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Population structure and spatial distribution of *Copaifera langsdorffii* Desf.

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Abstract

The aim of this work was to analyze the population structure and the spatial distribution of *Copaifera langsdorffii* Desf. in two areas of the Cerrado biome. The study was carried out in two physiognomies of the Cerrado biome: cerrado *sensu stricto* and cerradão, both located in the southern region of the state of Tocantins. The spatial distribution was evaluated using Morisita and dispersion indices, as well as the population structure of *C. langsdorffii*. We quantified 318 individuals of *C. langsdorffii* in the two studied areas. There were 200 individuals sampled in the cerrado *sensu stricto* and 118 in the area of cerradão. Regarding the type of spatial distribution of individuals of *C. langsdorffii*, the value found for the Morisita index was 2.67 in the physiognomy of cerrado *sensu stricto*, suggesting grouped spatial distribution (I >1). The dispersion index calculation showed that, in fact, the spatial distribution of the individuals sampled in the two areas was the grouped type; for the area of cerrado *sensu stricto*, the variance (S^2) found was 24.21 and for the cerradão it was 9.67, higher than their means 10.00 and 9.67 respectively. By analyzing the age structure of the population of *C. langsdorffii*, we found a typical trend of the inverted-J curve, suggesting that the areas studied are self-regenerating communities composed of young and developing individuals.

Keywords: diametric structure; dispersion index; Morisita index; copaiba.
Abbreviations: DBH_ Diameter at breast height; DI_ Dispersion index; MI_ Morisita index.

Introduction

Brazil is remarkable in terms of its continental dimensions; it occupies 47.3% of the total area of South America, in addition to the fact that it has an immense biological diversity distributed across six biomes. Within these biomes, the cerrado is the second largest, with an area of occupation equivalent to 204.7 million hectares (IBGE, 2004). The geographical position of the cerrado biome, located in the central portion of Brazil, gives rise to the richness of its vegetation, owing to its areas of contact with all other Brazilian biomes, except for that of the Campo Sulino/Pampa biome. Therefore, it is common to identify species in the Cerrado biome that are naturally found in other types of vegetation (Brazilian Flora, 2016).

The vegetation in Tocantins is marked by the influence of the two largest Brazilian biomes: the Amazon forest and the cerrado; 72% of its vegetation is composed of remnants of the cerrado biome (Brazil, 2015), thereby possessing one of the most well-preserved portions (Sano et al., 2010), and also one of those most threatened by the expansion of the agricultural frontier (Klink; Machado, 2005).

It should be noted that in southern Tocantins, there is a predominance of the physiognomy cerrado *sensu stricto*, characterized by 10% to 60% arboreal cover, with trees that reach up to seven meters in height (Felfili; Fagg, 2007). Furthermore, within the cerrado biome, there are other types of environment ranging from forest formations (including cerradão, riparian and gallery forests) to rural formations (“dirty” and “clean” fields) (Miguel et al., 2016).

The native flora of the cerrado can be efficiently used by farmers as economic alternatives (Felfili et al., 2004), because this biome includes a variety of species with potential for both timber and non-timber uses. The species *Copaifera langsdorffii* is highly resistant to natural degradation and is widely used in carpentry (Rudd, 1991); the oil-resin produced by this species is widely used by indigenous populations, as well as the cosmetics and pharmaceutical industries, representing a major export to Europe and the United States (Setzer, 2018).

C. langsdorffii, also known as *copaíba*, *copaibeira*, *pau d’óleo*, among others, is a tree species with great variation in size, depending on its habitat (Santos et al., 2016). In Brazil, the species occurs in the caatinga, cerrado, Atlantic forest and Amazon forest biomes. It is characterized by the presence of compound leaves, that are pinnate, alternating, and spiral with 4 to 12 alternating or opposing leaflets (Lorenzi, 2008).

Data regarding the spatial distribution of the populations is important, because this knowledge enhances understanding of the local ecology, assisting planning and delimiting of areas for the purposes of environmental conservation (Hutchings, 1986). These data also aid in the development of statistical methods and sample delineations, providing basic strategies for forest management and conservation. Trees may present three basic patterns of spatial distribution, defined by the Morisita and scatter indices: random, grouped and uniform. Factors including environmental conditions as well as natural and anthropogenic disturbances interfere with the spatial pattern of plant populations and may interfere with growth rates, seed production, leaf area, root length and ultimate tree size (Santos et al., 2016).

