

Structure and Composition of Atlantic Forest Fragments Inhabited by *Callicebus coimbrai* in Northeastern Brazil: Subsidies for Landscape Management Strategies

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Recebido em 27/11/2020 – Aceito em 03/02/2021

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ABSTRACT – Characterizing the *habitat* structure, identifying the functionality of tree species is an important strategy to assist in management programs. This study aimed to characterize the *habitat*'s structure, identify the ecological composition and the type of tree dispersion syndrome in fragments inhabited by the threatened *Callicebus coimbrai* in the Sergipe Atlantic Forest. A total of eight transects were covered by the errant quadrant method, with 780 points recorded in 3,166.71 m. At each point, we collected the DBH, height, the distance between two points (trees), in addition to the identification of the tree species. We analyzed abundance, density, frequency, basal dominance, Importance Value Index, in addition to the calculation of the Pielou diversity and Equitability index. The average distance between the sampled points (trees) was 4.05 ± 2.75 m, the mean tree height was 11.69 ± 3.10 m, and the mean DBH was 25.75 ± 13.53 cm, with few significant differences between the fragments. In general, the structures are unstable, and the composition of the trees is formed mainly by early pioneer and secondary species and species with zoochoric dispersion syndrome. These places possess an unstable structure for titi monkeys to inhabit. Besides, they are distant from other places, making it difficult for individuals to move. These results show the importance of characterizing the structure, using the ecological traces of trees to measure *habitat* quality, and assisting management programs to preserve and conserve threatened species and their *habitat*.

Keywords: Pitheciidae; *Callicebus*; tree succession; phytosociology; diversity.

Estrutura e Composição de Fragmentos de Mata Atlântica Habitados por *Callicebus coimbrai* no Nordeste do Brasil: Subsídios para Estratégias de Manejo da Paisagem

RESUMO – Caracterizar a estrutura do *habitat*, identificando a funcionalidade de espécies arbóreas, é uma estratégia importante para auxiliar programas de manejo. Este estudo objetivou caracterizar a estrutura do *habitat*, identificar a composição ecológica e o tipo de síndrome de dispersão das árvores em fragmentos habitados pelo ameaçado de extinção *Callicebus coimbrai*, Mata Atlântica em Sergipe. Foram percorridos oito transectos pelo método do quadrante errante, com 780 pontos registrados em 3.166,71m percorridos. Em cada ponto, coletamos o DAP, altura, distância entre dois pontos (árvores), além da identificação da espécie de árvore. Analisamos abundância, densidade, frequência, dominância basal, índice de valor de importância, além do cálculo do índice de diversidade e equitabilidade de Pielou. A distância média entre as árvores foi de $4,05 \pm 2,75$ m, a altura média foi de $11,69 \pm 3,10$ m, e o DAP médio foi de $25,75 \pm 13,53$ cm, com poucas diferenças significativas entre os fragmentos. Em geral, as estruturas são pobres e a composição das árvores é formada principalmente por espécies pioneiras e secundárias iniciais, e espécies com síndrome de dispersão zoocórica.

Esses locais apresentam uma estrutura instável para os macacos guigós habitarem. Além disso, estão distantes de outros locais, dificultando a movimentação dos indivíduos. Esses resultados mostram a importância de caracterizar a estrutura, utilizar os traços ecológicos das árvores como medida da qualidade do *habitat*, auxiliando programas de manejo que visem a preservação e conservação de espécies ameaçadas e seus *habitat*.

Palavras-chave: Pitheciidae; *Callicebus*; sucessão de árvores; fitossociologia; diversidade.

Estructura y Composición de los Fragmentos de Mata Atlántica Habitados por *Callicebus coimbrai* en el Noreste de Brasil: Subsídios para Estrategias de Gestión del Paisaje

RESUMEN – Caracterizar la estructura del *habitat*, identificar la funcionalidad de las especies arbóreas es una estrategia importante para ayudar en los programas de manejo. Este estudio tuvo como objetivo caracterizar la estructura del *habitat*, identificar la composición ecológica y el tipo de síndrome de dispersión de árboles en fragmentos del Mata Atlántica, Sergipe, habitados por el *Callicebus coimbrai*, en peligro de extinción. Se atravesaron ocho transectos utilizando el método de cuadrante errante, con 780 puntos registrados en 3.166,71 m atravesados. En cada punto, recolectamos DAP, altura, distancia entre dos puntos (árboles), además de la identificación de la especie arbórea. Analizamos abundancia, densidad, frecuencia, dominancia basal, índice de valor de importancia, además de calcular el índice de diversidad y equidad de Pielou. La distancia promedio entre los árboles fue de 4.05 ± 2.75 m, la altura promedio fue de 11.69 ± 3.10 m, y el DAP promedio fue de 25.75 ± 13.53 cm, con pocas diferencias significativas entre los fragmentos. En general las estructuras son deficientes y la composición de los árboles está formada principalmente por especies iniciales – pioneras y secundarias – y especies con síndrome de dispersión zoocrónica. Estos lugares presentan una estructura inestable para que habiten los monos guigo. Además, están lejos de otros lugares, lo que dificulta la movilidad de las personas. Estos resultados muestran la importancia de caracterizar la estructura, utilizando los rasgos ecológicos de los árboles como medida de la calidad del *hábitat*, ayudando a los programas de manejo orientados a la preservación y conservación de las especies amenazadas y sus *habitat*.

Palabras clave: Pitheciidae; *Callicebus*; sucesión de árboles; fitosociología; diversidad.

Introduction

Natural landscapes currently undergo severe transformations in their structure and distribution, mainly due to anthropic disturbance (Fahrig, 2003; Haddad *et al.*, 2015). Habitat loss seriously threatens biodiversity conservation, mainly in tropical areas (Arroyo-Rodríguez & Mandujano, 2009; Melo *et al.*, 2018). Most of the remaining natural areas consist of small fragments immersed in a non-habitat matrix, with strong edge effects (Magnago *et al.*, 2015). Consequently, the forest composition and structure may suffer essential changes, with a decrease of large trees and an overall simplification of forest structure due to habitat isolation and subsequently edge effects (Rocha-Santos *et al.*, 2016). This shifting in the habitat may have severe consequences on arboreal animal species, which depend almost exclusively on arboreal trees (Santos *et al.*, 2016, 2019). Considering forest-dwelling species, such as Neotropical primates, the combination of those factors may be crucial to their diversity (Gouveia *et al.*, 2014) and maintenance (Terborgh, 1983; Kinzey, 1997).

