavirostris* Vieillot, 1816 (Cotingidae) and *Dacnis cayana* Sundevall, 1836 (Thraupidae), and the plant species *Vismia parviflora* Cham. & Schltdl (Hypericaceae) which were found only in the native forest; and *Phaeomyias murina* (Spix, 1825, Tyrannidae) and *Miconia valtheri* Naudin (Melastomataceae) that were recorded only in the eucalyptus plantation.

Using the data obtained via fecal analysis, the highest degree of connection values in the native forest were

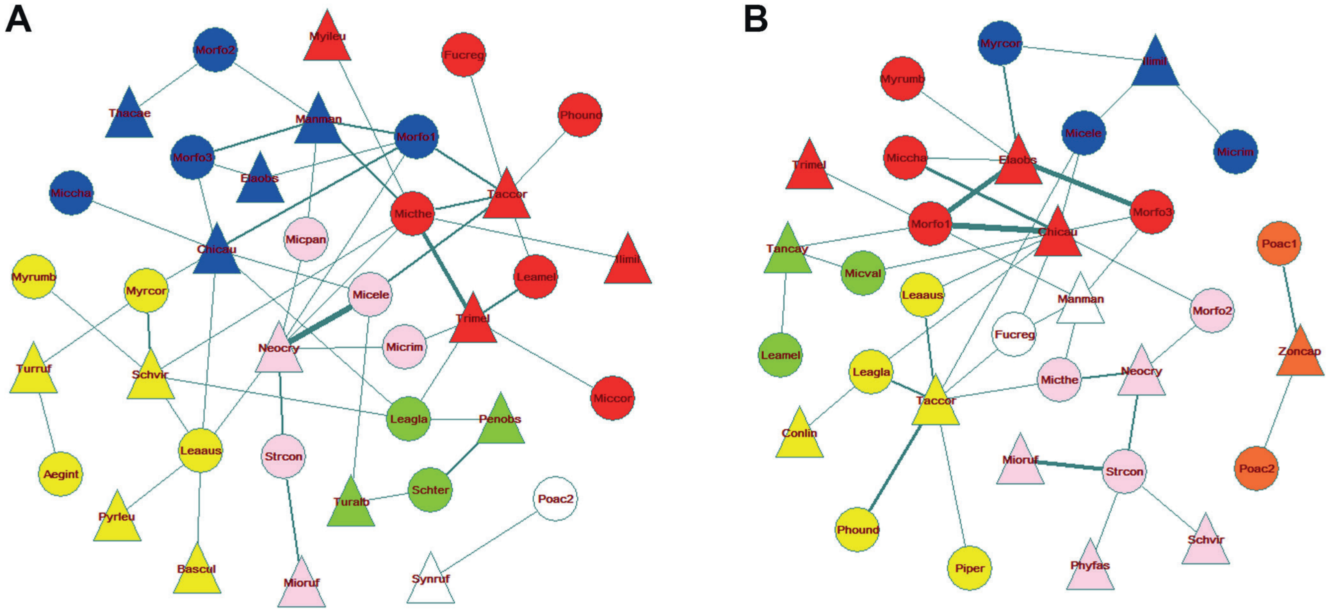

Figure 1. Interaction networks between frugivorous birds and zoochoric plants, according to the fecal samples of birds in the understory of the two sampled habitats. The circles represent the plant species, and the triangles are representing the species of birds. The acronyms in the center of the figures are the scientific names of the species (Supplementary material 1). The thickness of the links (lines) is related to the connectivity between each species (the thicker the line, the more records this interaction had). Each color represents a cluster of species that are more connected within each other than with species from other clusters due to its modularity (Q). (a): F fragments of native forest; (b): Fragments of eucalyptus plantation.

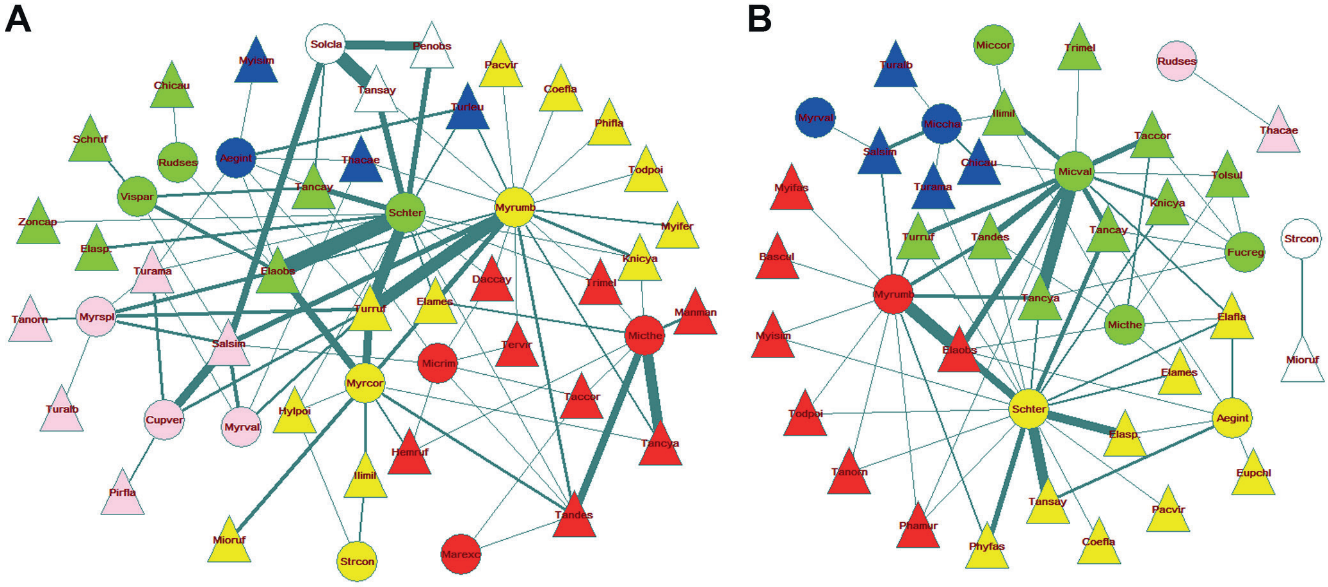

Figure 2. Interaction networks between frugivorous birds and zoochoric plants, according to the focal observations of birds in both sampled habitats. The circles represent the plant species, and the species of birds are represented by triangles. The acronyms in the center of the figures are the scientific names of the species (Supplementary material 1). The thickness of the links (lines) is related to the connectivity between each species (the thicker the line, the more records this interaction had). Each color represents a cluster of species that are more connected within each other than with between species from other clusters due to its modularity (Q). (a): Fragments of native forest; (b): Fragments of eucalyptus plantation.