According to the literature, size structure of individuals is a criterion for classification of species into ecological groups. To identify population size, the "inverted-J" method is most often used. This method is often used to indicate population stability or increase as well as its capacity for self-regeneration and reproduction under the canopy (Silva-Junior, 1999).

Therefore, the objective of this study was to analyze the population structure and spatial distribution of *C. langsdorffii* in an area of cerrado *sensu stricto* located in southern Tocantins, Brazil.

Results and Discussion

Population Structure

We quantified 318 individuals of *C. langsdorffii* in the two studied areas. There were 200 individuals sampled in the cerrado *sensu stricto* area and 118 in the cerradão area. Regarding the type of spatial distribution of individuals of *C. langsdorffii*, the value found for the Morisita index was 2.67 in the physiognomy of cerrado *sensu stricto*, suggesting grouped distribution (MI > 1). The same pattern was reported by Santos et al. (2016) in the Araripe-CE natural forest, Legendre and Fortin (1989) and Thomas and Kunin (1999) stated that, in general, living beings are distributed in a grouped manner in nature. In the physiognomy of cerradão, the value found for the Morisita index was 1.13, suggesting grouped spatial distribution (MI >1). The same pattern was found by Faria et al. (2013) for *Brosimum gaudichaldii* Trecul in the Cerrado of Mato Grosso.

The dispersion index showed that the spatial distribution of the individuals was grouped, because the variance (S^2) was 79.78, higher than its mean 53. Hay et al. (2000) published a comparative study of data found in their own work and those of other studies of the spatial distribution of five species of the cerrado biome, noting that, in general, these species also presented grouped distributions (Table 1).

It is very important to understand the distribution pattern of the species, especially those used for commercial purposes, because this knowledge facilitates silvicultural management (Martins et al., 2003). With most of the species that appear in grouped form, e.g. *C. langsdorffii* Desf., it is necessary to maintain some individuals at commercial size to perpetuate the natural distribution of the species; only then can timber and non-timber products be maintained in a sustainable and manageable manner into the future (Almeida et al., 2012).

To measure the auto-regenerative and reproductive capacity of the canopy of the study areas in the municipality of Cariri do Tocantins, individuals are distributed in diametric classes of typical models of inverted- or negative exponential-J patterns. According to Silva Júnior (1999), whenever there is a J-inverted pattern, with a decreasing number of individuals from the first to the last class, there is a positive balance between recruitment and mortality, demonstrating that the site is self-regulating.

The diametric distribution of living individuals from the cerradão presented a J-inverted form (Figure 1). In this area, we observed a predominance of young individuals, as approximately 71% of the total of individuals presented DBH of up to 14 cm. In this area, there was a tendency for larger diameters and higher heights. In the area of the cerradão, no individuals were found in the height class of 0–3 m, with the majority of individuals being observed in the classes of 7.4 to 11.8 m with approximately 57% of the total sampled individuals (Figure 2). In areas of cerradão, Andrade et al. (2002) observed the distribution of the diameter of living and dead individuals in J-inverted format. They found that 90% of the living individuals had maximum diameter of 13 cm and height of 5 m.

Considering the context, we observed a larger number of individuals in the first height and DBH than in the others. The graph plotted a J-inverted or negative exponential form, that is, there was a high concentration of individuals in the classes of smaller diameter with marked reduction in the direction of the larger classes. From this it can be inferred that the *C. langsdorffii* individuals are in regeneration process, suggesting that the cerrado *sensu stricto* and cerradão are basically composed of young individuals in full development (Figures 1 and 2). This same pattern of diametric distribution was verified in a Cerrado forest remnant located in the municipality of Gurupi - TO (Silva; Souza, 2017).

The diametric distribution of living individuals from the cerrado *sensu stricto* also presented J-inverted form (Figure 3). In the class of diameters 3 to 8.5 cm comprises 77.5% of the trees sampled in the area. We observed in the cerrado *sensu stricto*, that the height classes 5.2 to 9.6 m were more significant than in the other areas, representing 66% (Figure 4).

The individuals in the final diametric class in relation to height and DCH were equivalent to those of adult individuals that were reproductively mature, capable of producing fruits/seeds and reproduction; therefore, their existence allows natural regeneration of *C. langsdorffii*., and young individuals are greatly important to ensure the maintenance of the population (Antonini; Nunes-Freitas, 2004).

Materials and Methods

Characterization of the study area

The study was carried out on a private property, known as Chácara Santa Rita, in Cariri do Tocantins, southern Tocantins, latitude 11º49'47.49'' S, longitude 49º13'50.42'' W (Figure 5). The study area is located at 249 m above sea-level, with average annual precipitation and temperature of approximately 1.5 mm and 27 ºC, respectively. November to

Table 1. Spatial distribution of eight species of the cerrado biome, defined by the dispersion and Morisita indices.

