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SPATIAL STRUCTURE OF *Theobroma subincanum* Mart. AND *Theobroma speciosum* Willd. ex Spreng. IN THE PARQUE NACIONAL DO JURUENA, MATO GROSSO STATE, BRAZIL[1]

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ABSTRACT – Analysis of the spatial distribution is a very useful tool to understand the ecological behavior of the species in that it provides information that underlies management strategies and influences the population structure. To study the horizontal structure of the species *T. speciosum* (Cacaui) and *T. subincanum* (Cupui) in the “Parque Nacional do Juruena”, Mato Grosso state, a 200 x 160 m grid was implemented and divided into 40 adjacent 20 x 40 m subplots. All individuals of the species under study that had DBH > 1 cm were measured. The following parameters were analyzed: number of individuals, density, total height, basal area, diametric distribution, and spatial distribution. The research sampled 165 *T. speciosum* trees (51.56 ind.ha^{-1}) and 34 *T. subincanum* (10.62 ind.ha^{-1}) , with an average diameter of 6.72 cm and 12.44 respectively, the *T. speciosum* individuals showed an aggregated distribution pattern, while the *T. subincanum* individuals presented a random pattern. The diametric distribution of *T. speciosum* followed an exponential distribution in a reverse-J shaped pattern, behavior expected for a forest environment with little anthropic pressure, while *T. subincanum* did not follow the same pattern, though the species demonstrated to be well established in the area, with significant number of individuals in all diameter classes, thus,the results indicate the importance of conservation areas established in order to safeguard the natural environment from the pressures of anthropic actions, and also the need for studies in the region of the Amazon biome.

Keywords: Population structure; Diametric distribution; Amazonia.

ESTRUTURA ESPACIAL DE Theobroma subincanum Mart. E Theobroma speciosum Willd. ex Spreng. NO PARQUE NACIONAL DO JURUENA, MATO GROSSO

RESUMO – A análise dos padrões de distribuição espacial é uma ferramenta muito utilizada para entender o comportamento ecológico das espécies, pois embasa estratégias de manejo e influencia na estrutura populacional. Com o objetivo de estudar a estrutura horizontal das espécies ***T. speciosum*** *(Cacauí) e* ***T. subincanum*** *(Cupuí), , foi implementada uma grade de 200 x 160 m, dividida em 40 subparcelas de 20 x 40 m no Parque Nacional do Juruena – Mato Grosso. Nestas parcelas foram mensurados todos os indivíduos que apresentaram DAP > 1 cm. Os seguintes parâmetros foram analisados: número de indivíduos; densidade; altura total; área basal; distribuição diamétrica e distribuição espacial. A pesquisa amostrou 165 árvores de* ***T. speciosum*** *(51.56 ind.ha^{-1}) e 34 de* ***T. subincanum*** *(10.62 ind.ha^{-1}) com diâmetro médio de 6.72 e 12.44 cm respectivamente.*

Em relação à distribuição espacial, ***T. speciosum*** *apresentou padrão de distribuição agregado, enquanto* ***T. subincanum*** *padrão aleatório. A distribuição diamétrica de* ***T. speciosum*** *seguiu uma distribuição exponencial em forma de "J" invertido, comportamento esperado para um ambiente florestal com pouca pressão antrópica, já* ***T. subincanum*** *não seguiu o mesmo padrão, entretanto as espécies demonstraram estar bem estabelecidas na área, com número de indivíduos significativo em todas as classes diamétricas, assim, os resultados apontam a importância de áreas de conservação como forma instituída para salvaguardar ambientes naturais das pressões exercidas por diferentes ações antrópicas e também a necessidade de estudos na região do bioma amazônico.*

Palavras-chave: Estrutura populacional; Distribuição diamétrica; Amazônia.

1. INTRODUCTION

Currently, one of the biggest threats for the conservation of rain forests is the habitat´s transformation and exploration, the expansion of the agricultural frontier, mainly for the establishment of pastures, has increased the rate of native forest loss (Giustina et al., 2014). Such exploration significantly modifies the structure of the forest, acting directly on the spatial distribution and phenological patterns of native species (Silva et al., 2015).

Brazil has various categories of protected areas, in the levels federal, state and municipal. As the National System of Units Conservation of Nature (SNUC), Federal Law 9,985 / 00 (Brasil, 2004). According to Ferreira et al. (2005), the protected areas are one of the tools to stop or decrease the deforestation process, because the difference of the deforestation rate inside and outside the protected areas, varied ten times in the Mato Grosso and Rondônia states e twenty-five times in Pará state. This three states have the highest deforestation rates, being, 28,4, 29,2 and 20,4%, respectively.