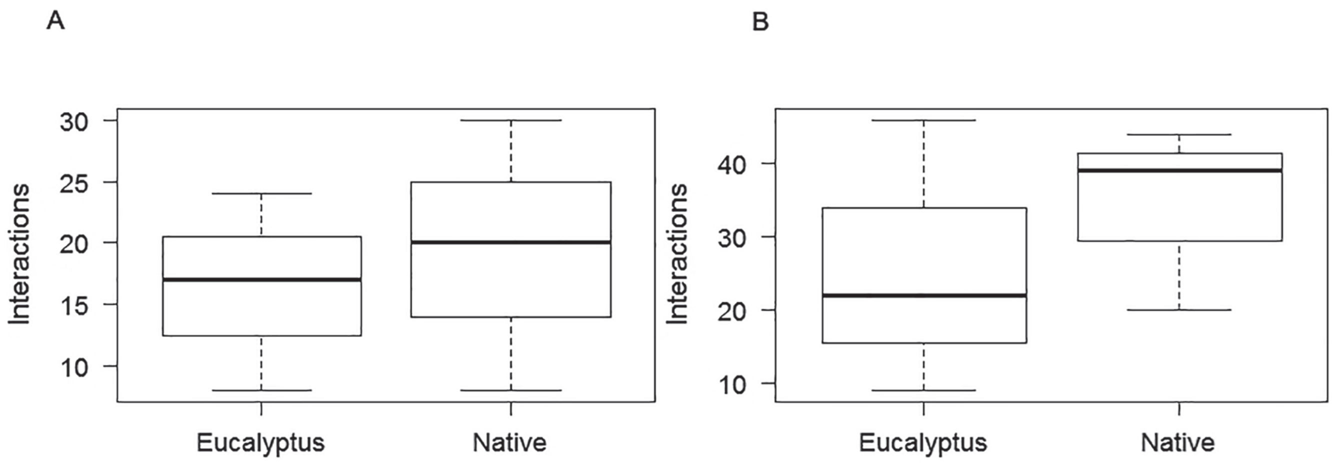

Figure 3. Comparison of the number of interactions between frugivorous birds and plants between native forest and eucalyptus plantation in the PEIT. (a): Fecal samples interactions (P-value = 0.83, W = 3.5); (b): Focal observation interactions (P-value = 0.99, W = 4.0).

observed in the interaction between *Neopelma chrysolophum* Pinto, 1944 (Pipridae) and *Miconia elegans* Cogn. (Melastomataceae). In the eucalyptus plantation, the highest degree of connection values was observed for the interaction between *Chiroxiphia caudata* (Shaw & Nodder, 1793; Pipridae) and the plant Morphospecies 1. Likewise, the degree of centrality showed that the bird *N. chrysolophum* and the plant *Miconia theaezans* Bonpl. were the pair of species with the highest number of interactions in the native forest network. In the eucalyptus plantation, the bird species *C. caudata* and the plant Morphospecies1, presented the highest degree of centrality values (Supplementary material 2).

In relation to the closeness centrality in both habitats, the bird species *C. caudata* and the plant *M. theaezans* were the ones that showed the highest proximity. The betweenness centrality metric showed that bird species *N. chrysolophum* and *C. caudata* presented the highest values in both habitats. The Dispersion Importance Index (DII) indicated *N. chrysolophum* and *Trichothraupis melanops* (Vieillot, 1818; Thraupidae) as the most important seed disperser bird species in the studied native forest; while in the eucalyptus plantation, *C. caudata* and *Tachyphonus coronatus* (Vieilott, 1822; Thraupidae) were the most important seed dispersers. Conversely, the Index of importance for plants (IVIP) indicated *M. theaezans* and *Leandra australis* Cham. (Melastomataceae) as the most important plants in native forest, while *Struthanthus concinnus* Mart. (Loranthaceae) and Morphospecies 1 were the most important plants in eucalyptus plantation (Supplementary material 2).

The network connectivity in the native forest obtained through the focal observations indicated the interaction between the tree *Schinus terebinthifolius* Raddi (Anacardiaceae) with the bird *Elaenia obscura* (d'Orbigny & Lafresnaye, 1837; Tyrannidae) as the one with the largest number of records. In the eucalyptus plantation, the greatest connectivity was observed for *M. valtheri* and *Tangara cyanoventris* (Vieillot, 1819; Thraupidae). The metrics of degree, closeness and betweenness centrality, in both habitats indicates that plants *Myrsine umbellate Mart.* (Primulaceae), *S. terebinthifolius,* and the bird *E. obscura* as the species with the highest number of links and importance for the network (Supplementary material 2). None of the network metrics showed significant statistical differences between native forest and eucalyptus plantations (Table 2). Also, according to the Sorensen Similarity Index, the frugivorous bird communities of both habitats presented a similarity of 0.71, while the zoochoric plant communities of both habitats presented a similarity of 0.72, indicating a high similarity (up to 70%) in the composition of species which play a role in seed dispersion in both habitats.

Table 2. Network metrics comparisons of mutualistic bird-plant interactions between native forest and eucalyptus plantation within the PEIT with the Man-Whitney Test (W) between the three applied methodologies (all of them P-value > 0.05).

Metrics	Focal observations	Mist nets
W / P – Value for C	2924.5 / 0.280	1066 / 0.684
W / P – Value for GC	918 / 0.477	585.5 / 0.940
W / P – Value for CC	845 / 0.198	477 / 0.168
W / P – Value for BC	948.5 / 0.648	608 / 0.848
W / P – Value for IVID	—	154 / 0.068
W / P – Value for IVIP	—	177 / 0.725

Finally, results for the modularity generated six groups of birds and plants more related to each other in both habitats, and these results were highly identical, with the values found from the mist nets (native forest: Q = 0.49, eucalyptus plantation: Q = 0.52) and focal observations (native forest: Q = 0.42, eucalyptus plantation: Q = 0.39), with an average of Q = 0.455 in the two habitats.

DISCUSSION

The richness of seed dispersing birds in the eucalyptus plantation and in native forest were similar. The interaction networks were remarkably similar in both habitats, partially corroborating the initial hypothesis. These similarities between the native forest and the eucalyptus plantation found in our study could be caused by environmental characteristics of the eucalyptus plantation; the area have not been disturbed by human extractive actions for 30 years, it remains close to the native forest fragments, and exhibit a well-developed understory. Similar results were found by Stallings (1991) and Machado & Lamas (1996), who observed that almost half of the species of mammals and birds found in the fragments of native forest were also found in eucalyptus plantations with well-developed understory; in contrast to the species found in eucalyptus plantations without understory. The understory can provide important habitat resources for wildlife species, thus improving the conservation value of eucalyptus plantations: Additionally, decreasing the use of herbicides during eucalyptus growth would allow the development of the understory and the maintenance of a greater biodiversity (Brockerhoff *et al.,* 2008; Pereira *et al.,* 2015). However, monocultures of introduced species, including those with a well-developed understory, certainly do not support all the diversity that would be found in a native forest (Brockerhoff *et al.,* 2013). Therefore, they must be avoided, always giving preference to the maintenance of native forests.

The results of the network metrics in the present study were moderately higher, at least for the degree of centrality and centrality by intermediate, when compared to those found by Mello *et al.* (2015), who evaluated the interaction networks of bird frugivory across the Neotropics, indicating that the patterns vary enormously between the interaction networks depending on the location. On the other hand, according to Vidal *et al.* (2014), the number of interactions between species in mutualistic networks is strongly associated with each species contribution to modularity, which would explain why the result of the Louvain modularity (Q) in this study was notoriously similar between the two types of habitats. Silva *et al.* (2002) also found a similarity of 70% of frugivorous birds between a fragment of non-protected Atlantic Forest and a conserved one, inside the Intervales state park in Brazil, which could indicate the efficiency of frugivory in impacted forests within reserves.

