VARIATION IN THE HERBACEOUS-SUBSHRUB STRATUM AS AN EFFECT OF FRAGMENTATION IN THE CERRADÃO

Juliana Silvestre Silva[1]
Maura Rejane de Araújo Mendes[2]
Jeanine Maria Felfili[3]

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ABSTRACT

Habitat fragmentation favors the invasion of exotic species. Cerradão is the most fragmented phytophysiognomy in the Brazilian savanna. Thus, to provide insights into the effects of fragmentation in the cerradão, we compared the composition and structure of the herbaceous-subshrub layer on the edge and inside a fragment of cerradão located in the Federal District, Brazil. Vegetation coverage, including floristic richness and diversity, was higher at the edge, where all registered exotic species were present. Invasive *Melinis minutiflora* and *Urochloa brizantha* were the most dominant species on the edge of the cerradão, while the native *Echinolaena inflexa* and *Rhynchospora exaltata* were dominant in the interior. Invasive species accounted for more than 10% of the total species observed at the edge and contributed to more than 50% of their live cover. Therefore, the studied cerradão seems to suffer from the effects of fragmentation. Further studies in the area are required.
Keywords: Coverage, Edge, Frequency, Invasive species, Savanna.

RESUMO

A fragmentação do habitat favorece a invasão de espécies exóticas. Cerradão é a fitofisionomia mais fragmentada da savana brasileira. Assim, para fornecer informações sobre os efeitos da fragmentação no cerradão, comparamos a composição e a estrutura da camada herbáceo-subarbustiva na borda e no interior de um fragmento de cerradão localizado no Distrito Federal, Brasil. A cobertura vegetal, assim como a riqueza e diversidade florística, foi maior na borda, onde todas as espécies exóticas registradas estavam presentes. As invasoras *Melinis minutiflora* e *Urochloa brizantha* foram as espécies mais dominantes na borda do cerradão, enquanto as nativas *Echinolaena inflexa* e *Rhynchospora exaltata* foram dominantes no interior. As espécies invasoras representaram mais de 10% do total de espécies observadas na borda e contribuíram com mais de 50% de sua cobertura viva. Com isso, o cerradão estudado parece sofrer os efeitos da fragmentação. No entanto, novos estudos na área são necessários para confirmar tais efeitos.
Palavras-chave: Cobertura, Borda, Frequência, Espécies invasoras, Savana.

INTRODUCTION

Habitat fragmentation is the reduction or loss of area and its division into smaller and isolated parts. The smaller the fragment, the greater the amount of edge and the

[1] Doutora em Botânica. Universidade de Brasília, Instituto de Ciências Biológicas, Departamento de Botânica. Campus Darcy Ribeiro, Asa Norte. CEP: 70919-900. Brasília, DF – Brasil. ORCID: 0000-0002-4051-7536. julay_silvestre@yahoo.com.br.

[2] Doutora em Botânica. Universidade Estadual do Piauí, Campus Alexandres Alves de Oliveira. Avenida Nossa Senhora de Fátima, S/N, Fátima. CEP: 64202-220. Parnaíba, PI – Brasil. ORCID: 0000-0002-5192-6300.

[3] Doutora em Ecologia Florestal. Universidade de Brasília, Faculdade de Tecnologia, Departamento de Engenharia Florestal. Campus Darcy Ribeiro, Asa Norte. CEP: 70919-970. Brasilia, DF – Brasil. (*In memorian*).

vulnerability to anthropogenic pressures (Primack & Rodrigues, 2001). Fragmentation can result from anthropogenic or natural activities, and both have very different ecological consequences. Anthropic fragments tend to possess low biodiversity and pose a threat to the population viability of species, mainly because of the scarcity of essential natural resources. Conversely, natural fragments are more likely to contain endemic species because of their longer isolation time (Constantino *et al.*, 2005; Aquino & Miranda, 2008).

Native vegetation refuges in man-altered spaces behave like islands for species that are dependent on natural habitats (Diamond, 1976). An island's degree of isolation and ecological dynamics affect the richness of local species. Large refuges are essential to minimize extinction rates, since small fragments tend to lose species that are dependent on well-established habitats, and retain successional and border species, which are characterized by rapid dispersion (MacArthur & Wilson, 2016). However, it is important to consider the spatiotemporal scale and the vegetation type analyzed, as landscapes are formed by mosaics due to the determination of ecosystems by edaphic, climatic, and historical conditions (Aquino & Miranda, 2008).

The Brazilian savanna is the second largest biome in Brazil, and is characterized by a vegetation complex that has ecological and physiognomic relationships with other savannas in tropical America, Africa, Southeast Asia, and Australia. Its extensive distribution in both latitude and altitude results in wide thermal diversification (Ribeiro & Walter, 2008). The Brazilian savanna is a mosaic of physiognomic forms (Coutinho, 2006), and edaphic, geomorphological, topographic, and climatic factors are particularly significant.

Although few long-term studies have investigated the ecological processes lost due to anthropic fragmentation in the Brazilian savanna, the main responses of this biome to fragmentation include an increase in species richness, principally exotic species, and the rapid recruitment of plants adapted to ambiental disorders. These factors, together with the presence of ruderal native species, reflect the vulnerability of the fragment and indicate that its border is an altered environment (Aquino & Miranda, 2008; Dodonov *et al.*, 2016; Pereira *et al.*, 2021). Newly formed forest edges seem to favor the regeneration of seedlings due to the high light availability and seed deposition. Conversely, changes to the local microclimate result in the loss of native plant species, which are adapted to temperature, humidity, and luminosity, in addition to changes in the distribution of insects and in plant–insect interactions, specifically in Brazilian savanna (Christianini & Oliveira, 2013; Dodonov *et al.*, 2013; Mendonça *et al*., 2015).