Species	Method	Result	Reference
Copaifera langsdorff Desf.	DI, MI	Grouped	This study
Myrciaria tranciflora Berg	MI	Grouped	Amaral et al., 2015
Copaifera langsdorff Desf.	MI	Grouped	Oliveira-Filho et al., 1996
Pterodon pubescens (Benth.) Benth.	DI	Grouped	Hay et al., 2000
Caryocar brasilienses Cambess	DI	Grouped	Silberbauer-Gottsberger and Eiten, 1987
Hancornia speciosa Gomes	MI	Grouped	Moura et al., 2011
Ocotea odorifera Rohwer	MI	Grouped	Amaral et al.,2015
Sclerolobium paniculatum Vogel	DI	Grouped	Hay et al., 2000
Copaifera langsdorff Desf.	MI	Grouped	Resende et al., 2003
Syagrus comosa (Mart.) Mart.	DI	Random	Hay et al., 2000
Syagrus flexuosa (Mart.) Becc.	DI	Grouped	Hay et al., 2000
Syagrus romanzoffiana Glassman	DI	Grouped	Amaral et al., 2015

(DI = dispersion index; MI = Morisita index. Source: Hay et al., 2000)

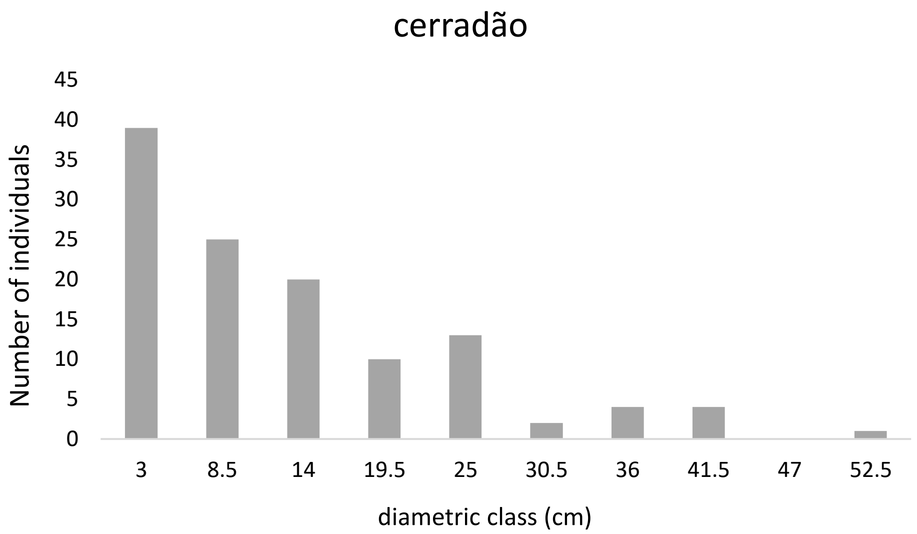

Fig 1. Distribution of *C. langsdorffii* diametric grades in the cerradão, in southern Tocantins.

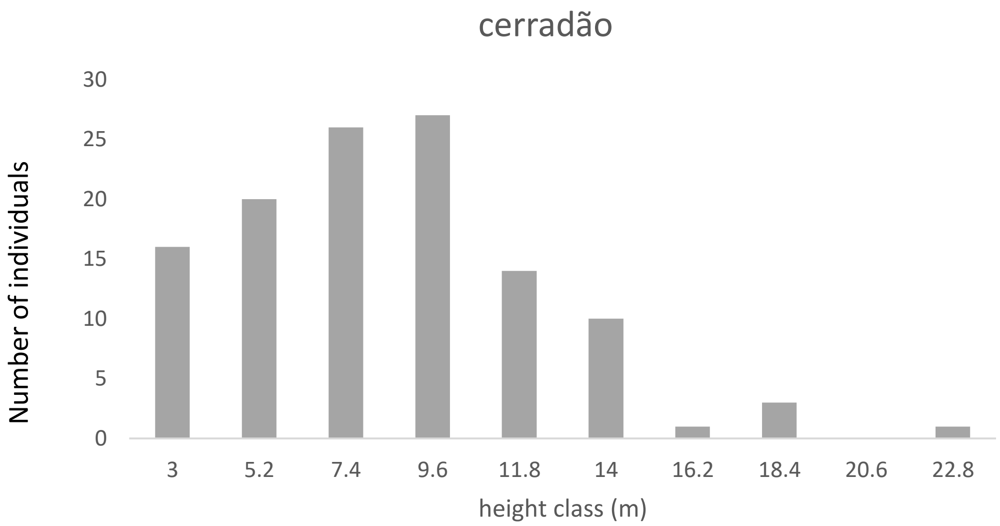

Fig 2. Distribution of *C. langsdorffii* height grades in the cerradão, in southern Tocantins.