The study of Vidal *et al.* (2014) registered 59 species of frugivorous birds interacting with 42 species of zoochoric plants in a well-preserved area with 120,000 ha of continuous Atlantic Forest in the south of São Paulo State. Athie & Dias (2012) registered 38 species of birds interacting with 22 plants in fragments of 5 ha of reforested Atlantic Forest. Sarmento *et al.* (2014) registered 10 species of birds interacting with 39 species of plants in Atlantic Forest fragments surrounded by sugar cane plantations. These studies showed the influences of anthropogenic impacts on the interaction networks of frugivore birds and plants, with the human actions (mainly deforestation) decreasing the richness of birds, plants, and their interactions, with important changes in the composition of the community and its succession processes.

According to Lopes *et al.* (2005), in the Atlantic Forest domain, it is common to find intact seeds, mainly from the Melatomataceae family, in the stomach contents of the frugivorous birds of the families Thraupidae, Turdidae, and Pipridae. León (2010) also found that several species of the Thraupidae, Pipridae, and Tyrannidae families presented higher IVID values in the forests of Mexico, being the main seed dispersers. Among these families, Thraupidae is considered by Schleuning *et al.* (2014) as the most important group of seed dispersers in frugivory networks. In the present study, birds of the families Thraupidae, Pipridae, and Tyrannidae were the main seed dispersers in both native forest and eucalyptus plantation.

Fadini & De Marco (2004), Lopes *et al.* (2005) and Athie & Dias (2012) pointed out some of the same species found on the present study, such as *C. caudata, Tangara sayaca* (Linnaeus, 1766), *T. coronatus* and *Turdus rufiventris* Vieillot, 1818, as being fundamental to the interaction network of potential seed dispersers in the Atlantic Forest of the southeastern Brazil. These species are considered tolerant to the presence of exotic monocultural species, for having a generalist diet and a wide distribution, being equally registered in preserved native vegetation and in eucalyptus plantations along the Atlantic Forest domain (Machado & Lamas, 1996; Manhaes *et al.,* 2010). In other domains, such as in the *Cerrado* (savannah-like vegetation), bird *T. sayaca* also showed the highest interaction values (Purificação *et al.,* 2014), while in *Restinga* (sandbank vegetation) in southern Brazil *T. rufiventris* was one of the most important bird species (Scherer *et al.,* 2007), showing that some of these species are important seed dispersers also in other vegetation types.

According to Athie & Dias (2012), *S. terebinthifolius* is one of the most important plant species in a frugivory network in the Atlantic Forest and have also been recommended for restoration processes due to its rapid growth and its importance as a resource for the avifauna (Avila *et al.,* 2010) and entomofauna (Somavilla *et al.,* 2010; Sühs *et al.,* 2009). Manhaes *et al.* (2010) and Vidal *et al.* (2014) found many species of the genus *Miconia,* including *M. theaezans,* as important for the diet of birds and possibly for mutualistic networks, corroborating Snow (1981), who indicates the Melastomataceae family as the one with the largest number of species that offer food for seed dispersing frugivores in Neotropical forests, results in accordance with the findings of the present study. León (2010) found that several species of the genus *Ficus* (Moraceae) have high index of importance of plants values, being important for seed dispersion. However, plants of this genus were uncommon in the PEIT areas (Messias *et al.,* 2017), not being recorded in the interactions observed in the present study.

Most of the species of birds and plants were recorded in both habitats, and they are common in the Atlantic Forest of southeastern Brazil, being not considered sensitive to anthropogenic impacts and do not presenting habitat restrictions in the region (Snow, 2004; Messias *et al.,* 2017). The exceptions were the Swallow-Tailed Cotinga (*P. flavirostris*), registered only in the native forest and considered near threatened by Birdlife International (2016), and *M. valtheri,* a species of zoochoric tree registered for the first time in the PEIT (OUPR 34035), only in the eucalyptus plantation. This is a pioneer species like many others of the *Miconia* genus (Manhaes *et al.,* 2010; Vidal *et al.,* 2014).

CONCLUSION

Species richness and the complexity of interactions between frugivorous birds and zoochoric plants were similar in both, the abandoned eucalyptus plantation and native forests in the present study. This indicates a possibly same potential for seed dispersal in both studied forests, also suggesting the same potential for regeneration. Therefore, in the PEIT, the presence of the abandoned eucalyptus plantation is not being considered an obstacle to the regeneration of the Atlantic Forest, thanks to the fact that the natural succession process is being allowed in the understory. It is important to mention that adding more sampling points in different areas of the two habitats in future studies would increase the representativeness of the mutualistic interaction networks and the power of the analysis, resulting in more robust and refined information.

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AUTHORS' CONTRIBUTIONS

CVB: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Visualization, Investigation. Writing – review & editing. **MFOP:** Conceptualization, Methodology, Writing – original draft, Visualization, Investigation. Writing – review & editing. **CSA:** Supervision, Writing – review & editing. All the authors actively participated in the discussion of the results, they reviewed and approved the final version of the paper.

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SUPPLEMENTARY MATERIAL 1

Plants	Acronym	Birds	Acronym
Aegiphila integrifolia	Aegint	*Basileuterus culicivorus*	Bascul
Cupania vernalis	Cupver	*Chiroxiphia caudata*	Chicau
Fuchsia regia	Fucreg	*Coereba flaveola*	Coefla
Leandra australis	Leaaus	*Conopophaga lineata*	Conlin
Leandra glabrata	Leagla	*Dacnis cayana*	Daccay
Leandra melastomoides	Leamel	*Elaenia flavogaster*	Elafla
Marlieria excoriata	Marexc	*Elaenia mesoleuca*	Elames
Miconia chartacea	Miccha	*Elaenia obscura*	Elaobs
Miconia corallina	Miccor	*Elaenia* sp.	Elasp
Miconia elegans	Micele	*Euphonia chlorotica*	Eupchl
Miconia paniculata	Micpan	*Hemithraupis ruficapilla*	Hemruf
Miconia rimalis	Micrim	*Hylophilus poicilotis*	Hylpoi
Miconia theaezans	Micthe	*Ilicura militaris*	Ilimil
Miconia valtheri	Micval	*Knipolegus cyanirostris*	Knicya
Morphospecie 1	Morfo1	*Manacus manacus*	Manman
Morphospecie 2	Morfo2	*Mionectes rufiventris*	Mioruf
Morphospecie 3	Morfo3	*Myiarchus ferox*	Myifer
Myrcia splendens	Myrspl	*Myiophobus fasciatus*	Myifas
Myrcia vauthieriana	Myrval	*Myiothlypis leucoblephara*	Myileu
Myrsine coriacea	Myrcor	*Myiozetetes similis*	Myisim
Myrsine umbellata	Myrumb	*Neopelma chrysolophum*	Neocry
Phoradendron undulatum	Phound	*Pachyramphus viridis*	Pacvir
Piper sp.	Piper	*Penelope obscura*	Penobs
Poacea 1	Poac1	*Phaeomyias murina*	Phamur
Poacea 2	Poac2	*Phibalura flavirostris*	Phifla
Rudgea sessilis	Rudses	*Phyllomyias fasciatus*	Phyfas
Schinus terebintifolios	Schter	*Piranga flava*	Pirfla
Solanum cladotrichum	Solcla	*Pyriglena leucoptera*	Pyrleu
Struthanthus conccinnus	Strcon	*Saltator similis*	Salsim
Vismia parviflora	Vispar	*Schiffornis virescens*	Schvir
		Schistochlamys ruficapillus	Schruf
		Syndactila rufosupercilliata	Synruf
		Tachyphonus coronatus	Taccor
		Tangara cayana	Tancay
		Tangara cyanoventris	Tancya
		Tangara desmaresti	Tandes
		Tangara ornata	Tanorn
		Tangara sayaca	Tansay
		Tersina viridis	Tervir
		Thamnophilus caerulescens	Thacae
		Todirostrum poliocephalum	Todpoi
		Tolmomyias sulphurescens	Tolsul
		Trichothraupis melanops	Trimel
		Turdus albicollis	Turalb
		Turdus amaurochalinus	Turama
		Turdus leucomelas	Turleu
		Turdus rufiventris	Turruf
		Zonotrichia capensis	Zoncap