With more than 4,800 endemic species of plants and vertebrates, the Brazilian savanna is a global biodiversity hotspot (Strassburg *et al.*, 2017). However, despite its importance for the conservation of species and the provision of ecosystem services, to date, the Brazilian savanna has lost almost 50% of its native vegetation cover, with only 19.8% remaining intact and less than 8% protected in public conservation units (Beuchle *et al.*, 2015), mainly because of the strong pressure for agricultural expansion (Strassburg *et al.*, 2017).

Among the various phytophysiognomies in the Brazilian savanna, which encompass forestry, savanic, and field formations, the cerradão is the most fragmented and degraded formation due to human activities, mainly due to its location on flat topography, fertile, and arable land. The cerradão is a woody savanna that occurs in the interfluvia in well-drained land, without association with water courses (Ribeiro and Walter, 2008; Miguel *et al*., 2017). According to Ribeiro & Walter (2008), cerradão is a forest phytophysiognomy with xeromorphic aspects, and is characterized by the presence of species that occur both in the savanna and in the dry forest. It varies between 8 and 15 m in height, and has a predominantly continuous canopy and tree cover that varies from 50 to 90%, providing light conditions that favor the formation of differentiated shrub and herbaceous strata.

Due to the size of the forest and the predominance of tree species, the areas they occupy have been used frequently for agricultural and carpentry purposes, resulting in the occurrence of fragments that are generally located between areas dominated by the savanna (Sano *et al.*, 2010). Studies focused on the phytosociology of the herbaceous-subshrub stratum in forest environments are rare because the arboreal component holds the most biomass and has great economic importance, although smaller species are highly sensitive to microclimatic and edaphic variations and are relevant for ecology and conservation studies (Meira-Neto & Martins, 2000; Miyamura *et al*., 2019).

The more fragmented and altered a landscape, the greater the chances of introducing alien species (Mendonça *et al*., 2015). For example, in the Brazilian savanna, exotic grasses pose a risk to biodiversity because they prevent the establishment of native grasses; however, plant phenology is also influenced by changes in abiotic conditions caused by habitat fragmentation, such as increased luminosity and temperature (Vogado *et al*., 2016). In a recent study, Tallamy *et al.* (2020) reported that the expansion of non-native plant species is responsible for the decline in populations of native herbivorous insects. This contributes to the trophic imbalance of the biome, as these species are important components of the diet for most terrestrial bird species, which are important dispersers in the Brazilian savanna.

Thus, to provide insights into the effects of fragmentation on cerradão phytophysiognomy, this study compared the composition and structure of the herbaceous-subshrub layer at the edge and inside of a cerradão fragment located in the Federal District, Brazil. The vegetation in this stratum is expected to be more dense at the boundary of the fragment due to colonization by exotic and invasive species.

MATERIAL AND METHODS

Study area

The Cerradão Biological Reserve (“REBIO do Cerradão”) (Figure 1) is an Integral Protection Conservation Unit that was created as an Area of Relevant Ecological Interest by decree no. 19.213/98 (Distrito Federal, 1998). It was transformed into a Biological Reserve through decree nº 31.757/10 (Distrito Federal, 2010) because of its environmental and ecological characteristics, which are important for the conservation of phytophysiognomy. According to the SNUC (Brasil, 2000), the objective of a Biological Reserve is the integral preservation of biota and other natural attributes existing in its limits, without direct human interference or environmental modifications. Conversely, an Area of Relevant Ecological Interest is a small unit of sustainable use with little or no human occupation, which presents notable natural characteristics or houses rare specimens of the regional biota. This type of conservation unit allows the regulated use of its areas, as long as this use is compatible with the objectives of nature conservation.

The “REBIO do Cerradão” is located within the Environmental Protection Area (EPA) Gama and Cabeça de Veado (a conservation unit of sustainable use) at the coordinates 15°51'S and 47°49'W. To the east, it borders the Contorno Park Road (EPCT; DF-001), to the west, the Dom Bosco Mansions Sector (SMDB, 4th stage), to the north, the Adventist Hospital, and to the south, the Cabeça de Veado Park Road (EPCV; DF-035). It has a reservoir supported by the CAESB (Federal District Environmental Sanitation Company). The conservation unit occupies an area of 54.12 ha, including 16 ha of cerradão and adjacent dense savanna (i.e., dense cerrado *sensu stricto*). Its location on the border between the São Bartolomeu and Paranoá River Basins, the “REBIO do Cerradão” is important for the infiltration of water in the soil, and is present within a region that has potential for aquifer recharge of approximately 50% (Instituto Brasília Ambiental, 2014).

According to physico-chemical analyses performed in the cerradão, the soil is of the Red Latosol dystrophic type, with base saturation of 6%, average CTC (8.3 cmolc/dm^3) and 81.4 g/kg of organic matter. The soil texture of the cerradão is clayey (60%) and the values of Al, Ca, Mg, K, and Na are, 1.4, 0.3, 0.1, 0.13, and 0.01 cmolc/dm^3, respectively. At pH 4.9, the cerradão is classified as strongly acidic, which characterizes dystrophic soils.

The local climate is tropical Aw according to the Köppen and Geiger classification, which is typical of the Federal District region, with two well-defined seasons: dry winter and rainy summer. The average annual temperature in the region is 21.1°C and the average annual rainfall is 1,668 mm (Cardoso *et al.*, 2014; Climate-Data, 2020).

The CAESB Supported Reservoir was built and activated in mid-May 1978 (H.O. Antunes, personal communication). The fragments revealed no traces of a recent fire.

Sampling

The floristic composition of “REBIO do Cerradão” was determined through biweekly collections carried out from September 2007 to November 2008. The collected individuals were herborized and incorporated in the Herbarium of the University of Brasília (UB). The identification was revised and followed the botanical nomenclature proposed by the Angiosperm Phylogeny Group IV (2016). The synonyms were updated based on Flora do Brasil 2020 (Brazil Flora Group, 2021).