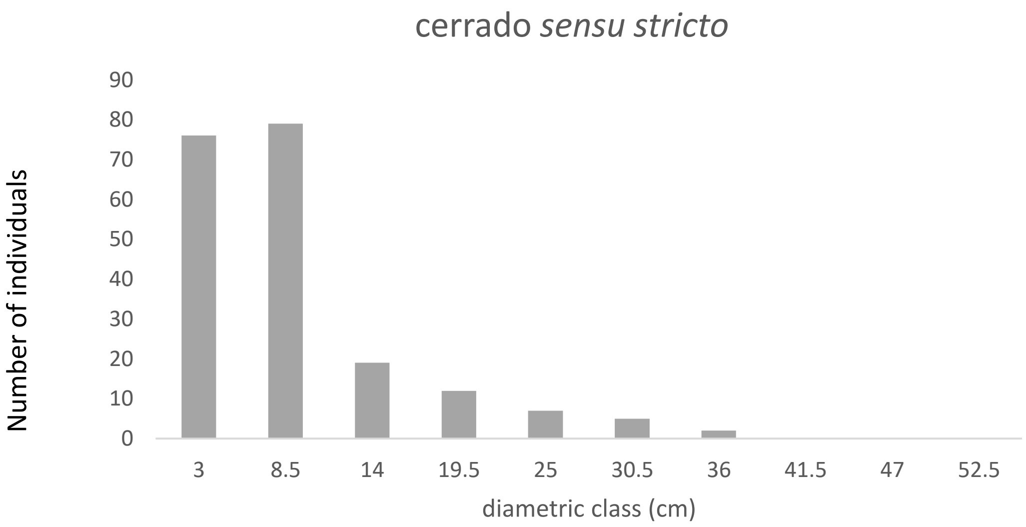

Fig 3. Distribution of *C. langsdorffii* diametric grades in the cerrado *sensu stricto*, in southern Tocantins.

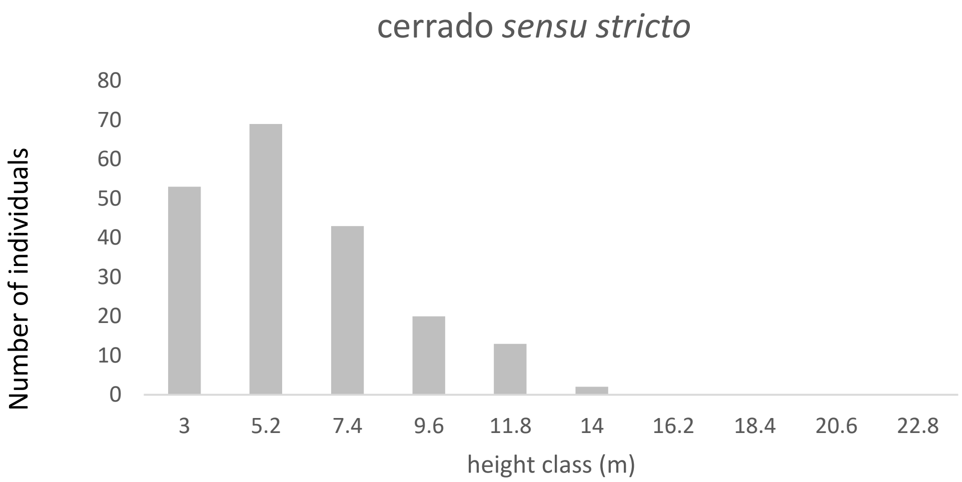

Fig 4. Distribution of *C. langsdorffii* height grades in the cerrado *sensu stricto*, in southern Tocantins.

