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EARTH SCIENCES

Cerrado physiognomies in Chapada das Mesas National Park (Maranhão, Brazil) revealed by patterns of floristic similarity and relationships in a transition zone

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Abstract: The Chapada das Mesas National Park is a federal reserve located in the State of Maranhão, in an ecotonal region of the Brazilian Northeast Cerrado. Aiming to assess the influence of biogeographic patterns and support restoration actions for regions where information is scarce, we analyzed the floristic composition of savanna and forest Cerrado physiognomies, the floristic relationships with other Brazilian Cerrado areas and investigated the floristic relationships between the Cerrado and the Amazon, and the Caatinga and Atlantic Forest biomes. A total of 242 species in 181 genera and 64 families are recorded in our study. Fabaceae was the most representative family. We report 50 new records of species for Maranhão, four new records for the Cerrado biome and one vulnerable species. The separation of the gallery forest from cerradão and typical cerrado by ordination shows the influence of water availability and soil characteristics on floristic composition. In Cerrado ecotonal regions, such as Mato Grosso and Maranhão, the presence of species shared with the Amazon is expressive. In addition to the Amazon, physiognomies had greater floristic connection with the Caatinga flora. Our data demonstrates that the marginal areas of the Brazilian Cerrado may present high species diversity.

Key words: conservation, endemism, flora, gallery forest, savanna.

INTRODUCTION

The Cerrado covers 200 million hectares (Mha) in Brazilian territory and houses about 4800 plant and vertebrate endemic species, in a vegetation complex that includes different physiognomies (Ribeiro & Walter 2008, Strassburg et al. 2016). The Cerrado is considered a threatened hotspot, which has already lost 88 Mha (46%) of its original coverage mainly due to agribusiness expansion (Strassburg et al. 2017). The extinction of some 397 endemic endangered plants may occur by 2050, if there is limited biome protection along with agricultural expansion, which highlights the influence of the socioeconomic and political dimensions for conservation (Faleiro & Loyola 2013, Strassburg et al. 2017).

In the Brazilian Central Plateau, the Cerrado has an average elevation of 1100 m (Miranda & Faria 2001) and an average annual rainfall of 1500 mm (Ribeiro & Walter 2008). However, the Cerrado has a large latitudinal range, between 5° and 20° south latitudes, so it is possible to find topographic and climatic variations in the areas of the biome distributed in the five Brazilian regions (Silva et al. 2008). These variations may influence the distribution of Cerrado species, as topography and climate are some of the main factors that determine vegetation composition (Castro & Martins 1999).

Another uniqueness of the Cerrado is its contiguous boundaries with all Brazilian biomes except the Pampa grasslands (Ribeiro & Walter 2008). The proximity of species-rich vegetation such as the Amazon Rainforest and the Atlantic Forest has been associated with Cerrado megadiversity (Simon et al. 2009). Indeed, in areas of the ecotonal Cerrado where there are no biogeographic barriers, species interpenetration and, consequently, the formation of subregional landscape complexes may occur (Ab'Saber 2003). In this context, the biome is a unique region for research on the influence of geographical and historical factors on its biota (Méio et al. 2003).

The relation of the floristic composition of the Cerrado with the dry and humid forests of South America has its origins in the climatic fluctuations of the Quaternary period, which allowed the expansion and retraction of the biome in these areas (Oliveira-Filho & Ratter 2002). Classic and recent phytogeographic studies have pointed to a greater influence of the Atlantic Forest on non-endemic floristic composition of the Cerrado (Rizzini 1963, Heringer et al. 1977, Méio et al. 2003, Françoso et al. 2016). However, greater knowledge about the floristics of Cerrado-Amazon transition zones may reveal a different proportion since the Cerrado has its largest border with the Amazonian biome.

In the Cerrado, there are forest formations associated with watercourses in moist soils where a considerable number of species have been identified as good indicators of the groundwater regime and are distributed in adjacent biomes (Ribeiro & Walter 2001, Oliveira-Filho & Ratter 2002). According to Oliveira-Filho & Ratter (1995), these forest formations would constitute a northwest-southeast route for the distribution of species from the Amazon to the Atlantic Forest.

Ecotonal Cerrado areas showed marked differences in woody species composition when compared to core Cerrado areas (Lenza et al. 2011, Marimon et al. 2014). In the Cerrado-Amazon transition zones it was shown that the floristic structural dissimilarity of woody species in forest and savannah physiognomies was mainly determined by geographical distance (Maracahipes-Santos et al. 2017). Other factors traditionally considered important for determining local-scale variation in vegetation composition are edaphic conditions and water availability (Carvalho et al. 2014, Soares et al. 2015).

Cerrado-Amazon transition zones are located in the Central-Western and North-Northeast phytogeographic provinces, which include the southern and southeastern portions of Maranhão (Ratter et al. 2003). In these portions, Cerrado heterogeneity is related to the wide range that it occupies, at altitudes ranging from 200 to 800 m, the presence of contiguous boundaries with the transition forest vegetation and especially the Amazon Forest (Silva-Moraes et al. 2019).

Aiming to contribute to the knowledge about the vegetation of ecotonal areas of the Brazilian Northeast Cerrado, we analyzed the floristic composition of savanna and forest physiognomies in the Parque Nacional da Chapada das Mesas (CMNP), Maranhão, including the occurrence of endemic, threatened and exotic species. The floristic relationships of the CMNP flora with the surrounding biomes were also determined, addressing the following questions: (1) Is the species composition of the woody vegetation more similar between the CMNP flora and the Cerrado-Amazon transition zones? (2) Is there a pattern of floristic composition associated with the proximity of well drained watercourses? (3) Does the distance among areas explain the floristic similarity between physiognomies?

MATERIALS AND METHODS

Study area

The CMNP, Unidade de Conservação de Proteção Integral, has an extension of 1600 km^2 (06°59’S and 47°02’W) and is comprised of the municipalities of Carolina, Riachão and Estreito, located in the State of Maranhão, Northeastern Brazil (Brasil 2005). The CMNP was created in December 2005, for the conservation of native species of flora, fauna and the protection of springs, waterfalls and river water courses that supply important hydrographic basins, such as the Farinha river (MMA 2007, Souza et al. 2015). The relief is predominantly flat-wavy, with altitudes ranging from 250 m in the valleys and up to 524 m in the hills. The top of the hills is relatively flat, which explains the denomination “Chapada das Mesas”. The regional climate is Tropical Aw according to the Köppen classification. The average annual temperature is 26.1° C and average annual precipitation is between 1250-1500 mm. The rainy season occurs between November and April and the dry season between May and October, the most critical period in relation to fire outbreaks. The quartzipsamment soil class is predominant in the study area (IBAMA 2013).