Phytosociological sampling of the herbaceous-subshrub stratum occurred at the beginning of the rainy season (November 2008). Two environments were determined along the cerradão: edge (the shortest distance from the fragment's limit) and interior (the longest distance from the fragment's limit). The 400 m external strip to the south of the fragment was considered as the edge environment. For the interior environment, the innermost area of the cerradão was considered, 175 m away from its limits, forming a sample area of 2,500 m² (50 × 50 m). The two environments were divided into 1 x 1 m squares. Each grid comprised one numbered sample unit (plot), and 40 numbers were randomly drawn in each of the areas using the Research Randomizer software (Urbaniak & Plous, 2007) (Figure 2). Only live biomass was considered in phytosociological sampling.

Coverage of the herbaceous-subshrub layer was estimated using the Braun-Blanquet scale (Kent, 2012), distinguishing the values of live and dead biomass in relation to the area of the plots and for each individual species. Herbaceous strata were considered herbs and non-woody lianas, and subshrub strata were considered the subshrub species and acaule palm trees. The species were classified as “naturalized exotic” following the information published by the Flora do Brasil 2020 (Brazil Flora Group, 2021).

Absolute frequency (FA) and relative dominance (DoR) were calculated using data obtained in the field and are presented as percentages. The occurrence of each species in the plots was used to calculate the frequency, and coverage was used to represent dominance. The formulas used for phytosociological calculations were adapted from Müeller-Dombois and Ellenberg (2002), as follows:

a) Absolute Frequency: $FA = pi / \sum p \cdot 100$

pi = number of plots in which a given species occurred

p = number of plots sampled

b) Relative Dominance: $DoR = (c/ha) / (C/ha) \cdot 100$

c = coverage value of a given species

C = total area coverage value

where: $c = \sum cpi$ (cpi = coverage of the plot in which a given species occurred)

$C = \sum cp$ (cp = coverage of each plot)

Data analysis

The species diversity of the whole cerradão and each sampled environment (border and interior) was measured using the Shannon-Wiener index (H') (Kent, 2012), which is based on the proportional abundance of species, and assigns greater values to rare species. Equability in the distribution of species area was calculated using the Pielou uniformity index (J') (Pielou, 1966). This index is derived from the Shannon diversity index and represents the uniformity of the distribution of individuals among the existing species.

Similarity between the edge and interior plots was assessed using the SØrensen index (Ss) (Kent, 2012), which qualitatively compares two samples within the same community, assigning greater weight to species that are common to the areas being compared. The statistical program MVSP was used to calculate the three indexes (Kovach, 2007).

Finally, to compare the percentage coverage of the herbaceous-subshrub layer in the edge and interior environments, we used the non-parametric Kolmogorov-Smirnov (K-S) test (Zar, 2010), with a significance level (α) of 0.05. The PAST statistical program was used for the K-S test (Hammer *et al.*, 2008).

RESULTS

Vegetation richness and diversity

The floristic composition of the cerradão includes approximately 95% native species of the biome, 60% of families represented by a single genus, and 50.66% represented by a single species. These values, together with the Shannon (H' = 3.85 nats/ind.) and Pielou (J' = 0.82) indices reflect the high richness and diversity of species in the area (Silva & Felfili, 2012).

A survey of herbaceous-subshrub flora identified 109 species, including 50 herbs, 37 subshrubs, and 22 climbers belonging to 90 genera and 39 botanical families. Of these, 56.41% were represented by only one species. The best-represented families were Poaceae (16 spp.), Asteraceae (14 spp.), Rubiaceae (11 spp.), and Fabaceae (10 spp.). Of the total species identified, 6.42% were naturalized exotic (Table 1).

Table 1. Herbaceous-subshrub flora of the cerradão in the “REBIO do Cerradão”, Federal District, Brazil. H = herb. C = climber. S = subshrub. *****: Exotic naturalized.

Family	Species	Habit	Voucher
Acanthaceae	*Justicia lanstyakii* Rizzini	H	UB109112
Alstroemeriaceae	*Alstroemeria gardneri* Baker	H	UB109465
Amaranthaceae	*Gomphrena agrestis* Mart	H	UB109578
	Pfaffia denudata (Moq.) Kuntze	H	UB109314
Anemiaceae	*Anemia phyllitidis* (l.) Sw.	H	UB109365
Apocynaceae	*Ditassa lenheirensis* Silveira	C	UB111984
	Ditassa obcordata Mart	C	UB109650
	Odontadenia lutea (Vell.) Markgr.	C	UB109473
	Prestonia coalita (Vell.) Woodson	C	UB109454
Arecaceae	*Allagoptera campestris* (Mart.) Kuntze	S	UB109299
Asteraceae	*Achyrocline satureioides* (Lam.) DC.	S	UB109643
	Aspilia foliacea (Spreng.) Baker	H	UB109339
	Baccharis dracunculifolia DC.	S	UB109359
	Campuloclinium megacephalum (Mart. ex Baker) R.M.King & H.Rob.	S	UB109480
	Echinocoryne holosericea (Mart.) H.Rob.	H	UB109644