The ecological, socio-environmental, and political importance of the legally protected area under study has increased due to its location at the biodiversity frontier between the Amazon and Cerrado biomes, where in recent years the Amazon forest has been gradually fragmented into islands. This has led the state of Mato Grosso to present the highest rates of deforestation and ground-clearing fires in Legal Amazonia resulting from a woven mesh of different policies over a long time. As a consequence of this converted landscape, the region currently shows a traced on the land use, denominated in public policy as the "arc of deforestation" and of "ground-clearing fires," whose formation and dynamics is described in detail by Loureiro (2009).

Among the wild species found in this ecotone are Cacaui (*Theobroma speciosum*) and Cupui (*Theobroma subincanum*), belonging to the family Malvaceae, with high nutritional potential (Silva et al., 2013). According to Dardengo et al. (2016), these species are commonly found in "terra firme" (land not subject to annual flooding) areas where they live in the shade of other trees.

The Cacaui and Cupui are medium-size trees. However, the Cacaui canopy is narrow and thin with a slightly velvety fruit peel (Silva et al., 2013), while Cupui presents a branchy canopy with fruit and hard and tough pericarp, covered by an indumentum similar to the real Cupuaçu (Dardengo et al., 2016).

Native species of the *Theobroma* genus have aroused wide interest of the international scientific community, and the knowledge of its structure and dispersion is of fundamental importance to science since it is the first step in breeding programs and domestication, facilitating the collection and preservation programming (Duarte et al., 2010).

The spatial distribution of a species is a tool that aids in the understanding of its ecological aspects, enabling the analysis of results that can assist in understanding the spatial dependence of the species and the distribution patterns, providing important support to techniques of sustainable forest management and even assisting in sampling and monitoring of plant species in protected areas (Pereira et al., 2011). The spatial distribution is the result of several factors that interact with each other, such as the soil type, altitude, light intensity, presence of pollinators and dispersers (Rode et al., 2010).

The distribution of the number of individuals in size classes is another way to evaluate the population structure. According to Salomão (1995), most tropical species present a balanced distribution; however, Oliveira and Amaral (2004) consider the reverse J-shaped distribution as characteristic of native forests with little or no anthropic pressure.

Individual trees of a plant species may be spatially distributed in the community so as to aggregate, randomly or uniformly (Brower and Zar, 1977). The diametric structure behavior of *T. speciosum* and *T. subincanum* is expected to be reverse J-shaped, typical for species of native forests, and to present aggregated spatial distribution, according to most studies conducted in "terra firme" forests. Nevertheless, the spatial distribution may differ from expected, as reported by Souza et al. (2011) and Queiroz et al. (2007).

Thus, the present study aimed to answer the following questions: What is the horizontal structure of the species *T. speciosum* and *T. subincanum* in "Parque Nacional do Juruena" - Mato Grosso state? Does the diametric structure of the species studied present a characteristic pattern found for rain forests species? What is the spatial distribution pattern of *T. speciosum* and *T. subincanum*?

2. MATERIALS AND METHODS

2.1 Study site

The "Parque Nacional do Juruena" (PNJu) is a unit of Integral Protection Conservation created in 2006 and administered by the Chico Mendes Institute for Biodiversity (ICMBio), with an area of 195,752,671 ha, 60% of the total park area is in the Mato Grosso state, distributed among the municipalities of Apiacás (971,935 ha or 50% of the park area), Cotriguaçu, and Nova Bandeirantes. The rest of the area (40%) is located in the state of Amazonia, distributed among Apuí and Maués municipalities (Dardengo et al., 2016).

The national program of biological diversity in evaluations and identification of priority areas for conservation, sustainable use, and benefit-sharing of biodiversity of the Brazilian Amazon laid out 27 Brazilian Legal Amazon ecoregions (Brasil, 2002) where the dry forests of Mato Grosso are located, in the northern region of Mato Grosso, where the "Parque Nacional do Juruena" lies. This Conservation Unit (CU) also covers headwaters and stretches of important Amazonian rivers, such as Aripuanã, a tributary of the Madeira, Juruena, and Teles Pires Rivers, tributaries of the Tapajós, constituting an area of great biogeographical interest.