The study was carried out at the CMNP in an area located in Carolina (Fig. 1). The general characterization of the Cerrado areas studied

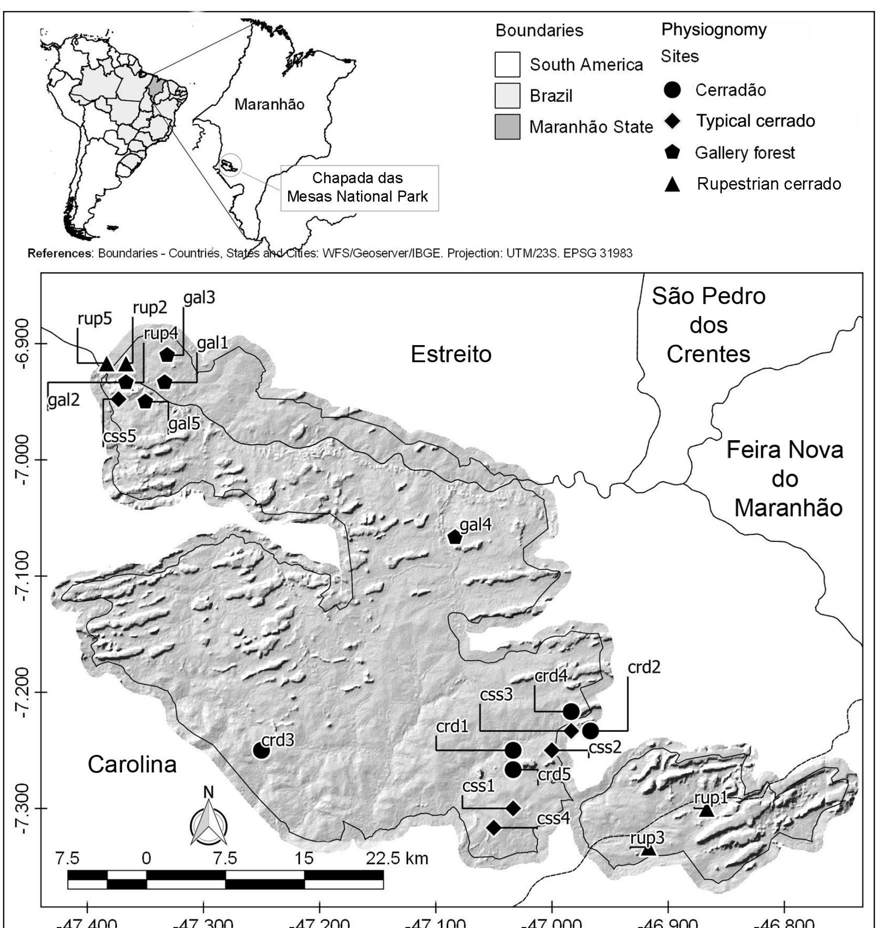

Figure 1. Map with the location of the Chapada das Mesas National Park (CMNP), Maranhão, Brazil and the points of data collection in the physionomies gallery forest (gal); typical cerrado (css); cerradão (crd) and rupestrian cerrado (rup).

was made in accordance with Ribeiro & Walter (2008), considering: (i) typical cerrado is a savanna formation in which tree and shrub stratum predominates with irregular, twisted branches and there is usually evidence of fires; (ii) cerradão is an arboreal stratum with gnarled and erect individuals, with few deciduous species in the dry season and there are elements of cerrado sensu stricto and forest; (iii) gallery forest is a perennial forest vegetation that accompanies the small rivers and streams of the central plateaus of Central Brazil, forming closed corridors over the watercourse and (iv) rupestrian cerrado is a savanna formation in which the herbaceous species and sparse arboreal-shrub strata with twisted branches grow in places where there are rock outcrops and well drained soils (Fig. 2). The collections obeyed the collection permits issued by the ethics committee of the Instituto Chico Mendes de Conservação da Biodiversidade (protocols of SISBio 57426-1, 57426-3).

Data collection

The CMNP inventory was made with data of species referring to four physiognomies, the cerradão, typical cerrado, gallery forest and rupestrian cerrado. One part of the data was collected in the field and the other through access to the database of the herbariums contained in the SpeciesLink database (splink.cria.org.br), an information system that contains data from scientific collections. All data were analyzed regarding the plant species composition (see next subsection).

For field sampling, five areas of 1 ha were selected on the physiognomies of typical cerrado and cerradão, covering ten collection areas. The collection areas in the typical cerrado and cerradão were about 5 to 52 km and 3 to 30 km apart, respectively (Fig.1). The floristic survey was carried out from September 2016 to April 2018, the sampling was quarterly and covered both dry and rainy seasons, completing 14 days of collection during the study period. We collected vascular plants, preferably in reproductive phase. Plants were sampled by using the “wide-patrolling” method (Filgueiras et al. 1994) on two trails for each area in the cerradão and typical cerrado physiognomies. According to this method, the collector has to walk on the trails to be inventoried, recording and collecting all present species that are observed over predetermined time intervals (Filgueiras et al. 1994). In this survey, the average walking time per trail was 1h 30 min at 15 min intervals

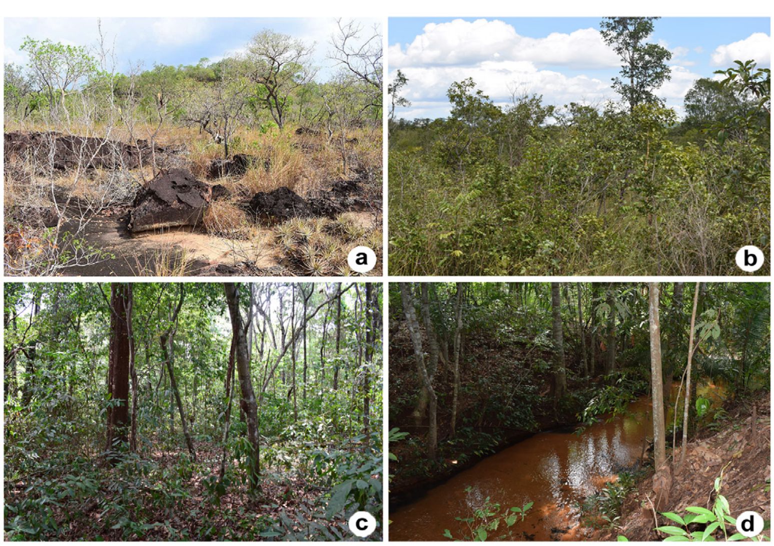

Figure 2. CMNP. (a) rupestrian cerrado; (b) typical cerrado; (c) cerradão; (d) gallery forest. Photos by R. Saraiva.

of observation and species of all habits were included, following the general descriptions in Souza et al. (2013) for tree, shrub, subshrub, herb, vine and hemiparasite. The collections obeyed the collection permits issued by the Instituto Chico Mendes de Conservação da Biodiversidade (SISBio 57426-1, 57426-3).

For the rupestrian cerrado and gallery forest physiognomies, data were obtained from the ALCB, CEN and SLUI herbariums contained in the SpeciesLink database in October 2017. Five sampling points were selected for the rupestrian cerrado and for the gallery forest, based on the recorded coordinates and descriptions of the habitat in the exsiccates contained in the SpeciesLink database for the CMNP. Specimens were only considered when identified at species level by taxonomic specialists.

The botanical material was herborized and voucher specimens were deposited in the SLUI herbarium, Universidade Estadual do Maranhão/ UEMA, with duplicates at ALCB, FLOR, HST, MAR and UB herbariums. The species were identified using specialized bibliography, taxonomists' expertise, and comparison with specimens in the SLUI herbarium and virtual international herbaria through the worldwide web.

The floristic list was compiled in accordance with the classification system based on Chase et al. (2016) for angiosperms, and the species names were confirmed by consulting the database of the Jardim Botânico de Missouri contained in the Tropical System (tropicos.org) and the Projeto Lista da Flora do Brasil (Flora do Brasil 2020 under construction). The species list of the Grupo da Flora Brasileira database (Filardi et al. 2018) was used to obtain information about endemism (species that only occur in the Cerrado biome), geographical distribution, phytogeographic analysis and new records of species in the State of Maranhão and the Cerrado biome. The threatened species were checked at the national level according to the Red Book of Brazilian Flora (Martinelli & Moraes 2013) and globally using the IUCN Lista Vermelha de Espécies Ameaçadas online databases (IUCN 2017).