	Elephantopus mollis Kunth	H	UB109623
	Emilia fosbergii Nicolson *	H	UB109354
	Hoehnephytum trixoides (Gardner) Cabrera	S	UB109677
	Ichthyothere latifolia (Benth.) Gardner	S	UB109464
	Lessingianthus compactiflorus (Mart.ex Baker) H.Rob.	S	UB109458
	Symphyopappus compressus (Gardner) B.L.Rob.	S	UB109388
	Trichogonia salviifolia Gardner	H	UB109355
	Tridax procumbens L. *	H	UB109482
	Wedelia bishopii H.Rob.	H	UB109507
Balanophoraceae	*Langsdorffia hypogaea* Mart.	H	UB109613
Bignoniaceae	*Anemopaegma acutifolium* DC.	S	UB109615
	Cuspidaria sceptrum (Cham.) L.G.Lohmann	C	UB109272
	Fridericia platyphylla (Cham.) L.G.Lohmann	C	UB109477
	Jacaranda ulei Bureau & K.Schum.	S	UB109199
Blechnaceae	*Blechnum auriculatum* Cav.	H	UB109370
Boraginaceae	*Varronia truncata* (Fresen.) Borhidi	S	UB109485
Bromeliaceae	*Dyckia* sp.	H	UB109616
Convolvulaceae	*Distimake contorquens* (Choisy) A.R.Simões & Staples	C	UB109563
	Ipomoea procumbens Mart. ex Choisy	C	UB109424
Cucurbitaceae	*Cayaponia tayuya* (Vell.) Cogn.	C	UB109439
Cyperaceae	*Cyperus laxus* Lam.	H	UB109366
	Rhynchospora consanguinea (Kunth) Boeckeler	H	UB109443
	Rhynchospora exaltata Kunth	H	UB109143
Dioscoreaceae	*Dioscorea dodecaneura* Vell	C	UB110707
Euphorbiaceae	*Dalechampia caperonioides* Baill.	H	UB109438
Fabaceae	*Bauhinia dumosa* Benth.	S	UB109675
	Bauhinia rufa (Bong.) Steud.	S	UB110711
	Calliandra dysantha Benth.	S	UB109139
	Centrosema brasilianum (L.) Benth.	C	UB109569
	Cerradicola boavista (Vell.) L.P.Queiroz	H	UB109310
	Cerradicola grewiifolia (Benth.) L.P.Queiroz	S	UB109468
	Chamaecrista conferta (Benth.) H.S.Irwin & Barneby	S	UB109181
	Crotalaria flavicoma Benth.	H	UB109472
	Mimosa somnians Humb. & Bonpl. ex Willd.	S	UB109441
	Stylosanthes guianensis (Aubl.) Sw.	H	UB109210
Gentianaceae	*Voyria aphylla* (Jacq.) Pers.	H	UB109495
Lamiaceae	*Hypenia brachystachys* (Pohl ex Benth.) Harley	S	UB109634
	Hyptis rubiginosa Benth.	S	UB109203
	Hyptis villosa Pohl ex Benth.	H	UB203032
	Oocephalus lythroides (Pohl ex Benth.) Harley & J.F.B.Pastore	S	UB109223
Lauraceae	*Cassytha filiformis* L.	C	UB109460
Loranthaceae	*Passovia ovata* (Pohl ex DC.) Tiegh.	H	UB109247
	Psittacanthus robustus (Mart.) Mart.	H	UB109322
Lythraceae	*Cuphea spermacoce* A.St.-Hil.	S	UB109338
Malpighiaceae	*Banisteriopsis anisandra* (A.Juss.) B.Gates	C	UB109174
	Banisteriopsis argyrophylla (A.Juss.) B.Gates	C	UB109455
	Banisteriopsis stellaris (Griseb.) B.Gates	C	UB109427

	Diplopterys pubipetala (A.Juss.) W.R.Anderson & C.C.Davis.	C	UB109233
Malvaceae	*Pavonia rosa-campestris* A.St.-Hil.	H	UB109213
	Sida linifolia Cav.	S	UB111995
Menispermaceae	*Cissampelos pareira* L.	C	UB110712
Myrsinaceae	*Cybianthus densiflorus* Miq.	S	UB109222
	Cybianthus detergens Mart.	S	UB109345
Myrtaceae	*Myrcia myrtillifolia* DC.	S	UB109269
Ochnaceae	*Ouratea floribunda* (A.St.-Hil.) Engl.	S	UB109570
	Ouratea riedeliana Engl.	S	UB109641
Orchidaceae	*Gomesa varicosa* (Lindl.) M.W.Chase & N.H.Williams	H	UB109414
Oxalidaceae	*Oxalis suborbiculata* Lourteig	S	UB109302
Passifloraceae	*Passiflora cerradensis* Sacco	C	UB110713
Poaceae	*Aristida pendula* Longhi-Wagner	H	UB109619
	Axonopus siccus (Nees) Kuhlm.	H	UB109620
	Echinolaena inflexa (Poir.) Chase	H	UB109435
	Hildaea pallens (Sw.) C.Silva & R.P.Oliveira	H	UB109384
	Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs *	H	UB111988
	Melinis minutiflora P. Beauv. *	H	UB109383
	Mesosetum loliiforme (Hochst. ex Steud.) Chase	H	UB111990
	Panicum cervicatum Chase	H	UB109463
	Panicum sellowii Nees	H	UB109506
	Paspalum polyphyllum Nees	H	UB109617
	Schizachyrium tenerum Nees	H	UB111991
	Trachypogon sp.1	H	UB111993
	Trachypogon sp.2	H	UB111994
	Urochloa brizantha (Hochst. ex A.Rich.) R.D.Webster *	H	UB111985
	Urochloa decumbens (Stapf) R.D.Webster *	H	UB109360
	Urochloa sp. *	H	UB111986
Polygalaceae	*Asemeia violacea* (Aubl.) J.F.B.Pastore & J.R.Abbott	H	UB109353
Rubiaceae	*Borreria poaya* (A.St.-Hil.) DC.	H	UB109470
	Chomelia ribesioides Benth. ex A.Gray	S	UB109330
	Coccocypselum aureum (Spreng.) Cham. & Schltdl.	H	UB109494
	Declieuxia fruticosa (Willd. ex Roem. & Schult.) Kuntze	S	UB109478
	Galium noxium (A.St.-Hil.) Dempster	H	UB109361
	Palicourea hoffmannseggiana (Willd. ex Schult.) Borhidi	S	UB109489
	Palicourea marcgravii A.St.-Hil.	S	UB109380
	Palicourea officinalis Mart.	S	UB109375
	Palicourea prunifolia (Kunth) Borhidi	S	UB109368
	Palicourea trichophora (Müll. Arg.) Delprete & J.H.Kirkbr.	S	UB109387
	Sabicea brasiliensis Wernham	S	UB109430
Sapindaceae	*Serjania erecta* Radlk.	C	UB109471
	Serjania lethalis A.St.-Hil.	C	UB109256
	Serjania ovalifolia Radlk.	C	UB109207
Smilacaceae	*Smilax brasiliensis* Spreng.	C	UB109436
Turneraceae	*Turnera lamiifolia* Cambess.	H	UB109584
Verbenaceae	*Lippia rotundifolia* Cham.	S	UB109607
	Stachytarpheta polyura Schauer	H	UB109389