SUPPLEMENTARY MATERIAL 2

Metrics of species in the fragments of native atlantic forest (focal observation method)

Connectivity: 0.18775510				Centrality				Closeness				Betweenness			
Average degree: 3.75510204				Arithmetic mean: 3.7551				Arithmetic mean: 0.3536				Arithmetic mean: 0.0406			
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id
1	2-15	18.00000	Schter-Elaobs	1	1	18.0000	Myrumb	1	1	0.4948	Myrumb	1	1	0.3527	Myrumb
2	14-22	15.00000	Solcla-Tansay	2	2	15.0000	Schter	2	2	0.4752	Schter	2	2	0.2637	Schter
3	1-18	14.00000	Myrumb-Turruf	3	13	9.0000	Myrcor	3	15	0.4706	Elaobs	3	15	0.1776	Elaobs
4	2-18	13.00000	Schter-Turruf	4	3	8.0000	Micthe	4	18	0.4615	Turruf	4	13	0.1479	Myrcor
5	3-29	12.00000	Micthe-Tancya	5	15	7.0000	Elaobs	5	16	0.4364	Tandes	5	18	0.1153	Turruf
6	10-17	10.00000	Cupver-Salsim	6	11	7.0000	Micrim	6	19	0.4211	Elames	6	17	0.1017	Salsim
7	14-41	10.00000	Solcla-Penobs	7	4	7.0000	Aegint	7	17	0.4211	Salsim	7	7	0.0925	Myrspl
8	3-16	9.00000	Micthe-Tandes	8	18	7.0000	Turruf	8	13	0.4174	Myrcor	8	16	0.0867	Tandes
9	13-18	9.00000	Myrcor-Turruf	9	17	7.0000	Salsim	9	23	0.4000	Trimel	9	3	0.0716	Micthe
10	13-15	8.00000	Myrcor-Elaobs	10	7	6.0000	Myrspl	10	20	0.4000	Knicya	10	4	0.0675	Aegint
11	14-17	8.00000	Solcla-Salsim	11	16	6.0000	Tandes	11	25	0.3934	Daccay	11	11	0.0627	Micrim
12	2-22	7.00000	Schter-Tansay	12	21	5.0000	Tancay	12	11	0.3902	Micrim	12	5	0.0483	Vispar
13	2-41	6.00000	Schter-Penobs	13	32	5.0000	Turama	13	24	0.3871	Turleu	13	10	0.0451	Cupver
14	1-17	6.00000	Myrumb-Salsim	14	14	4.0000	Solcla	14	4	0.3840	Aegint	14	8	0.0417	Rudses
15	1-19	6.00000	Myrumb-Elames	15	12	4.0000	Myrval	15	29	0.3810	Tancya	15	21	0.0413	Tancay
16	2-21	6.00000	Schter-Tancay	16	5	4.0000	Vispar	16	22	0.3810	Tansay	16	27	0.0370	Hylpoi
17	12-17	4.00000	Myrval-Salsim	17	10	4.0000	Cupver	17	21	0.3810	Tancay	17	32	0.0359	Turama
18	7-15	4.00000	Myrspl-Elaobs	18	19	4.0000	Elames	18	7	0.3780	Myrspl	18	19	0.0339	Elames
19	13-48	4.00000	Myrcor-Mioruf	19	31	3.0000	Thacae	19	32	0.3750	Turama	19	23	0.0183	Trimel
20	7-18	4.00000	Myrspl-Turruf	20	29	3.0000	Tancya	20	5	0.3664	Vispar	20	20	0.0183	Knicya
21	5-15	4.00000	Vispar-Elaobs	21	28	3.0000	Taccor	21	31	0.3582	Thacae	21	29	0.0180	Tancya
22	13-19	4.00000	Myrcor-Elames	22	27	3.0000	Hylpoi	22	12	0.3556	Myrval	22	22	0.0148	Tansay
23	7-17	3.00000	Myrspl-Salsim	23	25	3.0000	Daccay	23	10	0.3556	Cupver	23	24	0.0136	Turleu
24	12-18	3.00000	Myrval-Turruf	24	24	3.0000	Turleu	24	30	0.3529	Tervir	24	25	0.0123	Daccay
25	3-37	3.00000	Micthe-Manman	25	23	3.0000	Trimel	25	27	0.3529	Hylpoi	25	14	0.0116	Solcla
26	10-18	3.00000	Cupver-Turruf	26	22	3.0000	Tansay	26	35	0.3429	Hemruf	26	35	0.0110	Hemruf
27	10-32	3.00000	Cupver-Turama	27	20	3.0000	Knicya	27	14	0.3404	Solcla	27	31	0.0108	Thacae
28	1-16	3.00000	Myrumb-Tandes	28	35	3.0000	Hemruf	28	3	0.3357	Micthe	28	36	0.0093	Ilimil
29	5-21	3.00000	Vispar-Tancay	29	41	2.0000	Penobs	29	40	0.3333	Pacvir	29	12	0.0086	Myrval
30	13-16	3.00000	Myrcor-Tandes	30	30	2.0000	Tervir	30	41	0.3333	Penobs	30	28	0.0076	Taccor
31	1-20	3.00000	Myrumb-Knicya	31	6	2.0000	Marexc	31	44	0.3333	Todpoi	31	30	0.0039	Tervir
32	13-36	3.00000	Myrcor-Ilimil	32	9	2.0000	Strcon	32	38	0.3333	Myifer	32	41	0.0038	Penobs
33	2-26	3.00000	Schter-Elasp.	33	36	2.0000	Ilimil	33	34	0.3333	Coefla	33	6	0.0026	Marexc
34	4-24	3.00000	Aegint-Turleu	34	8	2.0000	Rudses	34	46	0.3333	Phifla	34	9	0.0016	Strcon
35	9-36	2.00000	Strcon-Ilimil	35	43	1.0000	Tanorn	35	8	0.3265	Rudses	35	43	0.0000	Tanorn
36	1-24	2.00000	Myrumb-Turleu	36	37	1.0000	Manman	36	26	0.3243	Elasp.	36	48	0.0000	Mioruf
37	13-35	2.00000	Myrcor-Hemruf	37	44	1.0000	Todpoi	37	45	0.3243	Zoncap	37	26	0.0000	Elasp.