Analysis of plant species composition

For species richness, a two-way ANOVA model was built, to seek the average difference of richness in plant phytogeographic distribution and plant habit. When the criterion of homogeneity of variance was not met, the nonparametric Kruskal-Wallis test was used. The Análise de Correspondência Distendida (DCA) was used to verify the pattern of plant species composition among physiognomies and the floristic relationships of woody species with another eight Brazilian Cerrado areas occurring in four Brazilian regions, where there is distribution of the biome (Table I). Floristic differences were determined between the studied areas with a dendrogram (Unweighted Pair Group Method- UPGMA), using the Jaccard index of community dissimilarity. The hypothesis that the floristic patterns are distance-dependent was tested by a Modelo Linear Generalizado (GLM) that investigated whether the number of species shared between the sampled areas is explained by the linear distance between them. All analyses were performed using the 'vegan' package, version 2.5-2 of R (R Development Core Team 2016).

RESULTS

Floristic diversity and geographical distribution

A total of 242 species of vascular plants were inventoried in CMNP, distributed in 181 genera and 64 families (Table SI- Supplementary material). The most representative families were Fabaceae (42 species); Rubiaceae (14

Table I. Cerrado areas of Brazil compared with the CMNP in Carolina municipality, MA, Brazil.

Cod.	Sites/State	Rainfall (mm year^{-1})	T (°C)	Lat (S)	Long (W)	Alt (m a.s.l.)	References
CB_DF	Cerradão Biological Reserve/ DF	1350 to 1450	21	15°51'	47°49'	1087	Silva & Felfili (2012)
CA_MT	"Cerrado"-Amazon transition zone/ MT	1598	25	12°49'	51°46'	379	Maracahipes-Santos et al. (2015)
ER_BA	Espinhaço Range/ BA	700 to 900	22	14°25' - 14°50'	42°35' - 42°30'	700 to 1230	Campos et al. (2017)
GU_MG	Guapé/ MG	1448	21	20°49' - 20°51'	46°00' - 46°02'	788 to 932	Torres et al. (2017)
NX_MT	Nova Xavantina/ MT	1600	24	14°41'	52°20'	250	Marimon-Junior & Haridasan (2005)
PN_SP	Pratânia/ SP	1454	21	22°48'	48°44'	714 to 753	Ishara & Maimoni-Rodella (2012)
TE_GO	Terra Ronca State Park/ GO	1406	24	13°35	46°16'	750	Teixeira et al. (2017)
TR_TO	Tocantins River Basin/ TO	1400 to 1800	25	13°08' -13°18'	48°13' - 48°10'	300 to 370	Medeiros et al. (2014)
CM_MA	Chapada das Mesas National Park/ MA	1250 to 1500	26	6°59'	47°02'	250 to 524	Present Study

species); Cyperaceae (12 species); Malvaceae (11 species); Asteraceae (9 species); Euphorbiaceae (9 species); Poaceae (9 species), corresponding to 43.80% of all the species. Twenty-six families (40.62% of all families) were represented by only one species. The most diverse genera were *Cyperus* (5 species) and *Chamaecrista* (5 species). Other genera counted three registered species: *Croton*; *Evolvulus*; *Annona*; *Polygala*; *Xylopia*; *Combretum*; *Rhynchospora*; *Bulbostylis* and *Lippia*. Of the recorded species, 123 (50.83%) were trees, 74 (30.58%) were herbaceous, 70 (28.93%) were shrubs, 17 (7.02%) were sub-shrubs and 15 (6.20%) were vines (Fig. 3). The richness data showed a significant mean difference for plant habit (Kruskal-Wallis: p = 0.006). Regarding the richness data per habit, vines and trees (Mann Whitney U: p = 0.014, Z = -2.309) and sub-shrubs and trees (Mann Whitney U: p = 0.029, Z = -2.309) were responsible for the significance in the Kruskal-Wallis model.

Most species are native to Brazil, but two are exotic, according to the Brazil Flora Group (2018): *Polycarpaea corymbosa* (L.) Lam. and *Eulophia alta* (L.) Fawc. & Rendle. One species was considered vulnerable: *Cedrela fissilis* Vell. There were 50 new occurrences for Maranhão State (Table SI) and four new occurrences for the Cerrado biome: *Anacardium giganteum* W.Hancock ex Engl.; *Mimosa modesta* var. *ursinoides* (Harms) Barneby; *Sacoglottis guianensis* Benth. and *Voyria flavescens* Griseb.

Physiognomies in the CMNP

The typical cerrado presented a larger number of species, with 113 records. Sixty-five species were recorded for the cerradão, 63 for the rupestrian cerrado and 58 species were recorded for the gallery forest. In the typical cerrado, 45 families were registered, Fabaceae (24), Bignoniceae (5) and Poaceae (5) were among the ones with the greatest richness. In the cerradão areas 38

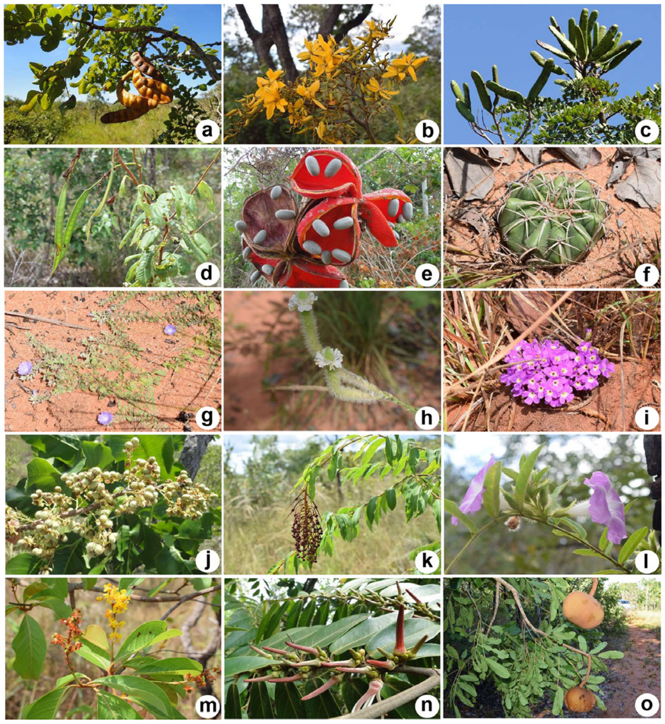

Figure 3. Cerrado flora species in CMNP, Maranhão, Brazil. (a) *Stryphnodendron coriaceum* Benth. (b) *Martiodendron mediterraneum* (Mart. ex Benth.) R.C.Koeppen (c) *Dimorphandra mollis* Benth. (d) *Bauhinia dubia* G.Don (e) *Sterculia striata* A.St.-Hil. & Naudin (f) *Discocactus catingicola* Buining & Brederoo (g) *Evolvulus frankenioides* Moric. (h) *Evolvulus lagopodioides* Meisn. (i) *Lippia horridula* (Epling) Salimena, Múlgura & Harley (j) *Curatella americana* L. (k) *Mabea angustifolia* Spruce ex Benth. (l) *Ipomoea burchellii* Meisn. (m) *Byrsonima crassifolia* (L.) Kunth (n) *Xylopia sericea A.* St.-Hil. (o) *Magonia pubescens* A.St.-Hil. Photos by L. Leonel (a, c, e, j, n), R. Saraiva (b, d, f, g, h, i, k, l, m, o).

families were registered and Fabaceae were the families with the highest number of species. In the gallery forests, 32 families were recorded and Fabaceae (8) and Malvaceae (6) presented the highest number of species. Twenty-eight families were registered for the rupestrian cerrado and Fabaceae (11) and Poaceae (7) had the biggest number of species.