The occurrence of the following four major sets of physiognomies can be identified in this region: sub-montane, inter-montane, lowland, and riparia. According to Köppen classification, the region presents climate type Awi, characterized by tropical rain with average temperatures between 24 º C and 26 ºC and an annual temperature range of up to 3 ºC. Rainfall is abundant (over 2,500 mm.yr^{-1}) and regular. In winter the region can receive cold fronts originating from the Atlantic polar mass that are responsible for the phenomenon of cold weather, a sharp decrease in temperatures reaching 10 ºC (Dardengo et al., 2016).

2.2 Methodology

To survey the structural data of the population of each species, a grid of 200 x 160m (3.2 ha.grid^{-1}) was implemented inside the research modules set up by the Program for Research on Biodiversity (PPBbio). In this grid study 40 adjacent subplots of 20 x 40m (800 m²) were systematically distributed (Figure 1).

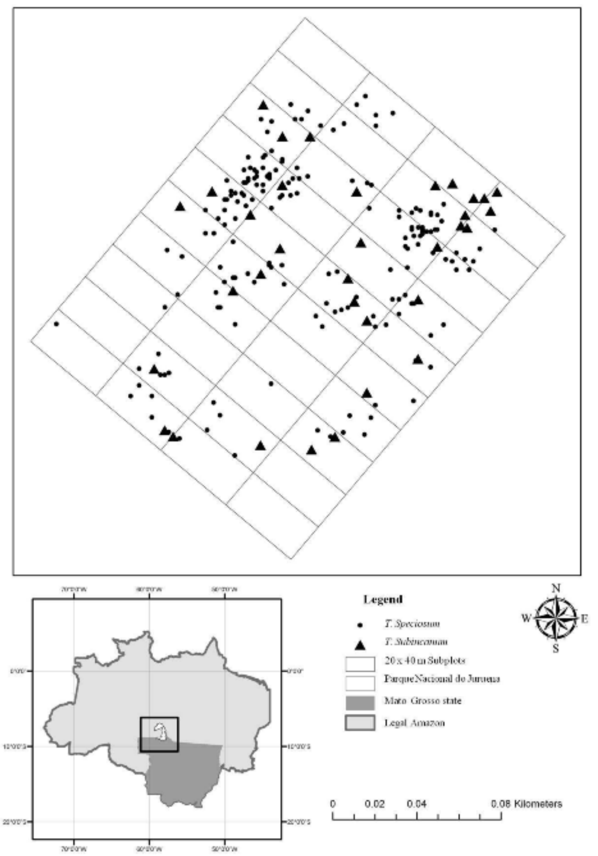

Figure 1 – Geographic location of the plots under study in the "Parque Nacional do Juruena", Brazil.
Figura 1 – *Localização geográfica das parcelas em estudo no Parque Nacional do Juruena.*

Inside the subplots, the height and diameter of all trees of living species with DBH (diameter at breast height measured 1.30m)> 1 cm were measured and all were georeferenced.

The taxonomic identification of the species was performed with the assistance of two experienced parataxonomists, and then all identified material was described according to the classification system of Angiosperm Phylogeny Group version II (Souza and Lorenzi, 2005).

The horizontal structure of species was characterized by the analyses of the following parameters: NI (number of individuals), D (density), G (basal area), diametric distribution, and spatial distribution.

For the study of diametric distribution in the environment, the number of groups used was calculated according to the methodology described by Higuchi et al. (2008): n groups= 1+3,33logN (N=data numbers), with the interval between the groups adjusted according to the number of groups. The analyses of diametric distribution were elaborated by using histograms (Figure 2), with the number of individuals per center of diameter classes, initiated by the minimum diameter inclusion (1cm). For the species *T. speciosum*, eight classes were used and for *T. subincanum* six.

The spatial distribution pattern was estimated through the Morisita index (Id), according to Brower and Zar's (1977) recommendations:

$$I_d = \frac{n.(\Sigma_{i=1}^{s} X^2 - N)}{N.(N-1)}$$

Wherein: Id: Morisita index; n: total number of subplots sampled; N: total number of species individuals, contained in n subplots; X^2: square of the number of individuals per plot; s: number of species sampled.

The significance of values calculated for the Morisita Index (Id) was obtained by the chi-square test and a significance level of 0.05.

$$X^2 = \frac{n.\Sigma_{i=1}^{s} X^2}{N} - N$$

The interpretation of the chi-square value was based on the following parameters: if the calculated value is smaller than the tabulated value and the (Id) does not differ significantly from one, then the species will present a random distribution pattern. However, if the value of chi-square is greater than the tabulated value, the species will tend to present an aggregate distribution pattern if (Id=1), or uniform if (Id>1) (Brower and Zar, 1977).