Qualifying the vegetation structure and quantifying its representative portion in forest remnants, along with identifying its tree composition, are potent approaches to verify forest fragments' quality and forest dynamics, identify possible territories to conserve, and support management programs (Felfili, 1997). Analyzing the physical structure of habitat through the Diameter values at Breast Height (DBH) or tree height, for example, along with phytosociological studies, such as tree's species dominance and frequency, may assist in understanding forest dynamics and stability (Felfili & Rezende, 2003, Magnano *et al.*, 2005; Williams-Limera, 2011; Gustafsson, 2016). The classical trade-off between DBH and tree height is widely recognized, a plant strategy to allocate resources to its vegetative growth (Iida *et al.*, 2011; Sumida *et al.*, 2013). In parallel, an area dominated by light-demanding trees may indicate a forest in the initial/second stage of succession or a forest with strong forest edge effects and disturbed (Felfili, 1997).

Another aspect to consider is the ecological species groups, which correspond to the type of succession that a species belongs to and share some crucial characteristics related to the habitat structure (Swaine & Whitmore, 1988, Kageyama & Castro, 1989; Lorenzi, 1992). Overall, there are two main groups – shade-intolerant and shade-tolerant (Swaine & Whitmore, 1988). The shade-intolerant (pioneer and early secondary) species exhibits a fast growth rate, a low wood density, and inhabits forest edges, gaps, and any forest in the initial stage of succession (Poorter *et al.*, 2008; Wright *et al.*, 2010; Gustafsson *et al.*, 2016). The shade-tolerant species (late secondary and climax), on the other, have a low growth rate, a high wood density, needing shaded microhabitats in the first stages of its development, and thus, avoiding gaps and forest edges (King *et al.*, 2006; Rozendaal *et al.*, 2006; Gustafsson *et al.*, 2016). This generic classification allows understanding the ecological succession, anthropogenic disturbances, and how the vegetation structure is within forests.

Finally, identifying and analyzing parameters such as dispersal syndromes may help understand habitat loss's effects on the plant community. Dispersal syndrome consists of sets of fruit or seed traits related to dispersing agents (Pijl, 1982), and, in general aspects, it may be of three primary types: anemochory (dispersal by wind), autochory (dispersal by auto-dispersing mechanism), and zoochory (dispersal by animals). Overall, habitat loss has a strong influence on zoochory species, once hindering animal species – including important seed dispersers – movements in non-forest habitats (Howe & Smallwood, 1982; Domingues *et al.*, 2013). The anemochory and autochory species are more likely to occur in open areas due to their dispersal facilities (Howe & Smallwood, 1982; Vieira, 2002). Therefore, areas with low zoochory species rates may indicate a continued habitat loss process and an intense defaunation process (Redford, 1992; McConkey *et al.*, 2012; Costa *et al.*, 2014).

Primates are essential for the recruitment of zoochoric species (Stevenson, 2007; Bueno *et al.*, 2013), acting directly on seed dispersal (Fuzessy *et al.*, 2018), including the endangered Coimbra's titi monkey (*Callicebus coimbrai* Kobayashi & Langguth, 1999; Baião, 2013). This arboreal primate inhabits forest fragments exclusively from the Atlantic Forest of Bahia and Sergipe in the Brazilian northeastern (Jerusalinsky & Souza-

Alves, 2015; Hilário *et al.*, 2017). The species is endemic to the narrow strip between the Paraguaçu River in Bahia, and the south of São Francisco River, in Sergipe (Printes, 2005; Jerusalinsky *et al.*, 2006; Marques *et al.*, 2013; Culot *et al.*, 2018). Like most biomes (Ribeiro *et al.*, 2009; Rezende *et al.*, 2018), this region has been devastated by deforestation, with few more than 10% of forest remnants (Santos *et al.*, 2013; Marques *et al.*, 2017). Sergipe state faces a similar situation, where federal, state, or private protected areas safeguard only 1.4% of its remaining forest cover (MMA, 2010). The Mata do Junco Wildlife Refuge and the Private Reserves of Natural Heritage (RPPN) Bom Jardim and Tapera are relatively recent prominent protected areas, established with the primary aim of protecting the local population of *Callicebus coimbrai* within others (Brasil, 2006; SEMARH, 2007). Agropastoral areas, such as sugar-cane and pasture, urban areas, and small ranches, dominate the local landscape, encompassing a range of forest fragments of different sizes and degrees of preservation. Some, but not all, hold titi monkeys' populations (Marques *et al.*, 2013).

According to Santos (2011), *Callicebus coimbrai* stands out for possessing a critical relationship between its occurrence and the habitat quality (floristic composition and habitat structure), probably to the species' detriment ecological-structural needs, such as dependence on forested habitats to perform several daily activities. In Sergipe Atlantic Forest, a hotspot for the species occurrence, studies on aspects of its distribution associated with habitat structure and functional diversity of tree species are still scarce regarding their ecological groups and their dispersion syndromes (Beltrão-Mendes, 2010; Soares *et al.*, 2011; Souza-Alves *et al.*, 2014; Chagas & Ferrari, 2010; Souza-Alves *et al.*, 2018).

Therefore, understanding the forest structure and composition is crucial for the species' conservation. Given the potential of this area for titi monkeys conservation (Gouveia *et al.*, 2017), the present study focused on characterizing the forest structure and verifying the composition, ecological groups, and dispersal syndrome in six forest remnants located within this landscape, on assisting in the development of management strategies for these areas. Additionally, we provide the first systematic data on the composition of the arboreal habitats within this area.

Methods

Study area

We focused the present study on six Atlantic Forest fragments located in two municipalities - Capela and Santa Luzia do Itanhy, North and South of Sergipe, respectively (Fig. 1). Three out of the six fragments are Protected areas: Mata do Junco Wildlife Refuge, RPPN Bom Jardim, and RPPN Tapera. The RPPN (an acronym for Private Reserve of Natural Heritage, in Portuguese) is a protected area of a private domain. The mean annual temperature is 24.8°C - with temperatures ranging from 18.4°C to 31.8°C - and the mean annual precipitation concentrate in May (Climate-data.org, 2020 a, b). The vegetation type consists of ombrophilous dense forest (IBGE, 2012), distributed in small and isolated fragments, surrounded by pastures and agriculture crops (Fig. 1).