As for habit distribution in physiognomies, in the cerradão the arboreal component was predominant (64.62%), as well as in the gallery forest (46.55%) and typical cerrado (35.40%) physiognomies. The total herbaceous component had a higher proportion in the rupestrian cerrado (39.68%). The highest proportion of endemic species was obtained for the typical cerrado (32.74%) and rupestrian cerrado (26.98%). In the gallery forest and rupestrian cerrado, higher percentages of exclusive species were observed, that is, they occurred only in these physiognomies, 77.59% and 73.02%, respectively.

In general, there was low species similarity among the sampled areas. However, one group was observed, cerradão + typical cerrado, with higher species similarity (30 species). The rupestrian cerrado and gallery forest physiognomies presented low similarity with the main group and among these physiognomies (Fig. 4). The increased similarity between these areas was higher because of trees (19 species in common). The presence of Poaceae contributed to decrease the similarity between the rupestrian cerrado and gallery forest species. The variation in number of shared species was not explained by linear distance between the physiognomy areas (GLM: p = 1.00).

The DCA performed in order to compare the physiognomies demonstrated the segregation of plant communities by physiognomies, showing the formation of two groups, one consisting of vegetation that accompanies small rivers or poorly drained soils and which generally presents high sensitivity to fire (gallery forest) and another formed by inter-fluvial

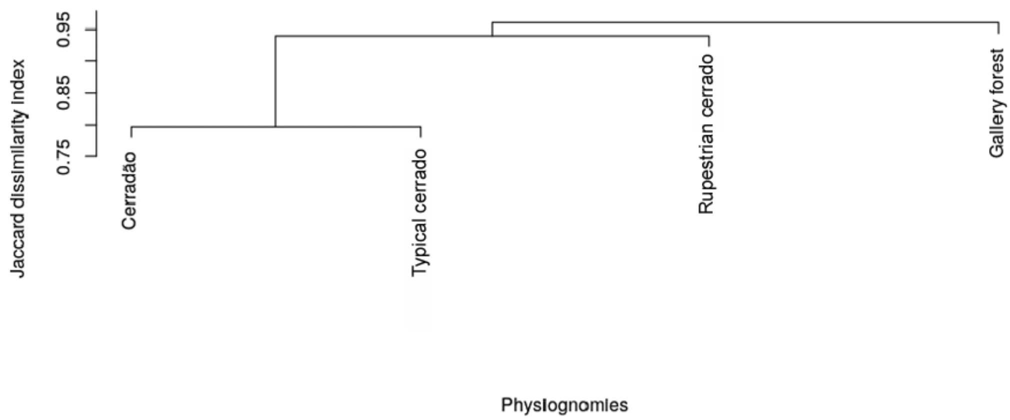

Figure 4. Cluster (UPGMA) of species by similarity (Jaccard index) among the four physiognomies areas in CMNP, Maranhão, Brazil. Graphics program used: R software.

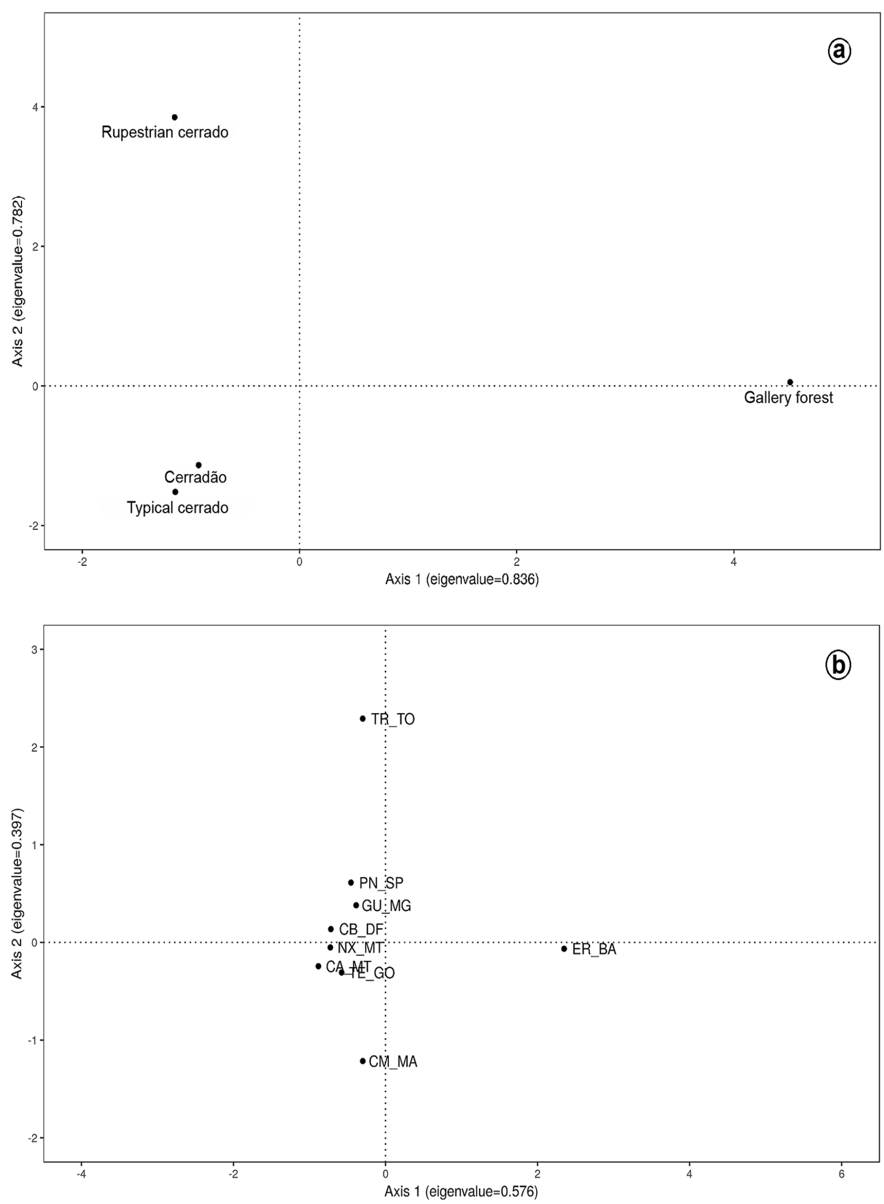

Figure 5. Análise de Correspondência Distendida (DCA) (a) DCA based on the species recorded in the physiognomies of the CMNP (b) DCA based on the floristic relationships with CMNP and other Brazilian Cerrado areas. The acronyms for the sites are listed in Table I. Graphics program used: R software.

vegetation with no association with well drained watercourses and the species are often resistant to the effect of fire (rupestrian cerrado, cerradão and typical cerrado) (Fig. 5a).