Comparing the diversity of species in the interior of the cerradão with the edge of the same fragment found a higher value in the edge environment (H' edge = 2.26 nats/ind.; H' interior = 1.50 nats/ind).

Phytosociology of the herbaceous-subshrub layer

Phytosociological sampling of the herbaceous-subshrub layer identified 18 families, including three that were indeterminate, and 29 species, including 24 that were on the edge and 11 in the interior plots. The herbaceous *Rhynchospora exaltata* Kunth and *Echinolaena inflexa* (Poir.), the climbers *Dioscorea dodecaneura* Vell, and the subshrubs *Myrcia myrtillifolia* DC., *Palicourea hoffmannseggiana* (Willd. ex Schult.) Borhidi, and *Palicourea trichophora* Müll. Arg were present in both environments. Four species found at the edge of the cerradão were naturalized exotic, accounting for 13.79% of the total sample. No invasive species were observed in the plots within the fragment (Table 2).

Table 2. Species identified by phytosociological sampling of the herbaceous-subshrub stratum of the cerradão in the "REBIO do Cerradão", Federal District, Brazil. I: interior; E: edge; *****: Exotic naturalized; •: Not collected.

Family	Species	I	E	Voucher
Apocynaceae	*Ditassa obcordata* Mart.	X		UB109650
Arecaceae	*Allagoptera campestris* (Mart.) Kuntze	X		UB109299
Asteraceae	*Achyrocline satureioides* (Lam.) DC.		X	UB109643
Cyperaceae	*Rhynchospora exaltata* Kunth	X	X	UB109143
Dioscoreaceae	*Dioscorea dodecaneura* Vell.	X	X	UB110707
Fabaceae	*Stylosanthes guianensis* (Aubl.) Sw.		X	UB109210
Lauraceae	*Cassytha filiformis* L.		X	UB109460
Malpighiaceae	*Banisteriopsis stellaris* (Griseb.) B.Gates	X		•
Malvaceae	*Sida linifolia* Cav.		X	UB111995
Menispermaceae	*Cissampelos pareira* L.		X	UB110712
Myrtaceae	*Myrcia myrtillifolia* DC.	X	X	UB109269
Oxalidaceae	*Oxalis suborbiculata* Lourteig		X	UB109302
Poaceae	*Axonopus siccus* (Nees) Kuhlm.		X	UB109620
	Echinolaena inflexa (Poir.) Chase	X	X	UB109435
	Hildaea pallens (Sw.) C.Silva & R.P.Oliveira	X		UB109384
	Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs *		X	UB111988
	Melinis minutiflora P. Beauv. *		X	UB109383
	Mesosetum loliiforme (Hochst. ex Steud.) Chase		X	UB111990
	Schizachyrium tenerum Nees		X	UB111991
	Trachypogon sp.1		X	UB111993
	Trachypogon sp.2		X	UB111994
	Urochloa brizantha (Hochst. ex A.Rich.) R.D. Webster *		X	UB111985
	Urochloa sp. *		X	UB111986
Rubiaceae	*Palicourea hoffmannseggiana* (Willd. ex Schult.) Borhidi	X	X	UB109489
	Palicourea trichophora (Müll.Arg.) Delprete & J.H.Kirkbr.	X	X	UB109387
Verbenaceae	*Stachytarpheta polyura* Schauer		X	UB109389
Indetermined	Indetermined 1		X	•

Indetermined 2		X	•
Indetermined 3	X		•

Greater coverage was observed in the border plots than in the interior. The results of the Kolmogorov-Smirnov test were significant (D = 0.475; P = 0.000133), with different distributions identified between the sampled environments. Similarly, the SØrensen index (Ss = 0.343) revealed that the environments were not floristically similar, since values less than 0.5 are considered indicative of low similarity (Kent, 2012).

Poaceae was the richest family in terms of species and constituted the largest number of sampled representatives (11 spp.). It presented phytosociological prominence, with species among the most frequent and dominant. In the interior plots, *E. inflexa* ("capim-flexinha") and *R. exaltata* ("capim-estrela") stood out in terms of frequency and dominance. On the border, *Melinis minutiflora* P. Beauv. and *Urochloa brizantha* (Hochst. ex A.Rich.) Webster - both exotic - were the most dominant species, although *E. inflexa* occurred in more than half of the plots sampled in this environment (Table 3).

Table 3. Phytosociological parameters of species present in samples of the herbaceous-subshrub stratum from the cerradão in the "REBIO do Cerradão", Federal District, Brazil, in descending order of the total value of relative dominance. FA: absolute frequency (%); DoR: relative dominance (%). •: Absent.