We selected the fragments to sample representative habitats of the landscape, either with titi monkeys' presence. We surveyed the six study sites between 2011 and 2016. Each fragment's size and configuration influenced the differences in transect length and the number of sampling points at each site. In some cases, deposits of domestic waste, erosion, or burnt vegetation impeded progress.

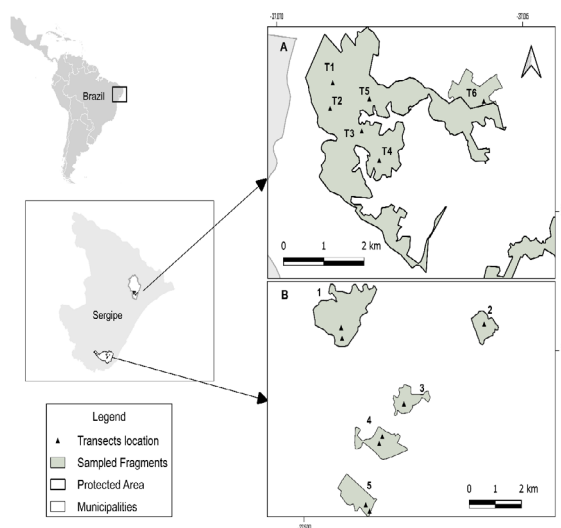


Figure 1 – Location of transects in the sampling areas, where: A) Mata de Junco Wildlife Refuge; B) Santa Luzia do Itanhy Fragments; T1) Transect 1; T2) Transect 2; T3) Transect 3; T4) Transect 4; T5) Transect 5; T6) Transect 6; 1) RPPN Bom Jardim; 2) RPPN Tapera; 3) SLI1; 4) SLI2; 5) SLI3. Geographic Coordinate System, Datum WGS 84.

Data sampling

We performed the wandering quarter method (Catana, 1963; Brower *et al.*, 1997) in each site sampling. The method consists of choosing a peripheral starting point, then selecting a compass point, according to the fragment configuration - to ensure maximum transect length - and we identified the nearest tree within 45° of either side of this line. We collected the following data in each sampled point (tree): species identification (scientific or common name); the distance (m) between the two points (trees); the tree height; and its diameter at breast height (DBH \geq 15cm of diameter, \approx 45cm of circumference). Only the Mata do Junco Wildlife Refuge had six transects (the closest transects were brought together, totaling three sampling areas - T1+T2 = MJWR1, T3+T4 = MJWR2; T5+T6 = MJWR and the other areas had a transect/area proportion. We perform statistical analyses through the mean value for these variables. An expert local field assistant assists us in obtaining the common name of each species. We marked each tree and collected a sample for identification at the herbarium of the Universidade Federal de Sergipe (UFS), at São Cristóvão, Sergipe, Brazil.

Data analysis

Tree diversity, Habitat Structure, and Phytosociological analysis

Through the Shannon-Wiener diversity index and the Pielou's Evenness Index (Oliveira & Amaral, 2004), we calculated the species richness and species evenness, respectively. The Pielou's Evenness Index ranges from 0 to 1, wherein values close to 0 indicate less evenness, consequently, the presence of one, or few, dominant species (Margurran, 2004). Shannon-Wiener diversity's values usually range from 1.5 to 3.5, rarely trespassing 4.0 (Margurran, 2004). Consequently, many statistics consider the index little representative, especially if we are comparing areas. In our case, we opted for the One-Way ANOVA test on RStudio 4.0.3 software (RStudio Team, 2020) to compare the sites, including the evenness to facilitate the results' interpretation. For this analysis, we compare the Shannon-Wiener and Pielou's Evenness values of three groups: MJWR, RPPN, and SLI.

To understand the grouping and spatial organization of tree species, we performed a Jaccard similarity index. The index is calculated using a matrix of presence ($p = 1$) and absence ($p = 0$) of

the species for each transect, using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA), through the software Past 3.16 (Hammer *et al.*, 2013).

We applied ANOVA to compare block designs (using transects as independent samples) according to their DBH, tree height, and distance between points. In statistical difference, we performed a pairwise comparison with the Kruskal-Wallis non-parametric test. We performed Pearson's correlation analyses to identify possible correlations between DBH, tree height, and distance between points in each transect. We treated the DBH and tree height as the two dependent variables and the distance between points as the independent variables. We performed all statistical analyzes using the Past 3.16 application (Hammer *et al.*, 2013).

Through a phytosociological methodology, we characterized the vegetation structure, analyzing the following main parameters: abundance, density (Relative Density – ReDe), frequency (Relative Frequency – ReFe), basal dominance (Relative Dominance - ReDo), and Importance Value Index (IVI) of each species per area (Felfili & Rezende, 2003). To estimate the volumetric parameters, such as basal area (g), referring to the sum of each individual's diameters belonging to a species, equation 1, proposed by Scolforo *et al.* (2008).

Ecological groups and dispersal syndrome

We classified the identified species in one of four ecological groups, concerning the succession categories in nature – pioneer, early secondary

(shade-intolerant or light-demanding), late secondary, or climax (shade-tolerant) – according to classification Swaine & Whitmore (1988) and Gandolfi *et al.* (1995).

Based on the morphological characteristics and the classification of the types of fruits (Barroso *et al.*, 2004; Lorenzi *et al.*, 2006), we categorized the tree species according to their dispersion syndromes (anemochory, autochory, and zoochory), based on Pijl (1982) and Santana *et al.* (2018).

Results

We covered 3,166.71m in all eight transects (MJWR = 1208.56m; Santa Luzia Itanhy = 1,958.15m), totaling 780 sampled points/trees (Table 1). Among these 780 sampled points, we identify the tree species of 645 points (83%), distributed in 47 species of 26 families (Table S.1).