Phytogeographic distribution of CMNP flora

The species listed occur in all Brazilian biomes; 236 (97.52%) species have been recorded in the Cerrado, 184 (76.03%) in the Amazon, 149 (61.57%) in the Caatinga and 135 (55.79%) in the Atlantic Forest. Of the species recorded, 22 occur exclusively in the Cerrado biome. There was greater floristic connection of all studied physiognomies with the Amazon flora (Fig. 6). The richness data showed a non significant mean difference for plant phytogeographic distribution (Two-way ANOVA: $F_{3,12}$ = 1,833, p = 0.195).

In addition to the Amazon Forest, species of the typical cerrado and gallery forest physiognomies had greater floristic connection with the Caatinga flora (Fig. 6). For the woody species in the inventory, the proximity to the Caatinga was 60.67%. The floristic connection with the Caatinga increases when considering only the herbaceous and sub-shrub species of the inventory (65.43%).

The DCA performed resulted in the formation of a main group formed by the Cerrado of Mato Grosso, Goiás, São Paulo, Minas Gerais and the Federal District. The Cerrado of Maranhão showed greater proximity to the main group. Bahia and Tocantins showed no pattern

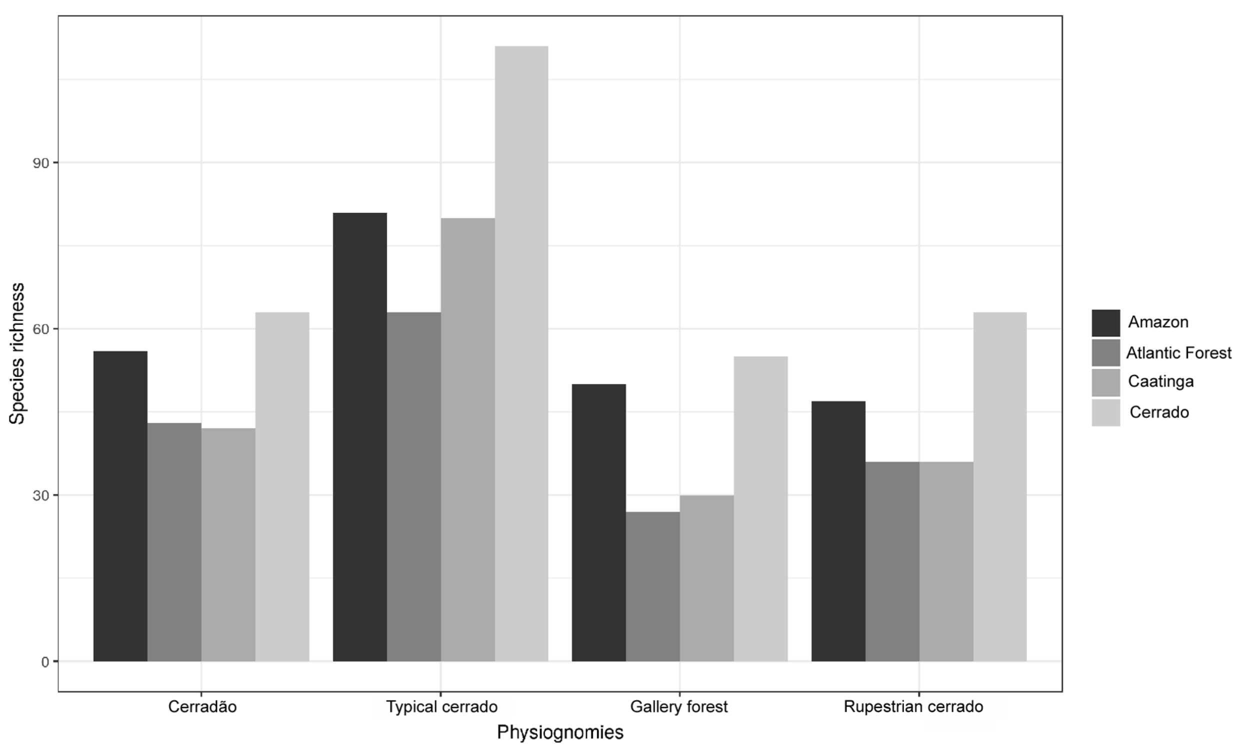

Figure 6. Occurrence of the species in the biomes according to the studied physiognomies in the CMNP, Maranhão, Brazil. Graphics program used: R software.

of similarity with the main group or between them (Fig. 5b).

DISCUSSION

Fabaceae was the most representative family in the CMNP, with a total of 25 woody species. This number was higher compared with the woody community in the Cerrado of the Tocantins River Basin (12 species, Medeiros et al. 2014) and in a Cerrado and Amazon transition region in Mato Grosso state, (20 species, Maracahipes-Santos et al. 2015). Fabaceae is a common family in the Brazilian Cerrado when considering species of both woody and herbaceous strata (Assunção et al. 2011, Campos et al. 2017, Souza et al. 2018). Thus, species of Fabaceae are a dominant floristic element and contributing significantly to regional diversity (Simon et al. 2009).

The total of 40 families of tree species registered for the CMNP approached the highest number registered for the Brazilian Cerrado, which was 52 families for the State of Tocantins (Françoso et al. 2016), which emphasizes the floristic importance of this Cerrado area. Regarding the genera most frequent in the CMNP, *Chamaecrista* has half of the native species described for the Cerrado, the probable radiation center of plant taxa (Rando et al. 2016, Souza et al. 2018). In addition, autochoric and anemochoric plants tend to predominate in open and dry environments (Amaral et al. 2013, Lima & Melo 2015), which may explain the representativeness of the genera *Cyperus*, *Croton*, *Rhynchospora*, *Bulbostylis* and *Polygala* in the Cerrado of the CMNP. The flora of the CMNP presented all the woody species considered most frequent in the Brazilian Cerrado, including *Bowdichia virgilioides* Kunth and *Qualea grandiflora* Mart., according to Françoso et al. (2016), who carried out the last synthesis of floristic knowledge of the Cerrado.

The separation of the gallery forest physiognomy from the main group (cerradão + typical cerrado) by UPGMA and DCA shows the influence of water availability and soil characteristics on floristic composition and vegetation structure, since these factors can act as environmental filters (Ribeiro & Walter 2008, Bao et al. 2018, Le Stradic et al. 2018). Texture and water retention in the soil are related to vegetation structural characteristics, such as the occurrence of species with morphoanatomic adaptations that confer tolerance to desiccation (Silveira et al. 2016). In parallel, the occurrence of exclusive species in gallery forests is related to the existence of pedoforms for which species may have preference (Van den Berg & Oliveira-Filho 1999, Torres et al. 2017) and highlights its function as a corridor between biomes that may contain species not shared in other physiognomies (Méio et al. 2003).

The variation in species richness in the CMNP is independent of the distance between physiognomies, which highlights the importance of environmental factors and evolutionary processes for the occurrence of species in the biome, whose lineages began to diversify less than 10 million years ago (Simon et al. 2009, Moncrieff et al. 2016). The occurrence of exclusive and endemic species in the rupestrian cerrado and typical cerrado can be explained by the concept of old-growth grasslands, in which biogeographic history of this vegetation formation favored repeated speciation and spreading events, contributing to the existence of plant populations with limited distribution and adaptive characteristics related to these environments (Veldman et al. 2015, Silveira et al. 2016).