Species	Edge		Interior		Total	
	FA	DoR	FA	DoR	FA	DoR
Echinolaena inflexa	52,5	11,38	67,5	51,53	60	62,91
Rhynchospora exaltata	27,5	7,77	80	39,56	53,75	47,33
Urochloa brizantha	37,5	21,23	•	•	18,75	21,23
Melinis minutiflora	42,5	19,19	•	•	21,25	19,19
Myrcia myrtillifolia	2,5	0,94	20	2,70	11,25	3,64
Palicourea hoffmannseggiana	2,5	0,47	7,5	2,99	5	3,46
Palicourea trichophora	2,5	1,40	5	1,61	3,75	3,01
Ichnanthus bambusiflorus	7,5	2,43	•	•	3,75	2,43
Axonopus siccus	7,5	2,11	•	•	3,75	2,11
Cassytha filiformis	5	2,11	•	•	2,5	2,11
Megathyrsus maximus	5	2,11	•	•	2,5	2,11
Achyrocline satureioides	2,5	1,87	•	•	1,25	1,87
Indetermined 1	2,5	1,87	•	•	1,25	1,87
Indetermined 2	5	1,08	•	•	1,25	1,08
Trachypogon sp.1	15	1,03	•	•	7,5	1,03
Cissampelos pareira	2,5	0,47	•	•	1,25	0,47
Mesosetum loliiforme	2,5	0,47	•	•	1,25	0,47
Hildaea pallens	•	•	2,5	0,44	1,25	0,44
Trachypogon sp.2	2,5	0,33	•	•	1,25	0,33
Allagoptera campestris	•	•	2,5	0,29	1,25	0,29
Ditassa obcordata	•	•	2,5	0,29	1,25	0,29

Indetermined 3	•	•	5	0,29	3,75	0,29
Schizachyrium tenerum	2,5	0,23	•	•	1,25	0,23
Stachytarpheta polyura	2,5	0,23	•	•	1,25	0,23
Dioscorea dodecaneura	2,5	0,05	5	0,15	1,25	0,19
Banisteriopsis cf.*stellaris*	•	•	2,5	0,15	1,25	0,15
Sida linifolia	2,5	0,09	•	•	1,25	0,09
Stylosanthes guianensis	2,5	0,09	•	•	2,5	0,09
Oxalis suborbiculata	2,5	0,05	•	•	2,5	0,05

The invasive grass *M. minutiflora* ("capim-gordura") occurred in the portion of the cerradão edge closest to the adjacent dense savanna, where the vegetation is lower due to the presence of smaller species that favor the reach of light in the lower strata of vegetation. At the edge of the cerradão, *M. minutiflora* and *E. inflexa* do not seem to be excluded, since the species share 80% of the plots occupied by *M. minutiflora*. Conversely, *U. brizantha* ("braquiária") was the only species able to stop its spread, since in the plots where it dominated, *M. minutiflora* was absent or presented low values of dominance.

R. exaltata, a common species in areas of cerradão (Mendonça *et al.*, 2008), was present in 80% of the plots in the interior and 27.5% of the plots on the edge of the cerradão, where it was represented by a large number of small individuals.

Dead biomass was only recorded on the edge, comprising up to 30% of the sampled biomass. *E. inflexa* and *M. minutiflora* accounted for 87.35% of the total mulching. In the interior of the fragment, where the environment is widely covered by the treetops, coverage of the herbaceous-subshrub stratum hardly exceeded 50%, while coverage of half the plots allocated at the edge exceeded 50%. Despite this, there was a greater number of plots on the edge (four plots) with less than 1% coverage compared to the interior (three plots) (Table 4).

Table 4. Number of plots by coverage class sampled in the cerradão in the "REBIO do Cerradão", Federal District, Brazil.

Braun-Blanquet coverage classes	Nº of plots	
	Edge	Interior
< 1%	4	3
1 - 5%	1	9
6 - 25%	7	17
26 - 50%	8	10
51 - 75%	6	0
76 - 100%	14	1
Total	40	40

DISCUSSION

Richness and diversity

Studies sampling the herbaceous stratum in cerradão are rare, therefore, limited data are available for comparison. However, the cerradão studied at "REBIO do Cerradão" presented high floristic richness, when compared to other cerradão areas (109 spp.). In the state of São Paulo, Batalha and Mantovani (2001) found 70 herbaceous-subshrub species, of which almost 3% were invasive. Rubiaceae (nine species), Asteraceae, and Poaceae (six species each) presented greater richness, and 18.6% of the total families were represented by only one species. In South Mato Grosso, Assunção *et al.* (2011) cataloged

59 species, 41.2% of families were represented by only one species, and 10.17% of subespontaneous species. Fabaceae was the richest family (15 spp.), followed by Poaceae (12 spp.), and Asteraceae (seven spp.). In "REBIO do Cerradão" the proportion of families represented by a single species (60.52%) is higher that reported in other areas of cerradão. Fabaceae, Poaceae, and Asteraceae are also among the richest families.

In the literature, these families are identified as the richest families in the Brazilian savanna and are best represented in the herbaceous communities of cerradão (Filgueiras, 2002; Mendonça *et al.*, 2008). Assunção *et al.* (2011) found that species belonging to the Asteraceae family were more common at the edges and in the clearings present inside the fragment. Although the family was represented by 14 species in the floristic survey of this cerradão, only one species (*Achyrocline satureioides* [Lam.] DC.) was sampled in a phytosociological study. Despite being native to Brazil, *A. satureioides* is common in open and altered environments, such as wastelands and roadsides (Moreira & Bragança, 2011).

Asteraceae is one of the main families of invasive plants, and is particularly common in open formations in Brazil, mainly in the Brazilian savanna (Souza & Lorenzi, 2019). According to Coutinho (1978), Asteraceae and Poaceae, together with Cyperaceae, include genera and species with a large number of heliophile representatives. In addition, that author noted the herbaceous-subshrub layer is predominantly composed of heliophilous perennial species and is poorly represented in the cerradão due to intolerance to shading. In the present study, the richness of this stratum was probably due to the presence of heliophilous species in the border environment and in the clearings within the fragment, where the incidence of light was greater.