Tree diversity, habitat structure, and Phytosociological analysis

Overall, the transects present similar tree diversity ($F(2, 5) = 1,2418; p > 0.05$) and evenness ($F(2,5) = 1.1629; p > 0.05$). Collectively, for both indexes, MJWR presented the highest values (Fig. 2A), while the RPPN group presented the lowest diversity and the SLI groups presented the lowest evenness (Fig. 2B). Nevertheless, all the sampled transects presented high evenness (Table S.2). 1

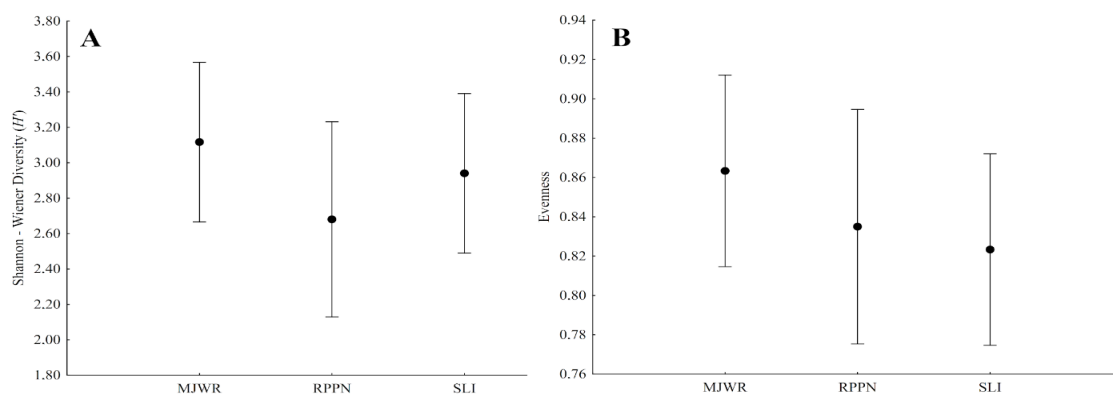


Figure 2 – Diversity (A) and Evenness (B) indexes from the three main groups used in one-way ANOVA tests. Vertical bars denote 0,95 confidence intervals. MJWR= Mata do Junco Wildlife Refuge; RPPN Bom Jardim= Reserva Particular do Patrimônio Natural Bom Jardim; RPPN Tapera= Reserva Particular do Patrimônio Natural Tapera; SLI= Santa Luzia Itanhy fragment.

Concerning the floristic composition, the clusters and subclusters reflect the sampled areas' spatial location, which presented low similarity (Jaccard = 0.20). The MJWR and Santa Luzia Itahny transects form two main clusters (Fig. 3). The transects MJWR2 and MJWR3 had the largest shares among themselves (Jaccard = 0.48), those considered closest (Fig. 3). In summary, the closest fragments/transects show a higher similarity (Fig. 3).

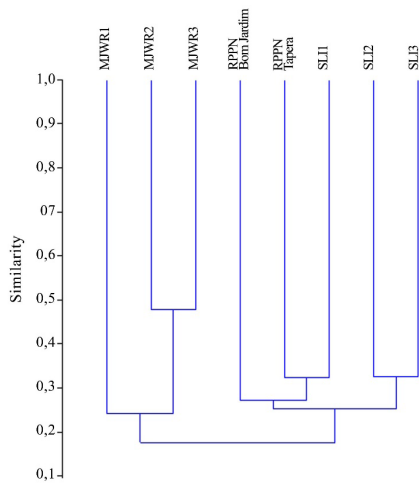


Figure 3 – Dendrogram of the sampled fragments, showing the formation of clusters that indicate similarity between areas. MJWR= Mata do Junco Wildlife Refuge; RPPN Bom Jardim= Reserva Particular do Patrimônio Natural Bom Jardim; RPPN Tapera= Reserva Particular do Patrimônio Natural Tapera; SLI= Santa Luzia Itahny fragments.

The average distance between the sampled points (trees) was $4.05 \pm 2.75\text{m}$ (Table S.3; Fig. 4A), the mean tree height was $11.69 \pm 3.10\text{m}$ (Table S.3; Fig. 4B), and the mean DBH was $25.75 \pm 13.53\text{cm}$ (Table S.3; Fig. 4C). MJWR transects had the majority of the three parameters' highest values, mainly for DBH and Distance (Table A.3). Only one transect in the MJWR (MJWR3) presented a mean tree height $> 12\text{m}$ (Table A.3). The ANOVA analysis attests to the differences between the transects in some analyzed parameters ($p\text{-value} < 0.05$). Concerning the DBH parameter, the Kruskal-Wallis non-parametric test highlights no significant differences between MJWR transects and RPPN Tapera, presenting the highest DBH (Fig. 4). Conversely, the RPPN Bom Jardim, SLI1, SLI2, and SLI3 had DBH differences ($p\text{-value} < 0.05$; Fig. 4). The tree height was different in all transects ($p\text{-value} < 0.05$), while the distance between points presented no significant differences (Fig. 4).

In the RPPN Bom Jardim, the tree height increases as the distance between points also increase (Pearson's correlation = 0.222; $p\text{-value} < 0.05$), while in the MJWR transects, the highest the DBH, the highest the distance between the points (Pearson's correlation = 0.121; $p\text{-value} < 0.05$).

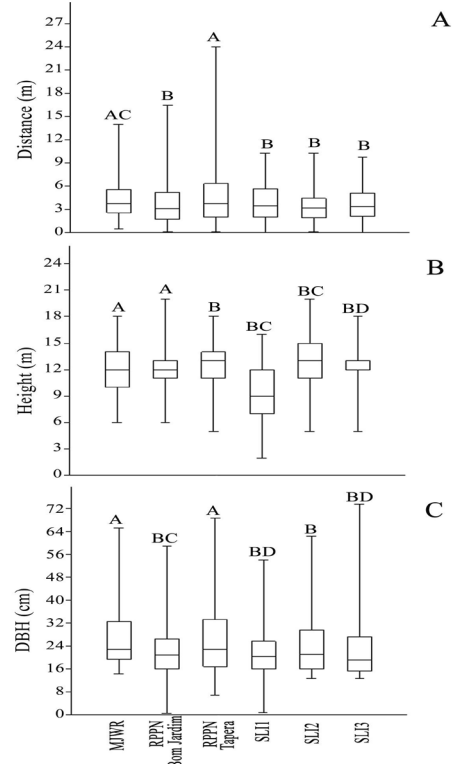


Figure 4 – Graphs demonstrating the average, maximum and minimum values of Distance (A), Diameter at Breast Height (DBH) (B), and Canopy Height (C). MJWR= Mata do Junco Wildlife Refuge; RPPN Bom Jardim= Reserva Particular do Patrimônio Natural Bom Jardim; RPPN Tapera= Reserva Particular do Patrimônio Natural Tapera; SLI= Santa Luzia Itahny fragments. Equal letters (A, B, or C) indicate that there is no significant difference.