3. RESULTS

Of the 165 *T. speciosum* trees and 34 *T. subincanum* sampled, the minimum, average, and maximum diameters were, respectively, 11, 6.72, and 19.41 cm for *T. speciosum* and 1.59, 12.44, and 30.55 cm for *T. subincanum*. The density for *T. speciosum* was 51.56 (ind.ha^{-1}) and the basal area 0.26 m².ha^{-1}, while for *T. subincanum,* the density presented was 10.62 (ind.ha^{-1}) and the basal area 0.17 m².ha^{-1}, for all the 40 plots studied (Table 1).

The majority of the sampled *T. speciosum* individuals presented DBH in the groups between 1-2.5 and 2.6-5.0 cm (74 individuals – 44.85%), (Figure 2A), whereas for *T. subincanum* only 5 (14.71%) sampled individuals were allocated to the same DBH group (Figure 2B). More than 70% of *T. subincanum* individuals were grouped into three groups which together comprise DBH from 5.1 to 20.0 cm (24 individuals), whereas *T. speciosum* presented only 18.78% (31 individuals) of all sampled individuals with DBH above 10.1 cm. Furthermore, it was observed that the studied species presented individuals in all diameter groups.

The diametric distribution of *Theobroma speciosum* individuals (Figure 2A) followed the typical pattern of native forest species, in other words, the reverse J-shaped exponential distribution, demonstrating the expected behavior if compared to the known patterns in rain forests. In contrast, the diametric distribution of *Theobroma subincanum* individuals (Figure 2B) did not follow the typical pattern of native forest species because few individuals presented a DBH between 1.0 and 5.0 cm.

As to the height, the *T. speciosum* individuals presented an average of 7.43 m and *T. subincanum* 12.43 m (Table 1). Most of the *T. speciosum* individuals presented a height between 1.2 and 6.2 (47.88%) and the *T. subincanum* individuals between 6.3 and 11.2 (35.29%).

The correspondence relation between diameter and height was linear for both the studied species; however, T. speciosum showed an R value higher (0.67) (Figure 3A) than T. subincanum (0.54) (Figure 3B).

Table 1 – Mean and standard error of the Density (ind.ha^{-1}), basal area (m².ha^{-1}), diameter (cm) and total height (m) of *T. speciosum* e *T. subincanum* in Parque Nacional do Juruena, Mato Grosso state, Brazil.
***Tabela 1** – Média e erro padrão da Densidade (ind.ha^{-1}), área basal (m².ha^{-1}), diâmetro (cm) e altura total (m) de **T. speciosum** e **T. subincanum** no Parque Nacional do Juruena, Mato Grosso.*

Species	Density(ind.ha^{-1})	Basal area (m².ha^{-1})	Diameter (cm)	Total height (m)
Theobroma speciosum	51.56 ± 11.53	0.26 ± 0.005	6.72 ± 4.45	7.43 ± 4.45
Theobroma subincanum	10.62 ± 1.15	0.17 ± 0.015	12.44 ± 6.84	12.43 ± 4.82

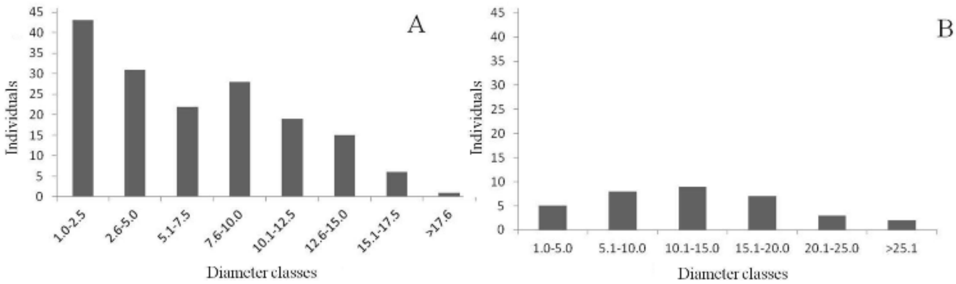

Figure 2 – Diameter distribution of *T. speciosum* and *T. subincanum* in Parque Nacional do Juruena, Mato Grosso state, Brazil. A - *T. speciosum;* B - *T. subincanum.*
***Figura 2** – Distribuição diamétrica de **T. speciosum** e **T. subincanum** no Parque Nacional do Juruena, Mato Grosso. A - **T. speciosum**; B - **T. subincanum**.*