Connectivity: 0.18775510				Centrality				Closeness				Betweenness			
Average degree: 3.75510204				Arithmetic mean: 3.7551				Arithmetic mean: 0.3536				Arithmetic mean: 0.0406			
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id
38	2-19	2.00000	Schter-Elames	38	39	1.0000	Myisim	38	6	0.3097	Marexc	38	40	0.0000	Pacvir
39	14-21	2.00000	Solcla-Tancay	39	46	1.0000	Phifla	39	28	0.3077	Taccor	39	46	0.0000	Phifla
40	1-29	2.00000	Myrumb-Tancya	40	33	1.0000	Chicau	40	36	0.3000	Ilimil	40	47	0.0000	Pirfla
41	10-47	2.00000	Cupver-Pirfla	41	26	1.0000	Elasp.	41	48	0.2963	Mioruf	41	33	0.0000	Chicau
42	5-42	2.00000	Vispar-Schruf	42	40	1.0000	Pacvir	42	39	0.2791	Myisim	42	42	0.0000	Schruf
43	2-24	2.00000	Schter-Turleu	43	45	1.0000	Zoncap	43	43	0.2759	Tanorn	43	34	0.0000	Coefla
44	7-43	2.00000	Myrspl-Tanorn	44	42	1.0000	Schruf	44	49	0.2759	Turalb	44	37	0.0000	Manman
45	1-38	2.00000	Myrumb-Myifer	45	49	1.0000	Turalb	45	42	0.2697	Schruf	45	39	0.0000	Myisim
46	1-15	2.00000	Myrumb-Elaobs	46	48	1.0000	Mioruf	46	9	0.2652	Strcon	46	49	0.0000	Turalb
47	3-19	2.00000	Micthe-Elames	47	47	1.0000	Pirfla	47	47	0.2637	Pirfla	47	45	0.0000	Zoncap
48	2-45	1.00000	Schter-Zoncap	48	38	1.0000	Myifer	48	37	0.2526	Manman	48	44	0.0000	Todpoi
49	1-40	1.00000	Myrumb-Pacvir	49	34	1.0000	Coefla	49	33	0.2474	Chicau	49	38	0.0000	Myifer
50	11-16	1.00000	Micrim-Tandes												
51	11-21	1.00000	Micrim-Tancay												
52	1-44	1.00000	Myrumb-Todpoi												
53	1-23	1.00000	Myrumb-Trimel												
54	3-20	1.00000	Micthe-Knicya												
55	3-23	1.00000	Micthe-Trimel												
56	1-46	1.00000	Myrumb-Phifla												
57	3-28	1.00000	Micthe-Taccor												
58	12-31	1.00000	Myrval-Thacae												
59	12-32	1.00000	Myrval-Turama												
60	3-35	1.00000	Micthe-Hemruf												
61	2-16	1.00000	Schter-Tandes												
62	4-15	1.00000	Aegint-Elaobs												
63	4-18	1.00000	Aegint-Turruf												
64	1-25	1.00000	Myrumb-Daccay												
65	4-21	1.00000	Aegint-Tancay												
66	4-31	1.00000	Aegint-Thacae												
67	4-32	1.00000	Aegint-Turama												
68	2-20	1.00000	Schter-Knicya												
69	11-17	1.00000	Micrim-Salsim												
70	4-39	1.00000	Aegint-Myisim												
71	11-25	1.00000	Micrim-Daccay												
72	11-28	1.00000	Micrim-Taccor												
73	11-30	1.00000	Micrim-Tervir												
74	11-35	1.00000	Micrim-Hemruf												
75	5-17	1.00000	Vispar-Salsim												
76	1-30	1.00000	Myrumb-Tervir												
77	6-16	1.00000	Marexc-Tandes												
78	2-23	1.00000	Schter-Trimel												

Connectivity: 0.18775510				Centrality				Closeness				Betweenness			
Average degree: 3.75510204				Arithmetic mean: 3.7551				Arithmetic mean: 0.3536				Arithmetic mean: 0.0406			
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id
79	6-28	1.00000	Marexc-Taccor												
80	1-31	1.00000	Myrumb-Thacae												
81	2-25	1.00000	Schter-Daccay												
82	7-32	1.00000	Myrspl-Turama												
83	13-27	1.00000	Myrcor-Hylpoi												
84	13-29	1.00000	Myrcor-Tancya												
85	1-34	1.00000	Myrumb-Coefla												
86	7-49	1.00000	Myrspl-Turalb												
87	8-15	1.00000	Rudses-Elaobs												
88	2-27	1.00000	Schter-Hylpoi												
89	8-33	1.00000	Rudses-Chicau												
90	9-27	1.00000	Strcon-Hylpoi												
91	2-32	1.00000	Schter-Turama												
92	1-22	1.00000	Myrumb-Tansay												

Metrics of species in the fragments of eucalyptus forest (focal observations method)

Connectivity: 0.212121				Centrality				Closeness				Betweenness			
Average degree: 3.41463415				Arithmetic mean: 3.4146				Arithmetic mean: 0.3177				Arithmetic mean: 0.0349			
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id
1	2-14	14.00000	Micval-Tancya	1	1	18.0000	Schter	1	1	0.4778	Schter	1	1	0.3266	Schter
2	3-12	14.00000	Myrumb-Elaobs	2	2	13.0000	Micval	2	12	0.4450	Elaobs	2	2	0.2080	Micval
3	1-28	12.00000	Schter-Tansay	3	3	12.0000	Myrumb	3	2	0.4275	Micval	3	3	0.1982	Myrumb
4	1-19	10.00000	Schter-Elasp.	4	4	7.0000	Micthe	4	14	0.4219	Tancya	4	7	0.0736	Miccha
5	1-12	9.00000	Schter-Elaobs	5	5	6.0000	Aegint	5	18	0.4219	Tandes	5	12	0.0722	Elaobs
6	2-12	7.00000	Micval-Elaobs	6	7	5.0000	Miccha	6	3	0.4165	Myrumb	6	16	0.0703	Ilimil
7	2-18	7.00000	Micval-Tandes	7	6	5.0000	Fucreg	7	24	0.4112	Turruf	7	17	0.0640	Salsim
8	2-13	6.00000	Micval-Tancay	8	12	5.0000	Elaobs	8	21	0.4112	Phamur	8	5	0.0593	Aegint
9	1-38	6.00000	Schter-Phyfas	9	15	4.0000	Elafla	9	15	0.3914	Elafla	9	4	0.0543	Micthe
10	2-22	6.00000	Micval-Taccor	10	14	4.0000	Tancya	10	13	0.3914	Tancay	10	14	0.0394	Tancya
11	1-13	5.00000	Schter-Tancay	11	13	4.0000	Tancay	11	20	0.3734	Knicya	11	18	0.0355	Tandes
12	2-16	5.00000	Micval-Ilimil	12	18	4.0000	Tandes	12	4	0.3692	Micthe	12	13	0.0332	Tancay
13	2-24	5.00000	Micval-Turruf	13	16	4.0000	Ilimil	13	30	0.3650	Turama	13	15	0.0323	Elafla
14	3-14	4.00000	Myrumb-Tancya	14	24	3.0000	Turruf	14	29	0.3493	Todpoi	14	30	0.0311	Turama
15	7-17	4.00000	Miccha-Salsim	15	23	3.0000	Tolsul	15	27	0.3493	Tanorn	15	24	0.0203	Turruf
16	3-18	4.00000	Myrumb-Tandes	16	22	3.0000	Taccor	16	26	0.3493	Elames	16	21	0.0203	Phamur
17	2-20	3.00000	Micval-Knicya	17	21	3.0000	Phamur	17	38	0.3493	Phyfas	17	20	0.0145	Knicya
18	5-28	3.00000	Aegint-Tansay	18	20	3.0000	Knicya	18	36	0.3493	Myisim	18	6	0.0145	Fucreg
19	11-34	2.00000	Strcon-Mioruf	19	17	3.0000	Salsim	19	16	0.3420	Ilimil	19	25	0.0135	Chicau
20	3-24	2.00000	Myrumb-Turruf	20	30	2.0000	Turama	20	7	0.3384	Miccha	20	28	0.0058	Tansay