The phytosociological analyzes describe different compositions related to the parameters of the analyzed forests. Considering the Importance Value Index (IVI) values for the 6 with the highest values, the MJWR presented the species *Byrsonima sericea* as the most important, mainly for its high abundance and dominance. The second most important was *Simaba versicolor* for its high frequency and basal dominance, followed by *Bowdichia virgilioides*, *Tapirira guianensis*, *Cecropia pachystachya*, and *Didymopanax morototoni*. For the fragments

found in the south of the State, *Tapirira guianensis* is the most important for the region, dominating all parameters (abundance, frequency, and basal

dominance). The second most important was *Protium heptaphyllum*, followed by *Himatanthus obovatus*, *Eschweilera ovata*, *Tachigali densiflora*, and *Ecclinusa ramiflora* (Table 1).

Table 1 – Species characterization based on phytosociological analysis (first 10 species with the highest IVI value), where: Abun = Abundance; Eco = Ecological Groups; Pio= pioneer; EaSe = Early Secondary; LaSe= Late Secondary; Disp= Dispersion syndromes; Ane= anemochory; Zoo= zoochory; ReDe= Relative Density; ReFe % = Relative Frequency; ReDo = Relative Dominance; IVI = Importance Value Index.

	Species	Eco	Disp	Abun	ReDe (ha)	ReFe (%)	ReDo	IVI
Mata do Junco Wildlife Refuge	<i>Byrsonima sericea</i>	EaSe	Zoo	35	145.83	1.79	13.03	9.18
	<i>Simaba versicolor</i>	LaSe	Zoo	13	54.17	2.68	9.62	5.68
	<i>Bowdichia virgilioides</i>	Pio	Ane	15	62.50	2.68	8.47	5.54
	<i>Tapirira guianensis</i>	Pio	Zoo	16	66.67	2.68	6.00	4.83
	<i>Cecropia pachystachya</i>	Pio	Zoo	8	33.33	0.89	9.59	4.46
	<i>Didymopanax morototoni</i>	Pio	Zoo	15	62.50	2.68	4.80	4.31
Santa Luzia do Itanhy Fragments	<i>Tapirira guianensis</i>	Pio	Zoo	61	156.41	3.20	15.14	10.14
	<i>Protium heptaphyllum</i>	EaSe	Zoo	51	130.76	2.56	6.06	6.24
	<i>Himatanthus obovatus</i>	Pio	Ane	37	94.87	3.20	6.11	5.54
	<i>Eschweilera ovata</i>	EaSe	Zoo	30	76.92	3.20	6.19	5.11
	<i>Tachigali densiflora</i>	LaSe	Ane	25	64.10	2.56	6.89	4.80
	<i>Ecclinusa ramiflora</i>	LaSe	Zoo	24	61.53	1.28	7.75	4.59

Ecological groups and dispersal syndrome

The fragments MJWR1, RPPN Bom Jardim, and SLI1 had the highest proportion of pioneer and early secondary species (Fig. 5). *Tapirira guianensis* (Anacardiaceae) is a pioneer species, and it showed high dominance in the fragments considered most impacted in the municipality of Santa Luzia do Itanhy. The pioneer species *T. guianensis* and *H. obovatus* were common among

the largest transects, mainly in SLI1 and RPPN Tapera (Table 1; Fig. 5). From this perspective, the high frequency of these species' pioneer individuals may be bioindicators of secondary forest. The MJWR fragment also presents the dominance of pioneer species in its transects, mainly MJWR3, which has a strong anthropic influence on its edge.

Concerning the dispersion syndrome, we have a high abundance of zoochoric tree individuals, with the majority reaching over 60% of this category, the same pattern found when the

fragments are analyzed separately, with zoochoric dispersal dominance in all the six sites. *Byrsonima sericea* (35 individuals), *Campomanesia dichotoma* (16 individuals), *T. guianensis* (16 individuals.), and *Simaba versicolor* (13 individuals.) are the most abundant species in Mata do Junco Wildlife Refuge. In the South fragments, *T. guianensis*

(61 individuals), *Protium heptaphyllum* (51 individuals), *Ecclinusa ramiflora* (24 individuals), and *B. sericea* (21 individuals) are the most abundant zoochoric species. A highlight for the SLI1 fragment, which presented about 90% of zoochoric individuals, reflecting the dominance of *B. sericea* and *T. guianensis* (Fig. 5).

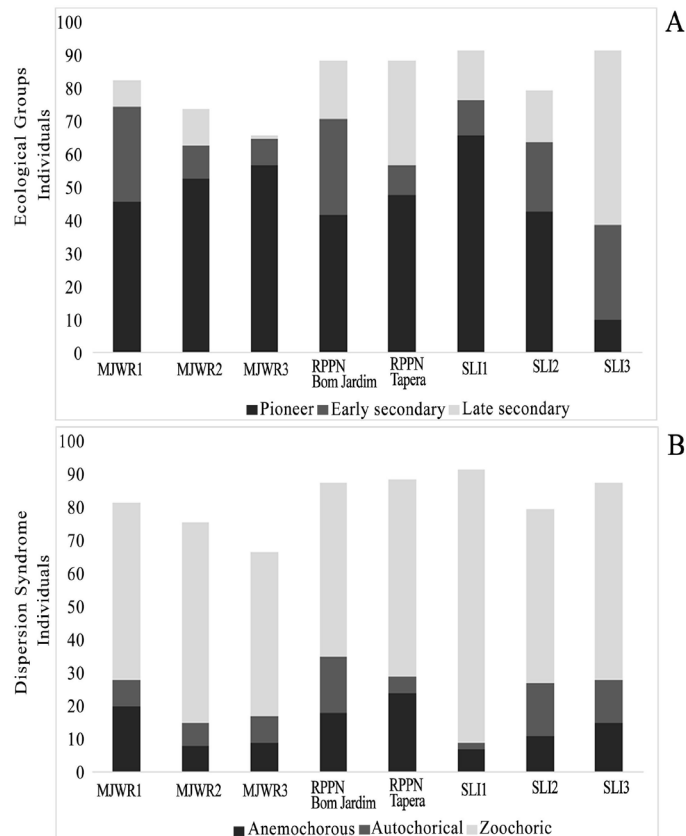


Figure 5 – Demonstrative of the proportion of tree individuals' composition, their ecological groups, and their Dispersion Syndrome for each site. MJWR = Mata do Junco Wildlife Refuge; RPPN Bom Jardim = Reserva Particular do Patrimônio Natural Bom Jardim; RPPN Tapera = Reserva Particular do Patrimônio Natural Tapera; SLI = Santa Luzia Itanhy fragments.