According to Castro & Martins (1999) climatic and altitudinal barriers are fundamental parameters for the separation of the Brazilian Cerrado in the Southeast, Central Plateau and Northeastern super-centers of biodiversity. In addition, the terms central or core Cerrado areas are commonly used, considered the maximum physiognomic expressions of the biome, and marginal areas, peripheral areas of the Brazilian Cerrado in which there is a marked presence of floristic elements originating from circumjacent vegetation formations (Castro et al. 1999, Castro & Martins 1999). Ratter et al. (2003) analyzed the floristic composition of 376 Cerrado and savanna Amazonian areas in Brazil and recognized the existence of seven phytogeographic groups. The Cerrado areas of Maranhão were included in the Northern and Northeastern provinces. Species that characterize and are indicative of the phytogeographic groups of this province were found in the present CMNP survey, such as *Hirtella ciliata* Mart. & Zucc., *Parkia platycephala* Benth., and *Platonia insignis* Mart.. These species are indicative of marginal areas where the Cerrado borders with other biomes (Ribeiro & Walter 2008).

It is suggested that the central areas of the Cerrado should present a greater diversity of species than the marginal areas (Castro et al. 1999, Ratter et al. 2003), a suggestion supported by mid-domain effects (Colwell et al. 2004). Nonetheless, there is disagreement as to this suggestion when considering widespread biomes (Hawkins et al. 2005). Recently, Rossatto (2014) used a meta-analysis approach and inferred that similar patterns were found for phylogenetic and traditional diversity indexes in core and marginal areas. The findings for the CMNP highlight the floristic richness of the Cerrado marginal area and the need for inventories in ecotonal areas (Françoso et al. 2016). Therefore, the marginal areas of the Brazilian Cerrado, especially those bordering other biomes, may present high species diversity (Rossato 2014, Maracahipes-Santos et al. 2015).

Despite similar diversity patterns observed for Cerrado phytogeographic provinces, there are differences in the number of dominant family species (Rossatto 2014). Representative families of the Cerrado, such as Malvaceae and Myrtaceae (Souza et al. 2018), have more species in the Central-Western province (Ratter et al. 2003, Rossatto 2014). Phytogeographic province richness is influenced by adjacent biome vegetation from ancestral strain diversification in response to selective pressures, especially the burn regime (Simon et al. 2009); and by the addition of species that have physiological capacity to occupy niches in Cerrado vegetation in the absence of fires (Hoffmann et al. 2004, Rossatto et al. 2013). In ecotonal Cerrado areas, the addition of Amazonian and Atlantic Forest species mainly occurs through connections between forest areas and forest physiognomies (Oliveira-Filho & Ratter 1995).

The floristic proximity between the Brazilian Cerrado areas present in the main group resulting from the DCA ordination emphasized the presence of species shared with the Amazon in the Cerrado areas in transition zones such as Mato Grosso and Maranhão. In parallel to this, the presence of the Federal District and Goiás in the main group revealed the influence of species from the North-Northeastern region on central areas of the Cerrado, which was also observed by Teixeira et al. (2017) in the area of the Parque Estadual Terra Ronca. The formation of the main group may be related to characteristics of climate, soil chemistry and physics, water and nutrient availability. The altitude was not a significant factor in restricting the occurrence of Amazonian species in the Cerrado (Méio et al. 2003), which may support the existence of species shared with the North-Northeastern region in the Cerrado of the Federal District, which presents higher elevations.

The Cerrado of the Southeast shares species mainly with the Atlantic Forest and is greatly influenced by the biome (Oliveira-Filho & Fontes 2000). The areas of Cerrado in São Paulo and Minas Gerais states have very different climatic conditions from the areas of Cerrado that transition with the Amazon, confirmed by the distance of the main group and their proximity in the DCA graph. Other areas of Cerrado that were outside the main group were the Southwestern region of Bahia in the Espinhaço Range and the Cerrado in the Tocantins River Basin. This was expected since in the first area there is presence of rocky Caatinga with vegetation, climate and specific edaphic interactions (Campos et al. 2017) and in the second there are dry semideciduous forests with links with seasonal forests of the Caatinga biome (Medeiros et al. 2014).

The floristic influence of the Amazon Forest in the Cerrado biome can vary with the type of physiognomy and geographic location. According to the hypotheses of Silva & Oniki (1988), Oliveira-Filho & Ratter (1995) and Méio et al. (2003), it was expected to find greater floristic influence of the Amazon Forest toward the marginal portions of the Cerrado. This trend in species distribution patterns is mainly related to climate, as decreasing latitude increases minimum winter temperature, favoring the establishment of Amazonian species (Dick et al. 2013). On the other hand, the results in CMNP differ from the phytogeographic patterns that indicated the existence of greater floristic affinity of the Cerrado with the Atlantic forest (Rizzini 1963, Heringer et al. 1977, Méio et al. 2003). Nonetheless, Françoso et al. (2016), emphasized the need for more research, especially in ecotonal regions, to know whether the pattern is found in different regions of the Brazilian Cerrado.

Despite the prevalence of species shared with the Amazon, the CMNP is considered a transition area with the Caatinga biome (IBAMA 2013), which also presented greater floristic influence than the Atlantic Forest. The influence of the Caatinga vegetation on Cerrado physiognomies can be seen in this inventory by the presence of new records of the species *Discocactus catingicola* Buining & Brederoo and *Mimosa modesta* var. *ursinoides* (Harms) Barneby. Teixeira et al. (2017) suggested that herbaceous flora may reveal distinct phytogeographic patterns in view of the difference in the affinities of the herbaceous and woody strata with the Atlantic Forest and Caatinga biomes, which was also verified in this research.

The research at the CMNP revealed the floristic richness of the marginal Cerrado area and can contribute to filling the gap on ecotonal areas, through the dissemination of new occurrences to the State, to the biome and results on Cerrado environmental heterogeneity. The CMNP is located in one of the most preserved regions of the Cerrado in the North-Northeast portion, but there are few Conservation Units in this region and they are in great risk of environmental degradation due to the advance of the agricultural frontier (Fernandes et al. 2016). We recommend identifying the areas most threatened by deforestation and those that need environmental restoration to ensure the conservation of one of the last continuous Cerrado areas in Brazil.

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REFERENCES

AB'SABER AN. 2003. Os domínios de natureza no Brasil: potencialidades paisagísticas, 1ª ed., São Paulo: Ateliê Editorial, 159 p.

AMARAL AG, MUNHOZ CBR, EUGÊNIO CUO & FELFILI JM. 2013. Vascular flora in dry-shrub and wet grassland Cerrado seven years after a fire, Federal District, Brasil. Checklist 9(3): 487-503.

ASSUNÇÃO VA, GUGLIERI-CAPORAL A & SARTORI ÂLB. 2011. Florística do estrato herbáceo de um remanescente de Cerradão em Campo Grande, Mato Grosso do Sul, Brasil. Hoehnea 38(2): 281-288.

BAO F, LEANDRO TD, ROCHA MD, SANTOS VS, STEFANELLO TH, ARRUDA R, POTT A & DAMASCENO-JÚNIOR GA. 2018. Plant species diversity in a Neotropical wetland: patterns of similarity, effects of distance, and altitude. An Acad Bras Cienc 90: 85-97.

BRASIL. 2005. Cria o Parque Nacional da Chapada das Mesas, nos municípios de Carolina, Riachão e Estreito, no Estado do Maranhão e dá outras providências. Decreto de 12 de dezembro de 2005, Brasília. Disponível em: < http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2005/dnn/Dnn10718.htm#:~:text=DECRETO%20DE%2012%20DE%20DEZEMBRO,Maranh%C3%A3o%2C%20e%20d%C3%A1%20outras%20provid%C3%AAncias.> Acessado em 21 Jan 2016.