Connectivity: 0.212121				Centrality				Closeness				Betweenness			
Average degree: 3.41463415				Arithmetic mean: 3.4146				Arithmetic mean: 0.3177				Arithmetic mean: 0.0349			
Rank	**Line**	**Value**	**Line-Id**	**Rank**	**Vertex**	**Value**	**Line-Id**	**Rank**	**Vertex**	**Value**	**Line-Id**	**Rank**	**Vertex**	**Value**	**Line-Id**
21	1-15	2.00000	Schter-Elafla	21	29	2.0000	Todpoi	21	5	0.3384	Aegint	21	19	0.0058	Elasp.
22	3-38	2.00000	Myrumb-Phyfas	22	28	2.0000	Tansay	22	6	0.3315	Fucreg	22	26	0.0057	Elames
23	1-26	2.00000	Schter-Elames	23	27	2.0000	Tanorn	23	28	0.3282	Tansay	23	23	0.0055	Tolsul
24	2-15	2.00000	Micval-Elafla	24	26	2.0000	Elames	24	19	0.3282	Elasp.	24	22	0.0055	Taccor
25	4-22	2.00000	Micthe-Taccor	25	25	2.0000	Chicau	25	17	0.3282	Salsim	25	38	0.0053	Phyfas
26	5-15	2.00000	Aegint-Elafla	26	19	2.0000	Elasp.	26	25	0.3217	Chicau	26	29	0.0053	Todpoi
27	7-25	2.00000	Miccha-Chicau	27	38	2.0000	Phyfas	27	37	0.3154	Pacvir	27	27	0.0053	Tanorn
28	3-17	2.00000	Myrumb-Salsim	28	36	2.0000	Myisim	28	32	0.3154	Coefla	28	36	0.0053	Myisim
29	1-20	2.00000	Schter-Knicya	29	11	1.0000	Strcon	29	23	0.3094	Tolsul	29	10	0.0000	Rudses
30	1-14	2.00000	Schter-Tancya	30	10	1.0000	Rudses	30	22	0.3094	Taccor	30	31	0.0000	Bascul
31	7-30	1.00000	Miccha-Turama	31	35	1.0000	Myifas	31	40	0.2927	Trimel	31	40	0.0000	Trimel
32	8-16	1.00000	Miccor-Ilimil	32	40	1.0000	Trimel	32	31	0.2875	Bascul	32	9	0.0000	Myrval
33	1-36	1.00000	Schter-Myisim	33	9	1.0000	Myrval	33	35	0.2875	Myifas	33	32	0.0000	Coefla
34	10-39	1.00000	Rudses-Thacae	34	41	1.0000	Turalb	34	8	0.2499	Miccor	34	39	0.0000	Thacae
35	1-37	1.00000	Schter-Pacvir	35	31	1.0000	Bascul	35	33	0.2480	Eupchl	35	37	0.0000	Pacvir
36	1-21	1.00000	Schter-Phamur	36	39	1.0000	Thacae	36	41	0.2480	Turalb	36	34	0.0000	Mioruf
37	3-21	1.00000	Myrumb-Phamur	37	33	1.0000	Eupchl	37	9	0.2424	Myrval	37	11	0.0000	Strcon
38	3-27	1.00000	Myrumb-Tanorn	38	32	1.0000	Coefla	38	34	0.0488	Mioruf	38	35	0.0000	Myifas
39	3-29	1.00000	Myrumb-Todpoi	39	8	1.0000	Miccor	39	39	0.0488	Thacae	39	8	0.0000	Miccor
40	1-24	1.00000	Schter-Turruf	40	37	1.0000	Pacvir	40	11	0.0488	Strcon	40	41	0.0000	Turalb
41	3-31	1.00000	Myrumb-Bascul	41	34	1.0000	Mioruf	41	10	0.0488	Rudses	41	33	0.0000	Eupchl
42	3-35	1.00000	Myrumb-Myifas												
43	3-36	1.00000	Myrumb-Myisim												
44	4-12	1.00000	Micthe-Elaobs												
45	4-15	1.00000	Micthe-Elafla												
46	4-16	1.00000	Micthe-Ilimil												
47	4-18	1.00000	Micthe-Tandes												
48	1-27	1.00000	Schter-Tanorn												
49	1-18	1.00000	Schter-Tandes												
50	4-23	1.00000	Micthe-Tolsul												
51	4-26	1.00000	Micthe-Elames												
52	5-12	1.00000	Aegint-Elaobs												
53	5-13	1.00000	Aegint-Tancay												
54	2-21	1.00000	Micval-Phamur												
55	5-19	1.00000	Aegint-Elasp.												
56	1-29	1.00000	Schter-Todpoi												
57	5-33	1.00000	Aegint-Eupchl												
58	6-13	1.00000	Fucreg-Tancay												
59	2-23	1.00000	Micval-Tolsul												
60	6-14	1.00000	Fucreg-Tancya												
61	6-20	1.00000	Fucreg-Knicya												

Connectivity: 0.212121				Centrality				Closeness				Betweenness			
Average degree: 3.41463415				Arithmetic mean: 3.4146				Arithmetic mean: 0.3177				Arithmetic mean: 0.0349			
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id
62	1-30	1.00000	Schter-Turama												
63	6-22	1.00000	Fucreg-Taccor												
64	6-23	1.00000	Fucreg-Tolsul												
65	7-41	1.00000	Miccha-Turalb												
66	2-25	1.00000	Micval-Chicau												
67	9-17	1.00000	Myrval-Salsim												
68	7-16	1.00000	Miccha-Ilimil												
69	2-40	1.00000	Micval-Trimel												
70	1-32	1.00000	Schter-Coefla												

Metrics of species in the fragments of native atlantic forest (fecal analysis method)