Discussion

Our results reveal that the mutual understanding of phytosociological, ecological, and structural patterns may be essential to understand the persistence of titi monkeys in forest remnants. The higher mean distance between trees associated with smaller DBH is undoubtedly an artifact of forest depletion, which leads us to believe that a higher incidence of light leads to the increasing of light-demanding trees in the

initial stages in those fragments. The results may demonstrate a positive ability of *Callicebus coimbrai* to survive in diverse environments in structural terms, with differences also regarding variations in the ecological successional stages and composition of plant species together with their dispersion syndromes.

Tree diversity, habitat structure, and phytosociological analysis

The tree diversity between the three major areas (MJWR, RPPN, and SLI) presented no significant differences, with the MJWR – the larger area in size – collectively gathering more species, which may be an artifact of sampled transects. Typically, larger areas hold more species and nearby forest fragments – since the proximity may allow a higher similarity due to metapopulations dynamic processes (Kadmon & Allouche, 2007; Fahrig, 2013). For instance, in Santa Luzia do Itanhya fragments, the three non-protected fragments (SLI, SL2, and SL3 – less isolated) presented a higher diversity than the two RPPNs – more isolated (Fig. 1). In contrast, the last areas are slightly more uniform than the early ones, indicating that perhaps the most remarkable diversity found may result from a few dominant species, while others are rare.

This pattern may indicate a possible floristic homogenization process, replacing shade-tolerant species to light-demand, dominant and small-seeded species, while others become increasingly rare (Laurence *et al.*, 2006; Tabarelli *et al.*, 2010). Similarly, it might also be the case of the pattern in cluster formation (Fig. 3). For instance, the three non-protected fragments and RPPN Tapera (the closest forest fragment) are more similar according to their tree composition within Santa Luzia do Itanhya fragments. Nevertheless, we must highlight that clusters' formation does not represent similarity properly since a similarity Index below 50% is considered weak (Magurran, 2011). Overall, the fragments may be undergoing a floristic differentiation – severely fragmented landscape characteristic – since the presence of an inhospitable environment can hamper the biotic seed dispersal (Arroyo-Rodrigues *et al.*, 2013).

Although some patterns remain undetected, the DBH values are higher in the transects at the protected areas (MJWR transects and RPPN Tapera) and the distance between the points. These areas naturally possess more protection against forest depletion and other anthropic disturbance, allowing a continuum tree growth with, consequently, larger DBH. This protection, nevertheless, may be insufficient against overall forest edge effects. Two remnants – MJWR and RPPN Bom Jardim – presented some positive relation between the parameters (DBH/Distance

between trees; Tree Height/Distance between trees). In both cases, we may suppose that the presence of large trees is scarce. In other words, those regions may present a high incidence of sunlight, favoring light-demanding trees – that possibly are in the early stage of growth. Consequently, in short distances, trees may present a short to medium height.

The phytosociological aspects may confirm this inference, in which in both areas, the most important trees are mainly pioneers and early secondary, that is, light-demanding species (Table 1). After the occurrence of any disturbance and in the presence of large amounts of sunlight, these initial stage trees tend to occupy any forest area. This rapid growth species may result in high canopy heights and small DBH (Iida *et al.*, 2011; Sumida *et al.*, 2013; Gustafsson *et al.*, 2016), and this may be the case we observe here. In parallel, we highlight the complicated relationship between the habitat structure and habitat fragmentation and loss since these two factors may increase the edge effects. Thus, the habitat structure becomes less complex and more fragile by reducing trees' diversity, large tree density, increasing the abundance of light-demanding trees (Hernandez-Stefanoni, 2005; Rocha-Santos *et al.*, 2016; Benchimol *et al.*, 2017).

Ecological groups and dispersal syndrome

The habitat structure and phytosociology are intrinsically related to the ecological groups in the study area. An enormous proportion of the early succession categories' tree species may indicate a large edge effect in those sites. Mature forests exhibit a low density and high mortality of pioneer and early secondary trees (Gandolfi *et al.*, 1995; Murcia, 1995; Hubbel *et al.*, 1999; Carvalho *et al.*, 2007; Santana *et al.*, 2020). Thus, the elevated amount of species of these two groups, and, therefore, the low incidence of shade-tolerant species is a characteristic of disturbed forests or in the initial ecological succession process, since these species exert an initial regeneration function (Gandolfi *et al.*, 1995; Murcia, 1995; Hubbel *et al.*, 1999; Carvalho *et al.*, 2007).

Light-demanding trees readily assimilate mineral/nutrient resources available in the environment, especially the nitrogen and those nutrients essential to the photosynthesis process (Reich *et al.*, 1998; Taiz & Ziegler, 1998).

They possess a fast-vertical growth and a strong positive response to light (Pooter *et al.*, 2008; Wright *et al.*, 2010; Gustafsson *et al.*, 2016). On the other hand, in a succession continuum, they present high mortality, being replaced by the shade-tolerant species (Gustafsson *et al.*, 2016), in a classic trade-off between rapid growth and increase of mortality (King *et al.*, 2006; Pooter *et al.*, 2008).

Species with climax properties, in contrast, invest their resources in endurance and stability (Rozendaal *et al.*, 2006; Pooter *et al.*, 2008; Wright *et al.*, 2010). However, because they need specific conditions to develop (e.g., low humidity and airspeed; Magnano *et al.*, 2015), these species are typically found in the forest's interior or mature forests. Forest edges contain characteristics, such as increased air temperature and speed and low humidity, which play an essential role in tree mortality (Tabarelli *et al.*, 2008, Magnano *et al.*, 2015). Therefore, virtually only early successional species can grow in those environments (Tabarelli *et al.*, 2008). In our study, all the sampled sites possess conditions typical of forest edge scenarios and secondary forests, with many shade-intolerant species (Fig.3). MJWR and SLI, for example, have much of their composition dominated by only one species (*Byrsonima sericea*, *Tapirira guianensis*, respectively), light-demanding species (Tables 1; A.1).

Another aspect typically associated with tree species richness is the dispersal syndrome. It is expected to find more significant variation in resource availability in areas with more incredible wealth since we will have a more significant variation in phenological cycles throughout the year (Monasterio & Sarmiento, 1976; Wright & Calderon, 1995). The zoochoric dispersal syndrome was dominant for all the analyzed fragments, a typical result for Sergipe Atlantic Forest (Santana *et al.*, 2017; Freire *et al.*, 2016). The abundance of zoochoric species is essential for feeding frugivore fauna, mainly for *Callicebus coimbrai* (Souza-Alves *et al.*, 2011). On the other hand, the dominance of only one zoochorous species can represent a disadvantage for the titi monkey and other frugivorous species, as the availability of the resource become limited through the year, as in the example of the dominance of *Tapirira guianensis* in the SLI1 fragment (60% of individuals), commonly fruiting between March and June (Santana *et al.*, 2018).