CAMPOS L, GUEDES MLS, ACEVEDO-RODRÍGUEZ P & ROQUE N. 2017. Contributions to the floristic and vegetation knowledge of Espinhaço Septentrional, Bahia, Brazil. Braz J Bot 40(2): 427-437.

CARVALHO GH, BATALHA MA, SILVA IA, CIANCIARUSO MV & PETCHEY OL. 2014. Are fire, soil fertility and toxicity, water availability, plant functional diversity, and litter decomposition related in a Neotropical savanna? Oecologia 175(3): 923-935.

CASTRO AAJF & MARTINS FR. 1999. Cerrados do Brasil e do Nordeste: caracterização, área de ocupação e considerações sobre a sua fitodiversidade. Pesq Foco 7(9): 147-178.

CASTRO AAJF, MARTINS FR, TAMASHIRO JY & SHEPHERD GJ. 1999. How rich is the flora of Brazilian Cerrados? Ann Mo Bot Gard 86(1): 192-224.

CHASE MW ET AL. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot J Linn Soc 181(1): 1-20.

COLWELL RK, RAHBEK C & GOTELLI NJ. 2004. The mid-domain effect and species richness patterns: what have we learned so far? Am Nat 163(3): 1-23.

DICK CW, LEWIS SL, MASLIN M & BERMINGHAM E. 2013. Neogene origins and implied warmth tolerance of Amazon tree species. Ecol Evol 3(1): 162-169.

FALEIRO FV & LOYOLA RD. 2013. Socioeconomic and political trade-offs in biodiversity conservation: a case study of the Cerrado Biodiversity Hotspot, Brazil. Divers Distrib 19(8): 977-987.

FERNANDES GW ET AL. 2016. Cerrado: em busca de soluções sustentáveis, 1ª ed., Rio de Janeiro: Vertente produções artísticas, 212 p.

FILARDI FLR ET AL. 2018. Brazilian Flora 2020: Innovation and collaboration to meet Target 1 of the Global Strategy for Plant Conservation (GSPC). Rodriguésia 69(4): 1513-1527.

FILGUEIRAS TDS, NOGUEIRA PE, BROCHADO AL & GUALA GF. 1994. Caminhamento: um método expedito para levantamentos florísticos qualitativos. Cad Geociências 12(1): 39-43.

FLORA DO BRASIL 2020 under construction. Jardim Botânico do Rio de Janeiro. Disponível em: < http://floradobrasil.jbrj.gov.br/ > Acessado em 02 Out 2017.

FRANÇOSO RD, HAIDAR RF & MACHADO RB. 2016. Tree species of South America central Savanna: endemism, marginal areas and the relationship with other biomes. Acta Bot Bras 30(1): 78-86.

HAWKINS BA, DINIZ-FILHO JAF & WEIS AE. 2005. The mid-domain effect and diversity gradients: is there anything to learn? Am Nat 166(5): 140-143.

HERINGER EP, BARROSO GM, RIZZO JÁ & RIZZINI CT. 1977. A flora do Cerrado. In: Ferri MG (Ed), IV Simpósio sobre o Cerrado, 1ª ed., São Paulo: Editora da Universidade de São Paulo, p. 211-232.

HOFFMANN WA, ORTHEN B & FRANCO AC. 2004. Constraints to seedling success of savanna and forest trees across the savanna-forest boundary. Oecol 140(2): 252-260.

IBAMA - INSTITUTO BRASILEIRO DE MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS. 2013. Plano operativo de prevenção e combate aos incêndios florestais do Parque

Nacional da Chapada das Mesas. Disponível em: < http://www.ibama.gov.br/phocadownload/prevfogo/planos_operativos/plano_operativo_parna_da_chapada_das_mesas.pdf >. Acessado em 02 Nov 2016.

ISHARA KL & MAIMONI-RODELLA R. 2012. Richness and similarity of the Cerrado vascular flora in the central west region of São Paulo State, Brazil. Checklist 8(1): 32-42.

IUCN - INTERNATIONAL UNION FOR CONSERVATION OF NATURE. 2017. The IUCN red list of threatened species, Version 2017.3. Available at: < http://www.iucnredlist.org > Accessed on 07 Nov 2017.

LENZA E, PINTO JRR, PINTO ADS, MARACAHIPES L & BRUZIGUESSI EP. 2011. Comparação da vegetação arbustivo-arbórea de uma área de cerrado rupestre na Chapada dos Veadeiros, Goiás, e áreas de cerrado sentido restrito do Bioma Cerrado. Braz J Bot 34(3): 247-259.

LE STRADIC S, BUISSON E, FERNANDES GW & MORELLATO LP. 2018. Reproductive phenology of two co-occurring Neotropical mountain grasslands. J Veg Sci 29(1): 15-24.

LIMA EA & MELO JIM. 2015. Biological spectrum and dispersal syndromes in an area of the semiarid region of north-eastern Brazil. Acta Sci Biol Sciences 37(1): 91-100.

MARACAHIPES-SANTOS LM, LENZA E, SANTOS JO, MARIMON BS, EISENLOHR PV, JUNIOR BHM & FELDPAUSCH TR. 2015. Diversity, floristic composition, and structure of the woody vegetation of the Cerrado in the Cerrado-Amazon transition zone in Mato Grosso, Brazil. Braz J Bot 38(4): 877-887.

MARACAHIPES-SANTOS L, LENZA E, SANTOS JO, MEWS HA & OLIVEIRA B. 2017. Effects of soil and space on the woody species composition and vegetation structure of three Cerrado phytophysiognomies in the Cerrado-Amazon transition. Braz J of Biol 77(4): 830-839.

MARIMON BS ET AL. 2014. Disequilibrium and hyperdynamic tree turnover at the forest-cerrado transition zone in southern Amazonia. Plant Ecol Divers 7(1-2): 281-292.

MARIMON-JUNIOR BH & HARIDASAN M. 2005. Comparação da vegetação arbórea e características edáficas de um cerradão e um cerrado *sensu stricto* em áreas adjacentes sobre solo distrófico no leste de Mato Grosso, Brasil. Acta Bot Bras 19(4): 913-926.

MARTINELLI G & MORAES MA. 2013. Livro Vermelho da Flora do Brasil, 1ª ed., Rio de Janeiro: Instituto de Pesquisas Jardim Botânico do Rio de Janeiro e Andrea Jakobson, 1100 p.

MEDEIROS MB, WALTER BMT & OLIVEIRA WL. 2014. Floristic and structural comparisons between woody communities of two seasonal forest fragments in the Tocantins river basin and other remnants of this forest physiognomy in Brazil. Rodriguésia 65(1): 21-33.

MÉIO BB, FREITAS CV, JATOBÁ L, SILVA ME, RIBEIRO JF & HENRIQUES RP. 2003. The influence of Amazonian and Atlantic flora in the vegetation of cerrado *sensu stricto*. Braz J Bot 26(4): 437-444.

MMA - MINISTÉRIO DO MEIO AMBIENTE. 2007. Áreas prioritárias para conservação, uso sustentável e repartição de benefícios da biodiversidade brasileira: Atualização - Portaria MMA n° 9, de 23 de janeiro de 2007. Ministério do Meio Ambiente, Secretaria de Biodiversidade e Florestas, Brasília.