Phytosociology of the herbaceous-subshrub layer

In the cerradão, there was greater coverage in the border environment. *E. inflexa* and *M. minutiflora* were among the most important herbaceous species in all cerradão areas studied by Felfili *et al.* (1994) in Chapada Pratinha, in the Brazilian Central Plateau. Pivello *et al.* (1999) recorded the highest frequency, dominance, and density values for *E. inflexa* among native herbs observed in a savanna reserve in the state of São Paulo.

According to Hoffmann and Haridasan (2008), *M. minutiflora* prefers shaded areas and tends to form a dense cover of approximately 1 m in height, which inhibits the survival of tree seedlings. However, at the edge of REBIO's cerradão, *E. inflexa* was present in 80% of the plots occupied by *M. minutiflora*; this was also observed by Pivello *et al.* (1999).

"Capim-gordura" is not efficient at exploring extensive areas of soil due to the small size of its roots; however, some variables, such as increased nutrient mineralization resulting from burning and/or increased organic matter, can improve nutrient availability on the soil surface. In these places, due to its capacity for vegetative expansion, the invasive species is able to replace the native species, thus reducing local biodiversity (Martins *et al.*, 2004). In the present study, no seedlings or subshrubs were found in the plots where *M. minutiflora* was present at a high density.

In addition to *E. inflexa*, *R. exaltata* stood out in the interior plots. Filgueiras (2002) and Alves *et al*. (2009) reported that the family Cyperaceae, more specifically *R. exaltata*, is characteristic of open areas, and tends to appear in high densities in forest edges and clearings, in humid areas of forest (edge and interior), and between outcrops of quartzitic fields (Longhi-Wagner & Araújo, 2014). In a dystrophic seasonal forest, Meira-Neto *et al.* (2005) found a positive correlation between *R. exaltata* and low coverage, high brightness, and soils with high exchangeable aluminum content and low exchangeable Ca, Mg and K levels; these edaphic characteristics are also observed in "REBIO do Cerradão."

Pivello *et al.* (1999) noted that *R. exaltata* acts as a background herb on which other species occupy smaller areas, except in the presence of "braquiária" (Urochloa decumbens

(Stapf) R. D. Webster). Of the 15 plots (37.5%) containing *U. brizantha,* which were all on the edge, *R. exaltata* was only present in one, with 3% coverage of the plot. Non-native herbs tend to disperse easily due to anemocory, have higher rates of photosynthesis, and are more efficient at using nutrients and nitrogen compared to native species (Eller & Oliveira, 2007; Silva & Haridasan, 2017).

Among the subshrub species sampled, *Achyrocline satureioides*, *Sida linifolia* Cav., *Oxalis suborbiculata* Lourteig, *Palicourea trichophora*, and *P. hoffmannseggiana* are common to anthropized areas and/or forest edges (Mendonça *et al.*, 2008), and the latter is one of the most frequent species in the cerradão areas of Chapada Pratinha (Felfili *et al.*, 1994). Within the studied fragment, the most frequent subshrub, present in eight plots, was *Myrcia myrtillifolia*, which is a native species commonly found in areas of woodland savanna (i.e., cerrado *sensu stricto*), rupestrian savanna, and grassland (Proença *et al.*, 2001; Mendonça *et al.*, 2008; Lucas *et al.*, 2016).

The presence of exotic species in the border plots only, totaling more than 10% of the total species observed in this environment and contributing 53% of its live cover, seems to corroborate the statement that the fragmentation of an area facilitates the invasion process, hindering, or even preventing the development of naturally occurring species. Felfili *et al.* (1994) found that the cerradão areas presented the highest number of invasive species, highlighting the vulnerability of phytophysiognomy. The high number of invasive species was also responsible for the greater richness and diversity of the border compared to the interior of the fragment, which reflects the low floristic similarity between the sampled environments.

The lower coverage in the interior plots was expected, since herbaceous species have a preference for more open environments where light falls more abundantly. This also explains why 10% of the plots on the edge have less than 1% coverage, because the portion of the edge where these plots were allocated was close to the water reservoir; therefore, it was more recent and shaded than the rest of the strip sampled. In this environment, the herbaceous layer is null or reduced and the tree species present form a canopy, which provides constant shading. As this occurs inside the fragment, it appears to hinder the establishment of herbaceous species that require high luminosity.

Research on the herbaceous-subshrub stratum in the cerradão is important for expanding our knowledge on this specific vegetation and for conservation purposes. It is a stratum that is floristically little known in phytophysiognomy, as observed by the limited number of studies with this objective. Because they are smaller, they face greater competition for light, nutrients, and water, and possess structural and physiological adaptations associated with the environment in which they live. Plants in the lower stratum become sensitive to changes in this environment, and act as indicators of environmental quality, providing useful data on the conservation status of forest communities (Müller & Waechter, 2001; Miyamura *et al*., 2019).

For the Brazilian savanna, little is known about vegetation dynamics in an edge environment since most studies have been performed in areas of tropical and temperate forests (Turner, 1996; Nascimento & Laurance, 2006; Laurance & Vasconcelos, 2009; Smith *et al.*, 2018). Based on the limited studies carried out in the Brazilian savanna, there is a wide variety of responses from the organisms, and the edge may or may not influence the structure and composition of the fragmented area (Lima-Ribeiro, 2008; Sampaio & Scariot, 2011; Arruda & Eisenlohr, 2016).