Additionally, more complex habitats, well stratified and heterogeneous, hold more species than simplified habitats (August, 1983; Passamani *et al.*, 1995; Stevenson, 2001; Grelle *et al.*, 2003; Aldana *et al.*, 2008; Wagner *et al.*, 2009), and in some cases, is the primary determinant of the presence of species in a given environment (Delciellos *et al.*, 2015). Overall, the sampled sites might manifest some specific resistance by contemplating zoochoric tree species for the most part. In other words, the fragments may encompass important fauna species responsible for transport and disperse plant seeds, even with a fragile and labile habitat structure. The occurrence of seed dispersers may indicate the continuity of succession within the forest fragments and the possibility of natural regeneration in a non-habitat matrix. In a general manner, it seems vital to guarantee the flux of seed-dispersal through fauna among the close forest remnants at each regional scenario, the WRMJ, and the SL-RPPN, to the maintenance of regional tree richness.

Implications for conservation

As shown by Gouveia *et al.* (2016), if the climate and the land-use change scenario continue, the population of titi monkeys is predicted to shrink to about 4.0%. This disturbing picture is related to the forest fragmentation and habitat loss (Andren *et al.*, 1994; Fahrig *et al.*, 2003; Ribeiro *et al.*, 2009; Marques *et al.*, 2017), that also affect the already established Protected Areas, with the decrease of surrounding forests, isolating, even more, those areas (DeFries *et al.*, 2005). Thus, the need for management and conservation of potential habitats becomes quite urgent.

The protected areas are essential to protect endangered species and manage populations (Strier & Fonseca, 1996). Three of the sampled transects in this study are in a critical State Protected Area, the Mata do Junco Wildlife Refuge, while only two are protected from five fragments in the south of the state. Thus, it is essential to create alternatives for connectivity between those fragments and at close distances. The other fragments of Santa Luzia do Itanhy, for example, can be transformed into private natural heritage reserves (RPPN, in Portuguese) once those areas may also englobe the threatened maned sloth (*Bradypus torquatus*) (Santos *et al.*, 2019), plus management that improves

the quality of all the fragments. Additionally, future reforestation programs resulting from environmental compensation (as a compensation process from massive infrastructure constructions) might prioritize the plant species enrichments in those areas.

Callicebus are monogamous with small groups composed of a mature/reproductive couple and their immature offspring (Kinzey, 1981; Robinson *et al.*, 1987; Vallegia *et al.*, 1999; Chagas & Ferrari, 2011). When the young reach adult age, they have to leave the group, finding a new territory to live and form a family (Bicca-Marques & Heymann, 2013). This is a very critical characteristic since they need the forest to disperse. The fragmentation disrupts this movement, decreasing the species' potential areas to live, making its dispersion difficult. Sometimes, they risk their lives when passing through roads or small ranches (with domestic dogs), for instance. In the last years, in the MJWR surroundings, it has happened on at least three occasions: In January 2011 (killed by a dog), in December 2013 (roadkill), and in February 2016 (roadkill); in both road kills, the titi monkeys were killed by a motor vehicle (RB-M, pers. obs.), the most recent of them in the vicinity of the MJWR.

Several studies report the establishment of wildlife corridors since they facilitate the animal movements between sites (Arendt, 2004; Hudgens & Haddad, 2003; Pardini *et al.*, 2005), including specific studies on titi monkeys (see Gouveia *et al.*, 2017). These proposals can be a plausible alternative to those fragments close to each other and other sites, as fragments SLI1, 2, and 3. As they are near, the simple establishment of a green corridor (Goosem *et al.*, 2005) may facilitate the titi monkeys flow between them, contributing to the maintenance of both titi monkeys and the tree species richness in those areas. This movement of *Callicebus* individuals should not only be one of the reasons for the current maintenance of plant diversity in these small fragments, as its facilitation should further promote the increasing tree species richness of them, in the future, due to seed zoochory (Baião *et al.*, 2015; Souza-Alves *et al.*, in press).

Conclusions

Knowing the habitats of titi monkeys and identifying the factors that influence their distribution is essential for planning and developing practical management actions (Gouveia *et al.*, 2017) for the species' long-term survival. Contrary to what was typically expected, the titi monkeys may inhabit various environments (Ferrari *et al.*, 2013), including those considered unstable and poor. Finally, the species might benefit from secondary forests' structure, with a certain degree of disturbance, as long as there are available resources and conditions throughout the year.

Acknowledgments

The data we present here come from two scientific trainee initiatives for undergraduate students from the CNPq in association with the ICMBio to evaluate habitat structure in forest fragments with titi monkeys. We would like to thank the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) and the National Council for the Scientific and Technological Development (CNPq) for the Scientific Initiation Program (PIBIC) scholarships to JPS (2016-2017) and PMS (2009-2011). The CNPq for the undergraduate, technical and predoctoral scholarships to PMS (process 503122/2010-6; 350057/2020-6), and Post-Doctoral fellowship to RB-M (503372/2014-5, 150123/2018-3). The Brazilian Coordination for Higher Education Personnel Training (CAPES) for the post-doctoral fellowships to RB-M (88887.320996/2019-00). RB-M was also supported by Mohamed bin Zayed Species Conservation Fund (12055114), Primate Action Fund (1001257), and Primate Conservation Inc. (1158). We thank the Sergipe Environment State Secretariat for the research permit (License n°: 2011.05.0706/00119-017) and the Boticário Foundation (Project 0846_20092). We are also grateful to Marcelo Guigó, Elisa Cravo, and Gilmara Freire for their field assistance and Gerson Buss for their valuable comments in developing the research projects in the paper's first drafts. We are incredibly grateful to Mr. Francisco (Farm Manager) and Mr. Raimundo Juliano (*in memoriam*) for their kind acceptance to run field researches in the Private Nature Reserves mentioned above. Mr. Raimundo

Juliano is one of the first, if not the first, to promote the private nature reserves in the State of Sergipe, mainly to protect the Endangered Coimbra-Filho's titi monkey (*Callicebus coimbrai*), and sadly died as a result of the COVID-19, thank you for your contribution and pioneering.

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Supplementary material

Table S.1 – Tree species listed per family, where: MJWR = Mata do Junco Wildlife Refuge fragment; SLI = Santa Luzia Itanhy fragment.