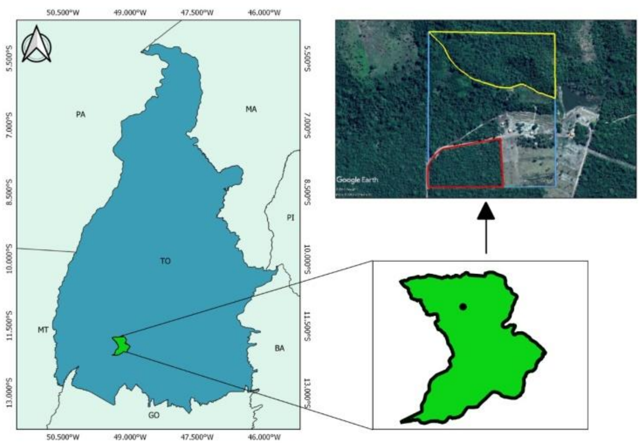

Fig 5. Map of the study area in the cerradão, in southern Tocantins.

April are the rainiest months and May to October are the driest. According to Köppen, the climate of the region is type B1wA'a humid, with moderate water deficiency (Seplan, 2012).
The total area of the study area is 23 hectares, parts of which are managed in various ways. Of the total area, 14.46 hectares are allocated to legal reservation or permanent preservation areas, 4.5 hectares are designated for cultivated pasture, 0.6 hectares are designated for passion fruit cultivation and 3.44 hectares are designated for alternative use.
The study area was selected because it presents forest fragments of the cerrado biome such as the physiognomy cerrado *sensu stricto* and cerradão, as well as for the abundance of individuals of the species *C. langsdorffii*.

Evaluation of individuals

The studied area was selected for presenting forest fragments as cerrado *sensu stricto* and cerradão, and a forest inventory was taken in the two areas where the fixed area sampling method was adopted, the vegetation of the shrub-tree component was quantitatively evaluated by the plots method (Mueller – Dombois; Ellenberg, 1974). Twenty sample plots were installed in each experimental area with dimensions of 20 x 50 m (1000 m²) each, i.e., 2.0 ha of sample area, where 50 subplots of 10 x 10 m (100 m²) were demarcated within each plot. The distribution of these plots occurred systematically throughout the study areas of cerrado *sensu stricto* and cerradão, being 20 m apart. The size of the plots used in this work was standardized according to the project "Biogeografia do Bioma Cerrado - Biogeography of the Cerrado Biome" (Felfili; Silva Junior, 1992).
In the plots, we sampled all live shrub-trees individuals with diameter at breast height (DBH) greater than 3 cm, measuring the circumference at breast height (CBH - measured at 1.30 m from the soil). For the measurement of DCH, a measuring tape graduated in centimeters was used. The relationship of DCH to CCH was determined by the following formula:

$$DCH = \frac{CCH}{\pi} \quad (1)$$

The heights of the trees were measured using a ruler graduated in meters.
All shrub-arboreal individuals of *C. langsdorffii* were catalogued by collecting their geographic coordinates, using a Garmin Etrex GPS device.

Phytosociological parameters

Spatial distribution was determined by the dispersion and Morisita indices (Gomes; Ferreira, 2004). The dispersion index (DI) can be established from the mean and variance values as follows:
RANDOM PATTERN: $S^2 = X$
GROUPED PATTERN: $S^2 > X$ (2)
UNIFORM PATTERN: $S^2 < X$
where S is the variance of the number of individuals and X is the mean number of individuals.
The Morisita index (MI) is described by equation 3:

$$MI = q\left[\frac{\Sigma n(n-1)}{N(N-1)}\right] \quad (3)$$

where q is the total number of plots sampled, n is the number of individuals in the i-th plot and N is the total number of individuals sampled.
According to these calculations, the spatial pattern should be considered random when MI < 1, regular or uniform if MI = 1, and aggregated or grouped if MI > 1.
The age distribution of the population was analyzed by constructing graphs of height and diameter distribution, where the parameters were taken from the formula A/K, where A is the amplitude between the highest and lowest values, and K is the number of classes.
The basic data obtained from the 20 plots of 2.0 ha were analyzed for the purpose of obtaining the matrix that relates the number of trees per hectare of the i-th species in the j-th diameter class. The individuals sampled were distributed in ten diameter classes, with intervals of 5.5 cm and by height classes, in intervals of 2.2 cm. The diametrical distribution was done by means of the sampled individuals of each species within the diametric class to which they belonged, where to generate the graphs and tables were used the Microsoft Office Excel and Fitopac version 2.1.2.

Conclusion

The spatial distribution found for the population of *C. langsdorffii* demonstrated a grouped distribution pattern, defined on the basis of the Morisita (MI >1) and dispersion indices ($S^2 > X$). The age structure of *C. langsdorffii* was an inverted-J type, suggesting that the study area has a population in the process of self-regeneration, composed of young individuals in full development.

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