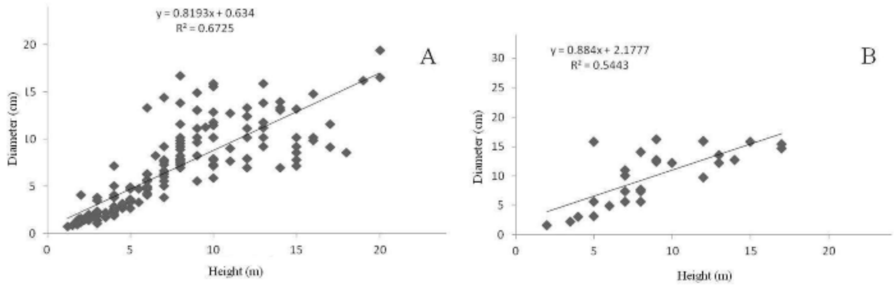

Figure 3 – Hipsometer relation of *T. speciosum* and *T. subincanum* in Parque Nacional do Juruena, Mato Grosso state, Brazil. A - *T. speciosum;* B - *T. subincanum.*
***Figura 3** – Relação hipsométrica de **T. speciosum** e **T. subincanum** no Parque Nacional do Juruena, Mato Grosso. A - **T. speciosum**; B - **T. subincanum**.*

In relation to the spatial distribution, *T. speciosum* presented a chi-square value higher (153.78) than the tabulated (54.5) and *T. subincanum* a smaller value (41.29). Therefore, the *T. speciosum* individuals had a grouped distribution pattern, whereas the *T. subincanum* individuals presented a random pattern (Tab. 2). This pattern is also observed in the cumulative curves per plot sampled, with the *T. speciosum* curve more pronounced than the *T. subincanum* curve.

4. DISCUSSION

Many studies have registered the presence of *Theobroma speciosum* and *Theobroma subincanum* in the Amazon biome (Herault et al., 2010; Amaral et al., 2011; Santos et al., 2012 and Marchant et al., 2002). Souza et al. (2011), in a study with *T. subincanum* in Amapá state, sampled 37 trees in an area of approximately 1.1 ha, with a density of 33.63 ind.ha^{-1} and a basal area of 3.07 m².ha^{-1}, higher results than those found in this study for the species (10.62 ind.ha^{-1} and 0.17 m².ha^{-1}). For the species *T. speciosum*, in a study conducted near the Xingu River (Pará state), Campbell et al. (1986) sampled 48 individuals in an area of 4.5 ha, with a density of 10.67 ind.ha^{-1} and an average basal area of 8.95 m².ha^{-1}. Whereas in the present study the 165 individuals sampled in an area of 3.2 ha showed a higher density (51.56 ind.ha^{-1}), these individuals showed a smaller average

Table 2 – Statement of the values foud in the calculation of spatial distribution of *T. speciosum* e *T. subincanum* in Parque Nacional do Juruena, Mato Grosso state, Brazil.
Tabela 2 – *Demonstração dos valores encontrados no cálculo de distribuição espacial de* ***T. speciosum*** *e* ***T. subincanum*** *no Parque Nacional do Juruena, Mato Grosso.*

Species	Morisita Index	X^2 Cal	X^2 Tab.	Spatial distribution
Theobroma speciosum	1.69	153.78	54.5	Aggregate
Theobroma subincanum	1.06	41.29	54.5	Random

basal area (0.26 $m^2.ha^{-1}$) when compared to the results found by the authors cited above.

The species in this study presented an average diameter of 6.72 cm for *T. speciosum* and 12.44 cm for *T. subincanum*, values similar to those verified by Souza et al. (2011), who found an average diameter of 11.63 cm for *T. subincanum*. However, Guorlet-Fleury and Houllier (2000) in a floodplain rain forest (French Guiana), using DBH $\geq$10 cm as a level of inclusion, identified 57 individuals of the same species with an average DBH of 17.38 cm, higher than that found in this study.

As in the Souza et al. (2011) study, the diametric distribution of *T. subincanum* individuals in this study did not follow the characteristic J-shaped pattern of exponential distribution. According to the same author, this behavior can be explained because the population in question has biological factors, abiotic or even intrinsic factors to the species, hampering their regeneration and making the mortality rate exceed the rate growth. In this way, detailed studies in the area would be required to reveal the exact cause of the high mortality rate among young individuals.