Connectivity: 0.14705882				Centrality				Closeness				Betweenness				IVID		IVIP	
Average Degree: 2.70270270				Arithmetic mean: 2.7027				Arithmetic mean: 0.2895				Arithmetic mean: 0.0571							
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Line-Id	Value	Line-Id	Value
1	6-27	6.00000	Micele-Neocry	1	27	7.0000	Neocry	1	9	0.4232	Micthe	1	9	0.2516	Micthe	Neocry	1.08	Micthe	3.88
2	9-31	4.00000	Micthe-Trimel	2	21	7.0000	Chicau	2	27	0.3971	Neocry	2	27	0.2245	Neocry	Trimel	0.58	Leaaus	2.49
3	15-29	2.00000	Myrcor-Schvir	3	9	7.0000	Micthe	3	21	0.3971	Chicau	3	21	0.2230	Chicau	Chicau	0.58	Strcon	2.29
4	3-31	2.00000	Leamel-Trimel	4	30	6.0000	Taccor	4	12	0.3922	Morfo1	4	30	0.1515	Taccor	Taccor	0.42	Micele	1.83
5	12-24	2.00000	Morfo1-Manman	5	1	5.0000	Leaaus	5	29	0.3784	Schvir	5	29	0.1477	Schvir	Schvir	0.33	Morfo1	1.66
6	12-21	2.00000	Morfo1-Chicau	6	31	5.0000	Trimel	6	6	0.3740	Micele	6	24	0.1372	Manman	Manman	0.25	Morfo2	1.20
7	19-25	2.00000	Strcon-Mioruf	7	29	5.0000	Schvir	7	30	0.3614	Taccor	7	1	0.1348	Leaaus	Mioruf	0.17	Myrcor	1.04
8	9-30	2.00000	Micthe-Taccor	8	12	5.0000	Morfo1	8	1	0.3574	Leaaus	8	12	0.1216	Morfo1	Penobs	0.17	Leagla	1.04
9	12-30	2.00000	Morfo1-Taccor	9	24	5.0000	Manman	9	2	0.3496	Leagla	9	6	0.1162	Micele	Turalb	0.17	Morfo3	1.04
10	9-24	2.00000	Micthe-Manman	10	6	4.0000	Micele	10	31	0.3458	Trimel	10	15	0.1074	Myrcor	Bascul	0.08	Poac2	1
11	6-30	2.00000	Micele-Taccor	11	2	4.0000	Leagla	11	24	0.3458	Manman	11	2	0.1069	Leagla	Elaobs	0.08	Schter	1
12	14-24	2.00000	Morfo3-Manman	12	15	3.0000	Myrcor	12	14	0.3282	Morfo3	12	31	0.1030	Trimel	Ilimil	0.08	Leamel	0.57
13	19-27	2.00000	Strcon-Neocry	13	14	3.0000	Morfo3	13	15	0.3216	Myrcor	13	13	0.0524	Morfo2	Myileu	0.08	Aegint	0.5
14	18-28	2.00000	Schter-Penobs	14	7	2.0000	Micpan	14	8	0.3093	Micrim	14	19	0.0524	Strcon	Pyrleu	0.08	Micpan	0.34
15	12-22	1.00000	Morfo1-Elaobs	15	3	2.0000	Leamel	15	7	0.3034	Micpan	15	33	0.0524	Turruf	Synruf	0.08	Micrim	0.34
16	6-32	1.00000	Micele-Turalb	16	28	2.0000	Penobs	16	26	0.2951	Myileu	16	14	0.0334	Morfo3	Turruf	0.08	Miccor	0.2
17	2-29	1.00000	Leagla-Schvir	17	13	2.0000	Morfo2	17	23	0.2951	Ilimil	17	32	0.0306	Turalb	Thacae	0.08	Myrumb	0.2
18	7-24	1.00000	Micpan-Manman	18	32	2.0000	Turalb	18	3	0.2872	Leamel	18	28	0.0243	Penobs			Fucreg	0.17
19	7-27	1.00000	Micpan-Neocry	19	22	2.0000	Elaobs	19	19	0.2872	Strcon	19	8	0.0130	Micrim			Phound	0.17
20	2-31	1.00000	Leagla-Trimel	20	19	2.0000	Strcon	20	22	0.2846	Elaobs	20	7	0.0110	Micpan			Miccha	0.14
21	1-34	1.00000	Leaaus-Bascul	21	18	2.0000	Schter	21	4	0.2821	Miccha	21	3	0.0096	Leamel				
22	8-27	1.00000	Micrim-Neocry	22	8	2.0000	Micrim	22	32	0.2797	Turalb	22	18	0.0057	Schter				
23	8-31	1.00000	Micrim-Trimel	23	33	2.0000	Turruf	23	16	0.2726	Myrumb	23	22	0.0026	Elaobs				
24	3-30	1.00000	Leamel-Taccor	24	16	1.0000	Myrumb	24	28	0.2658	Penobs	24	23	0.0000	Ilimil				
25	9-23	1.00000	Micthe-Ilimil	25	26	1.0000	Myileu	25	11	0.2636	Fucreg	25	26	0.0000	Myileu				

Connectivity: 0.14705882				Centrality				Closeness				Betweenness				IVID		IVIP	
Average Degree: 2.70270270				Arithmetic mean: 2.7027				Arithmetic mean: 0.2895				Arithmetic mean: 0.0571							
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Line-Id	Value	Line-Id	Value
26	18-32	1.00000	Schter-Turalb	26	35	1.0000	Pyrleu	26	17	0.2636	Phound	26	35	0.0000	Pyrleu				
27	1-35	1.00000	Leaaus-Pyrleu	27	23	1.0000	Ilimil	27	34	0.2615	Bascul	27	16	0.0000	Myrumb				
28	1-27	1.00000	Leaaus-Neocry	28	36	1.0000	Synruf	28	35	0.2615	Pyrleu	28	36	0.0000	Synruf				
29	9-26	1.00000	Micthe-Myileu	29	5	1.0000	Miccor	29	13	0.2594	Morfo2	29	5	0.0000	Miccor				
30	9-27	1.00000	Micthe-Neocry	30	20	1.0000	Poac2	30	5	0.2553	Miccor	30	11	0.0000	Fucreg				
31	4-21	1.00000	Miccha-Chicau	31	37	1.0000	Thacae	31	33	0.2455	Turruf	31	25	0.0000	Mioruf				
32	9-29	1.00000	Micthe-Schvir	32	25	1.0000	Mioruf	32	18	0.2365	Schter	32	10	0.0000	Aegint				
33	12-27	1.00000	Morfo1-Neocry	33	11	1.0000	Fucreg	33	25	0.2218	Mioruf	33	4	0.0000	Miccha				
34	5-31	1.00000	Miccor-Trimel	34	34	1.0000	Bascul	34	37	0.2049	Thacae	34	17	0.0000	Phound				
35	13-24	1.00000	Morfo2-Manman	35	17	1.0000	Phound	35	10	0.1961	Aegint	35	20	0.0000	Poac2				
36	13-37	1.00000	Morfo2-Thacae	36	10	1.0000	Aegint	36	36	0.0541	Synruf	36	34	0.0000	Bascul				
37	14-21	1.00000	Morfo3-Chicau	37	4	1.0000	Miccha	37	20	0.0541	Poac2	37	37	0.0000	Thacae				
38	14-22	1.00000	Morfo3-Elaobs																
39	2-21	1.00000	Leagla-Chicau																
40	15-21	1.00000	Myrcor-Chicau																
41	10-33	1.00000	Aegint-Turruf																
42	15-33	1.00000	Myrcor-Turruf																
43	16-29	1.00000	Myrumb-Schvir																
44	17-30	1.00000	Phound-Taccor																
45	6-21	1.00000	Micele-Chicau																
46	11-30	1.00000	Fucreg-Taccor																
47	2-28	1.00000	Leagla-Penobs																
48	1-29	1.00000	Leaaus-Schvir																
49	20-36	1.00000	Poac2-Synruf																
50	1-21	1.00000	Leaaus-Chicau																

Metrics of species in the fragments of eucalyptus forest (fecal analysis method)