Family	Species	Number of individuals	
		MJWR	SLI
Anacardiaceae	<i>Tapirira guianensis</i> Aubl.	16	61
Annonaceae	<i>Annona montana</i> Macfad. & R.E.Fr.	3	1
	<i>Xylopia frutescens</i> Aubl.	2	3
Apocynaceae	<i>Aspidosperma spruceanum</i>	3	0
	<i>Tabernaemontana laeta</i> Mart.	0	3
	<i>Himatanthus bracteatus</i> (A.DC.) Woodson	0	3
	<i>Himatanthus obovatus</i> Müll.Arg.	8	37
Araliaceae	<i>Didymopanax morototoni</i> (Aubl.) Decne. & Planch.	15	7
Bignoniaceae	<i>Tabebuia aurea</i> (Silva Manso) S.Moore	4	1
Burseraceae	<i>Protium heptaphyllum</i> March.	8	51
Celastraceae	<i>Maytenus obtusifolia</i> Mart.	0	12
Clusiaceae	<i>Clusia nemorosa</i> G.Mey	0	1
Dilleniaceae	<i>Curatella americana</i> L.	0	1
Ehretiaceae	<i>Cordia toquete</i> Sieber ex Griseb.	0	7
Fabaceae	<i>Bowdichia virgilioides</i> Kunth	15	9
	<i>Caesalpinia ferrea</i> Mart. ex Tul.	8	5
	<i>Cassia grandis</i> L.f.	0	2
	<i>Inga vera</i> Willd.	0	1
	<i>Parkia pendula</i> Benth. ex Walp.	0	1
	<i>Swartzia dipetala</i> Willd. ex Vogel	0	3
	<i>Tachigali densiflora</i> (Benth.) L.F.Gomes da Silva & H.C.Lima	0	25
Lamiaceae	<i>Vitex rufescens</i> Gürke	0	1
Lauraceae	<i>Ocotea canaliculata</i> Mez	8	0
	<i>Ocotea duckei</i> Vattimo-Gil	0	12
Lecythidaceae	<i>Eschweilera ovata</i> Mart	14	30
Malpighiaceae	<i>Byrsonima sericea</i> DC.	35	21
Malvaceae	<i>Apeiba tibourbou</i> Aubl.	9	4
Moraceae	<i>Sorocea hilarii</i> Gaudich.	0	2
Myrtaceae	<i>Campomanesia aromatica</i> (Aubl.) Griseb.	0	1
	<i>Campomanesia dichotoma</i> (O.Berg) Mattos	16	4
	<i>Campomanesia ilhoensis</i> Mattos	0	2
	<i>Eugenia candolleana</i> DC.	0	2
	<i>Myrcia polyantha</i> DC.	0	1
	<i>Psidium guajava</i> L.	9	0
Nyctaginaceae	<i>Guapira opposita</i> (Vell.) Reitz	9	4
Peraceae	<i>Pera anisotricha</i> Müll.Arg.	0	2
Peraceae	<i>Pogonophora schomburgkiana</i> Miers ex Benth.	4	4
Polygonaceae	<i>Coccoloba laevis</i> Casar.	0	3
	<i>Coccoloba rosea</i> Meisn.	0	1

Sapindaceae	<i>Allophylus edulis</i> Radlk. ex Warm.	1	1
	<i>Cupania impressinervia</i> Acev.-Rodr.	0	18
	<i>Cupania oblongifolia</i> Mart.	0	3
Sapotaceae	<i>Ecclinusa ramiflora</i> Mart.	0	24
	<i>Micropholis gardneriana</i> Pierre	0	7
	<i>Pouteria gardneri</i> (Mart. & Miq.) Baehni	0	4
Simaroubaceae	<i>Simaba versicolor</i> A.St.-Hil	13	13
Urticaceae	<i>Cecropia pachystachya</i> Trécul	8	5

Table S.2 – Diversity parameters, where: Trans = Transect; Dist = Distance; N Points = Number of Points; N Spp. = Number of species; MJWR= Mata do Junco Wildlife Refuge; RPPN Bom Jardim = Reserva Particular do Patrimônio Natural Bom Jardim; RPPN Tapera = Reserva Particular do Patrimônio Natural Tapera; SLI = Santa Luzia Itanhy fragment.

Trans	Fragments	N Points	Dist	N Spp.	Shannon's Diversity	Pielou's Evenness
1	MJWR1	101	466.80	49	3.51	0.90
2	MJWR2	90	407.51	30	2.93	0.86
3	MJWR3	84	334.25	33	2.91	0.83
4	RPPN Bom Jardim	99	381.77	24	2.67	0.84
5	RPPN Tapera	104	478.93	25	2.69	0.83
6	SLI1	95	367.1	26	2.55	0.78
7	SLI2	104	355.92	42	3.14	0.84
8	SLI3	103	374.43	39	3.13	0.85
Total	-	780	3166.71	-	-	-

Table S.3 – Characterization of fragments based on the analysis of structural parameters. Different and lowercase letters represent a significant difference (p-value <0.05) between treatments.

Transect	Fragment	Distance (m)		Height (m)		DAP (cm)	
		Mean	SD	Mean	SD	Mean	SD
1	MJWR1	4.62 a	2.72	11.37 ab	2.74	26.81 a	10.77
2	MJWR2	4.53 aC	2.90	10,92 Ab	2.67	28.46 a	13.85
3	MJWR3	3.97 a	2.57	12,69 aB	3.67	32.00 a	22.00
4	RPPN Bom Jardim	3.86 B	2.87	12,07 aBC	2.29	23.11 BC	10.19
5	RPPN Tapera	4.61 a	3.72	12,35 AB	3.18	26.31 a	13.88
6	SLI1	3.42 B	1.99	12,58 ABC	2.89	24.18 BD	11.13
7	SLI2	3.86 B	2.39	8,93 AB	3.48	22.33 B	9.33
8	SLI3	3.64 B	2.32	12,66 AB	2.25	24.01 BD	12.68



Biodiversidade Brasileira – BioBrasil.

Edição Temática: PIBIC

n. 1, 2022

<http://www.icmbio.gov.br/revistaeletronica/index.php/BioBR>

Biodiversidade Brasileira é uma publicação eletrônica científica do Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) que tem como objetivo fomentar a discussão e a disseminação de experiências em conservação e manejo, com foco em unidades de conservação e espécies ameaçadas.

ISSN: 2236-2886