The diametric distribution of *T. speciosum* individuals was close to the characteristic reverse J-shaped pattern of exponential distribution, which, according to Oliveira and Amaral (2004), proved to be the behavior for a forest environment with little or no anthropic pressure, the expected pattern for this study, as the sampled area is in a permanent protected area. Furthermore, it was observed that both species were distributed in all the diameter groups, the behavior type that Boufleuer (2004) describes as characteristic of shade species, which keeps the establishment rate of seedlings approximately constant.

Regarding the height, the *T. speciosum* individuals presented an average of 7.43 m and *T. subincanum* 12.43 m. A study conducted by Coelho et al. (2013) in Itupiranga (Pará state) recorded the *T. speciosum* presence in all the strata analyzed (higher – DBH>10cm; medium - DBH <10; and height $\geq$ 2.0 and lower - height < 2.0). On the other hand, *T. subincanum* was found only in the higher and medium strata, confirming the *T. subincanum* tendency to have higher averages for height than *T. speciosum*.

The correspondence relation of diameter and height was linear for both species. Paiva (2009) obtained similar results in a study on Brazil-nuts.

In relation to the spatial distribution, the *T. speciosum* individuals presented an aggregate distribution pattern, corroborating the results of the Santos et al. (2008) study, which also found an aggregate distribution for the same species in a forest fragment in Alta Floresta (Mato Grosso state).

T. subincanum individuals presented a random distribution pattern, different from the results of Souza et al. (2011) and Bentes-Gama et al. (2002), in whose studies the species presented a grouped pattern. However, Queiroz et al. (2007) in Mazagão (Amapá state) found a uniform distribution for the same genus (*Theobroma* sp). Souza et al. (2011) maintained that the results about the spatial distribution have been controversial, which could represent a distinct behavior among different regions of the Amazon or simply reflect the use of different methodologies for data collection and analysis of the spatial distribution.

The spatial distribution pattern of *T. speciosum* could be related to the high density of the individuals found (51.56 $ind.h^{-1}$), with a participation of small trees (DBH average of 6.72 cm), tending to form small dense spots on the vegetation as observed in the field.

Plant species frequently present an aggregate spatial distribution, in other words, forming groups of individuals due to the forms of reproduction, the presence of disturbances or environmental factors that limit its distribution, or even the the complex interactions between community members (Perry and Dixon, 2002).

The reproduction type and fruit dispersion can explain the grouped distribution of *T. speciosum*.

According to Silva et al. (2015), each plant produced a large quantity of fruits, which are consumed by medium-sized mammals, such as monkeys. This consumption, associated with the high digestive efficiency of these animals, contributes to the occurrence of shadows of seeds grouped near the maternal plants. This effect can, in the long run, contribute to the occurrence of highly aggregated genetic kinship patterns, especially for zoochoric perennial plants (Jordano et al., 2006).

The various spatial distribution patterns of species composition, such as density, diametric distribution, and forest structure, create favorable conditions for the development of natural processes, such as mortality, regeneration, gap formation, among others responsible for the maintenance of biodiversity and for the stages of forest succession (Maltamo et al., 2000).

Therefore, studies like this are important in that they provide information about ecology, support the definition of strategies for management or conservation, assist in sampling procedures, or simply clarify the spatial structure of a species (Anjos et al., 2004). The obtained results indicate the importance of conservation areas to safeguard natural environments from the pressures of different anthropogenic actions. Furthermore, the results underscore the need to enlarge the areas of study in the region of occurrence of the Amazonian biome, to enable the establishment of spatial distribution patterns for not only the species of the genus *Theobroma* but also many others because, according to Anjos et al. (2004), this information is still scarce for most Brazilian forests.

5. CONCLUSION

The diametric distribution of *Theobroma speciosum* individuals followed the reverse J-shaped pattern of exponential distribution, demonstrating an expected behavior compared to the known patterns in the rain forest, whereas the diametric distribution of *Theobroma subincanum* individuals did not follow the characteristic pattern of native forests. The species was found to be well established in the area, distributed with a number of significant individuals in all diametric classes, which allows one to infer that the conservation status of the species is satisfactory and also elucidates the importance of maintaining such PA as the “Parque Nacional do Juruena”.

The *T. speciosum* individuals demonstrated an aggregate distribution pattern, whereas the *T. subincanum* individuals presented a random pattern.

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