Connectivity: 0.16599190				Centrality				Closeness				Betweenness				IVID		IVIP	
Average Degree: 2.562500				Arithmetic mean: 2.5625				Arithmetic mean: 0.2627				Arithmetic mean: 0.0642							
Rank	Line	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Rank	Vertex	Value	Line-Id	Line-Id	Value	Line-Id	Value
1	11-20	6.00000	Morfo1-Chicau	1	20	9.0000	Chicau	1	20	0.4160	Chicau	1	20	0.3627	Chicau	Chicau	1.48	Strcon	6.67
2	11-21	5.00000	Morfo1-Elaobs	2	27	7.0000	Taccor	2	11	0.3524	Morfo1	2	25	0.2112	Neocry	Taccor	0.82	Morfo1	3.25
3	13-21	5.00000	Morfo3-Elaobs	3	11	5.0000	Morfo1	3	7	0.3429	Micthe	3	27	0.1935	Taccor	Elaobs	0.82	Leagla	1.40
4	16-24	4.00000	Strcon-Mioruf	4	21	5.0000	Elaobs	4	5	0.3429	Micele	4	11	0.1748	Morfo1	Neocry	0.66	Morfo3	1.36
5	15-27	3.00000	Phound-Taccor	5	23	4.0000	Manman	5	27	0.3383	Taccor	5	16	0.1677	Strcon	Mioruf	0.66	Micthe	1.06
6	4-20	3.00000	Miccha-Chicau	6	16	4.0000	Strcon	6	12	0.3339	Morfo2	6	7	0.1324	Micthe	Ilimil	0.33	Poac2	1
7	1-27	2.00000	Leaaus-Taccor	7	7	3.0000	Micthe	7	23	0.3295	Manman	7	12	0.1183	Morfo2	Zoncap	0.33	Myrcor	0.73
8	9-21	2.00000	Myrcor-Elaobs	8	30	3.0000	Tancay	8	14	0.3253	Fucreg	8	5	0.1169	Micele	Conlin	0.16	Micele	0.59

Connectivity: 0.16599190				Centrality				Closeness				Betweenness				IVID		IVIP	
Average Degree: 2.562500				Arithmetic mean: 2.5625				Arithmetic mean: 0.2627				Arithmetic mean: 0.0642							
Rank	**Line**	**Value**	**Line-Id**	**Rank**	**Vertex**	**Value**	**Line-Id**	**Rank**	**Vertex**	**Value**	**Line-Id**	**Rank**	**Vertex**	**Value**	**Line-Id**	**Line-Id**	**Value**	**Line-Id**	**Value**
9	7-25	2.00000	Micthe-Neocry	9	14	3.0000	Fucreg	9	13	0.3253	Morfo3	9	21	0.1137	Elaobs	Manman	0.16	Miccha	0.53
10	2-27	2.00000	Leagla-Taccor	10	13	3.0000	Morfo3	10	2	0.3253	Leagla	10	23	0.0805	Manman	Phyfas	0.16	Fucreg	0.50
11	18-29	2.00000	Poac1-Zoncap	11	25	3.0000	Neocry	11	1	0.3172	Leaaus	11	22	0.0770	Ilimil	Schvir	0.16	Poac1	0.5
12	16-25	2.00000	Strcon-Neocry	12	2	3.0000	Leagla	12	4	0.3095	Miccha	12	2	0.0730	Leagla	Tancay	0.16	Micval	0.44
13	8-20	1.00000	Micval-Chicau	13	22	3.0000	Ilimil	13	8	0.3021	Micval	13	30	0.0625	Tancay	Trimel	0.16	Morfo2	0.44
14	8-30	1.00000	Micval-Tancay	14	5	3.0000	Micele	14	25	0.2985	Neocry	14	13	0.0433	Morfo3			Phound	0.43
15	4-21	1.00000	Miccha-Elaobs	15	12	2.0000	Morfo2	15	21	0.2917	Elaobs	15	8	0.0320	Micval			Leaaus	0.40
16	16-26	1.00000	Strcon-Schvir	16	1	2.0000	Leaaus	16	22	0.2728	Ilimil	16	14	0.0318	Fucreg			Leamel	0.33
17	17-27	1.00000	Piper-Taccor	17	29	2.0000	Zoncap	17	30	0.2671	Tancay	17	9	0.0231	Myrcor			Micrim	0.33
18	9-22	1.00000	Myrcor-Ilimil	18	9	2.0000	Myrcor	18	28	0.2563	Trimel	18	4	0.0222	Miccha			Myrumb	0.2
19	5-20	1.00000	Micele-Chicau	19	4	2.0000	Miccha	19	15	0.2488	Phound	19	1	0.0149	Leaaus			Piper	0.14
20	10-21	1.00000	Myrumb-Elaobs	20	8	2.0000	Micval	20	9	0.2488	Myrcor	20	29	0.0022	Zoncap				
21	5-22	1.00000	Micele-Ilimil	21	3	1.0000	Leamel	21	17	0.2488	Piper	21	28	0.0000	Trimel				
22	11-23	1.00000	Morfo1-Manman	22	24	1.0000	Mioruf	22	32	0.2417	Conlin	22	32	0.0000	Conlin				
23	5-27	1.00000	Micele-Taccor	23	28	1.0000	Trimel	23	16	0.2394	Strcon	23	24	0.0000	Mioruf				
24	2-32	1.00000	Leagla-Conlin	24	15	1.0000	Phound	24	10	0.2226	Myrumb	24	15	0.0000	Phound				
25	11-28	1.00000	Morfo1-Trimel	25	18	1.0000	Poac1	25	6	0.2115	Micrim	25	26	0.0000	Schvir				
26	11-30	1.00000	Morfo1-Tancay	26	17	1.0000	Piper	26	3	0.2080	Leamel	26	19	0.0000	Poac2				
27	6-22	1.00000	Micrim-Ilimil	27	26	1.0000	Schvir	27	26	0.1908	Schvir	27	10	0.0000	Myrumb				
28	12-20	1.00000	Morfo2-Chicau	28	31	1.0000	Phyfas	28	31	0.1908	Phyfas	28	6	0.0000	Micrim				
29	12-25	1.00000	Morfo2-Neocry	29	10	1.0000	Myrumb	29	24	0.1908	Mioruf	29	31	0.0000	Phyfas				
30	7-23	1.00000	Micthe-Manman	30	32	1.0000	Conlin	30	29	0.0938	Zoncap	30	17	0.0000	Piper				
31	14-23	1.00000	Fucreg-Manman	31	19	1.0000	Poac2	31	18	0.0625	Poac1	31	18	0.0000	Poac1				
32	14-27	1.00000	Fucreg-Taccor	32	6	1.0000	Micrim	32	19	0.0625	Poac2	32	3	0.0000	Leamel				
33	3-30	1.00000	Leamel-Tancay																
34	13-20	1.00000	Morfo3-Chicau																
35	13-23	1.00000	Morfo3-Manman																
36	14-20	1.00000	Fucreg-Chicau																
37	16-31	1.00000	Strcon-Phyfas																
38	7-27	1.00000	Micthe-Taccor																
39	2-20	1.00000	Leagla-Chicau																
40	19-29	1.00000	Poac2-Zoncap																
41	1-20	1.00000	Leaaus-Chicau																

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