CONCLUSIONS

Considering the difference in the coverage and composition of the flora of the herbaceous-subshrub layer between the two distances evaluated, since inside the fragment the vegetation remains closer to the original formation with species typical of phytophysiognomy, and that the native species of the biome that occur on the edge are species that tend to appear in anthropized areas or edges of forests, we conclude that the cerradão of REBIOS presents fragmentation effects. However, a future study in this fragment comparing the data obtained here, may provide more definitive answers.

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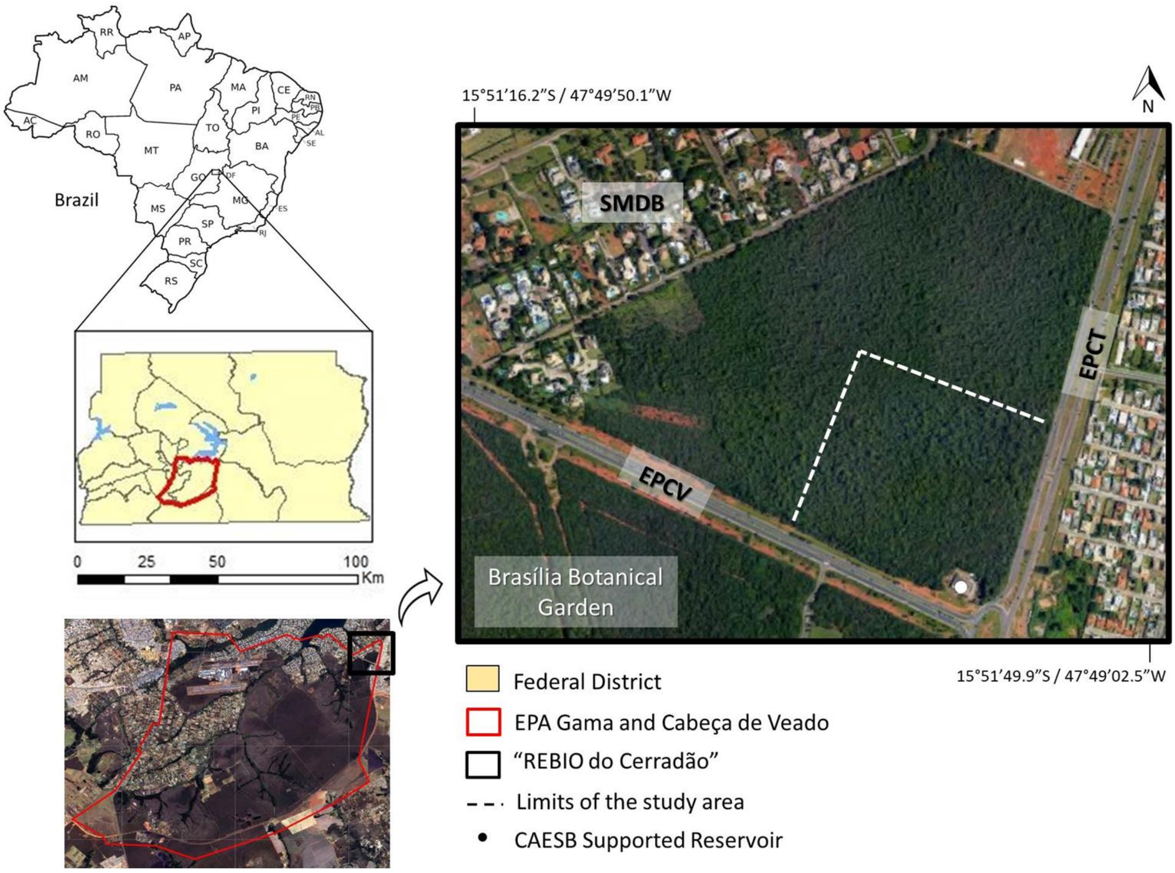

Figure 1. Study area location. Source: Modified from Instituto Brasília Ambiental (2014) and Google Earth (Year of the image: 2020).

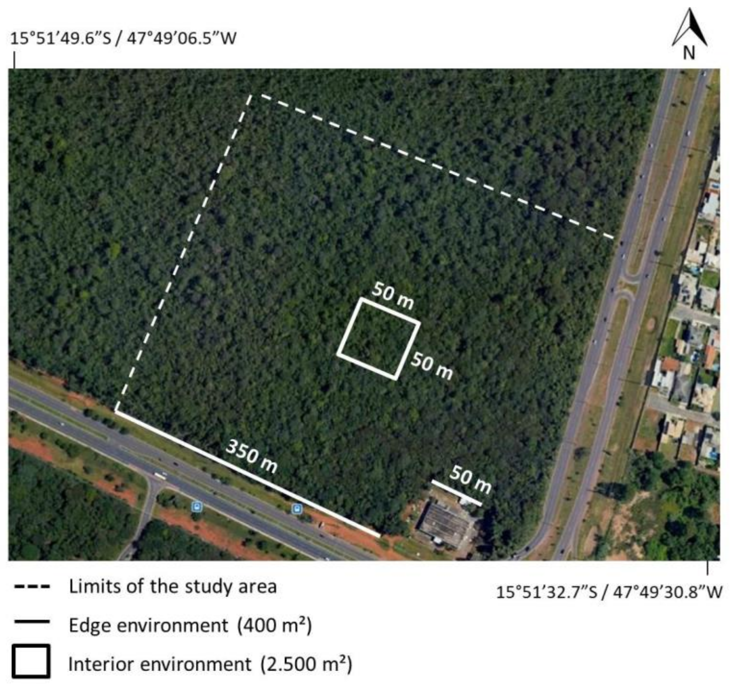

Figure 2. Edge and interior environments sampled at "REBIO do Cerradão", Federal District, Brazil, for a phytosociological study of the herbaceous-subshrub stratum. Source: Modified from Google Earth (Year of the image: 2020).