MIRANDA GHB & FARIA DS. 2001. Ecological aspects of black-pincelled marmoset (*Callithrix penicillata*) in the cerradão and dense cerrado of the Brazilian Central Plateau. Braz J Biol 61(3): 397-404.

MONCRIEFF GR, BOND WJ & HIGGINS SI. 2016. Revising the biome concept for understanding and predicting global change impacts. J Biogeogr 43(5): 863-873.

OLIVEIRA-FILHO AT & FONTES MAL. 2000. Patterns of floristic differentiation among Atlantic forests in southeastern Brazil and the influence of climate. Biotropica 32(4): 793-810.

OLIVEIRA-FILHO AT & RATTER JA. 1995. A study of the origin of central Brazilian forests by the analysis of plant species distribution patterns. Edinb J Bot 52(2): 141-194.

OLIVEIRA-FILHO AT & RATTER JA. 2002. Vegetation physiognomies and woody flora of the Cerrado biome. In: Oliveira PS & Marquis RJ (Eds), The Cerrados of Brazil: ecology and natural history of a Neotropical Savanna, 1st ed., New York: Columbia University Press, p. 91-120.

R DEVELOPMENT CORE TEAM. 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: <https://www.R-project.org/> Accessed on 10 Nov 2016.

RANDO JG, ZUNTINI AR, CONCEIÇÃO AS, VAN DEN BERG C, PIRANI JR & QUEIROZ LP. 2016. Phylogeny of *Chamaecrista* ser. Coriaceae (Leguminosae) unveils a lineage recently diversified in Brazilian campo rupestre vegetation. Int J Plant Sci 177(1): 3-17.

RATTER JA, BRIDGEWATER S & RIBEIRO JF. 2003. Analysis of the floristic composition of the Brazilian cerrado vegetation III: comparison of the woody vegetation of 376 areas. Edinb J Bot 60(1): 57-109.

RIBEIRO JF & WALTER BMT. 2001. As matas de galeria no contexto do bioma Cerrado. In: Ribeiro JF, Fonseca CEL & Sousa-Silva JC (Eds), Cerrado: caracterização e recuperação de matas de galeria, 1ª ed., Planaltina: Embrapa Cerrados, p. 29-47.

RIBEIRO JF & WALTER BMT. 2008. As principais fitofisionomias do Bioma Cerrado. In: Sano SM, Almeida SP & Ribeiro JF (Eds), Cerrado: ecologia e flora, 1ª ed., 1 vol, Brasília: Embrapa Informação Tecnológica, p. 153-212.

RIZZINI CT. 1963. A flora do cerrado - análise florística das savanas centrais. In: Ferri MG (Ed), Simpósio sobre o Cerrado, 1ª ed., São Paulo: Ed. Univ. São Paulo, p. 125-177.

ROSSATTO DR. 2014. Spatial patterns of species richness and phylogenetic diversity of woody plants in the Neotropical Savannas of Brazil. Braz J Bot 37(3): 283-292.

ROSSATTO DR, HOFFMANN WA, SILVA LCR, HARIDASAN M, STERNBERG LS & FRANCO AC. 2013. Seasonal variation in leaf traits between congeneric savanna and forest trees in Central Brazil: implications for forest expansion into savanna. Trees 27(4): 1139-1150.

SILVA FAM, ASSAD ED & EVANGELISTA BA. 2008. Caracterização climática do bioma Cerrado. In: Sano SM, Almeida SP & Ribeiro JF (Eds), Cerrado: ecologia e flora, 1ª ed., Brasília: Embrapa Informação Tecnológica, p. 69-88.

SILVA JMC & ONIKI Y. 1988. Lista preliminar da avifauna da estação ecológica Serra das Araras, Mato Grosso, Brasil. Bol. Mus. Para. Emílio Goeldi, ser. Zoo 4(2): 123-143.

SILVA JS & FELFILI JM. 2012. Floristic composition of a conservation area in the Federal District of Brazil. Braz J Bot 35(4): 377-384.

SILVA-MORAES HG, CORDEIRO I & FIGUEIREDO N. 2019. Flora and floristic affinities of the Cerrados of Maranhão State, Brazil. Edinb J Bot 76(1): 1-21.

SILVEIRA FAO ET AL. 2016. Ecology and evolution of plant diversity in the endangered campo rupestre: a neglected conservation priority. Plant Soil 403(1-2): 129-152.

SIMON MF, GRETHER R, QUEIROZ LP, SKEMA C, PENNINGTON RT & HUGHES CE. 2009. Recent assembly of the Cerrado, a neotropical plant diversity hotspot, by *in situ* evolution of adaptations to fire. PNAS 106(48): 20359-20364.

SOARES MP, REYS P, PIFANO DS, SÁ JLD, SILVA POD, SANTOS TM & SILVA FG. 2015. Relationship between edaphic factors and vegetation in savannas of the Brazilian midwest region. Rev Bras Cienc Solo 39(3): 821-829.

SOUZA FT, KOERNER TC & CHLAD R. 2015. A data-based model for predicting wild fires in Chapada das Mesas National Park in the State of Maranhão. Environ Earth Sci 74(4): 3603-3611.

SOUZA VC, FLORES TB, COLLETTA GD & COELHO RLG. 2018. Guia das plantas do Cerrado, 1ª ed., Piracicaba, São Paulo: Taxon Brasil Editora e Livraria, 584 p.

SOUZA VC, FLORES TB & LORENZI H. 2013. Introdução à Botânica: morfologia, 1ª ed., Nova Odessa: Instituto Plantarum de Estudos da Flora, 224 p.

STRASSBURG BBN ET AL. 2017. Moment of truth for the Cerrado hotspot. Nat Ecol & Evol 1(4): 1-3.

STRASSBURG BBN, LATAWIEC A & BALMFORD A. 2016. Brazil: urgent action on Cerrado extinctions. Nature 540(7632): 199-199.

TEIXEIRA AMC, PINTO JRR, AMARAL AG & MUNHOZ CBR. 2017. Angiosperm species of "Cerrado" *sensu stricto* in Terra Ronca State Park, Brazil: floristics, phytogeography and conservation. Braz J Bot 40(1): 225-234.

TORRES DM, FONTES MAL & SAMSONAS HDP. 2017. Soil-vegetation relationships in structuring cerrado *sensu stricto* communities in southern Minas Gerais, Brazil. Rodriguésia 68(1): 115-128.

VAN DEN BERG E & OLIVEIRA-FILHO AT. 1999. Spatial partitioning among tree species within an area of tropical montane gallery forest in south-eastern Brazil. Flora 194(3): 249-266.

VELDMAN JW ET AL. 2015. Toward an old-growth concept for grasslands, savannas, and woodlands. Front Ecol Environ 13(3): 154-162.

SUPPLEMENTARY MATERIAL

Table SI.

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Each author presented relevant contribution to elaboration of the present manuscript as follows:
MSc. Raysa VC Saraiva, MSc. Léo V. Leonel and Felipe F. Reis participated in field trips to the CMNP, herbaric practices, species identification, participated in writing, supplying figures, organization of maps, statystical analyses and its interpretations. Dr. Tiago M. Ferraz, Dr. José Roberto P. Sousa and Dr. Francisca H. Muniz participated in field trips to the CMNP, sampling design, species identification, statystical analyses and its interpretations and discussion of the results. Dr. Fábio A.M.M.A. Figueiredo and Dr. Fabrício O. Reis participated in sampling design, methodology and discussion of the results.