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Potential nursing effects of *Parkia platycephala* Benth. (Fabaceae) in a disturbed Brazilian Savanna area undergoing restoration

Efeitos potenciais da facilitação de *Parkia platycephala* Benth. (Fabaceae) em uma área antropizada da Savana brasileira em processo de recuperação

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We evaluated the influence of *Parkia platycephala* on plant assemblages under its crown and surrounding areas in a disturbed Brazilian Savanna, as well as the effects of aqueous extracts of its leaves on the germination and development of three species, under the hypothesis that *P. platycephala* might work as a nurse species. Eleven areas of direct (ADIs) and indirect (AIIs) influence of *P. platycephala* and 11 control areas (COs) were delineated. All tree and shrub species present in these areas, including seedlings, were sampled. Richness, composition and abundance of woody taxa were determined. Laboratory studies analyzed the effects of *P. platycephala* aqueous leaf extracts on the germination and initial development of *Dipteryx alata*, *Enterolobium gummiferum* and *Magonia pubescens*, which in the field exhibited different abundance levels under its crown. Regarding plant assemblages, no differences in terms of richness and abundance of woody taxa were detected among the areas. However, we recorded a gradient of species composition and abundance ranks from ADI to CO areas. The number of seedlings also differed, with higher values near *P. platycephala*. Soil characteristics were similar among areas, but shading, plant height and diameter differed. The aqueous leaf extract at 25% provided the best germination of *M. pubescens*. The extract at 75% favored the initial development of this species in terms of root length. These results indicate that the presence of *P. platycephala* affects the structure of neighboring plant assemblages, possibly working as a facilitator for some species in areas undergoing restoration.
Keywords: Cerrado, facilitation, leaf extracts.

Avaliou-se a influência de *Parkia platycephala* na assembleia de plantas sob sua copa e áreas adjacentes numa área antropizada de Cerrado, bem como os efeitos de extratos aquosos de suas folhas na germinação e desenvolvimento de três espécies sob a hipótese de que *P. platycephala* pode provavelmente atuar como espécie facilitadora. Foram delimitadas 11 áreas de influência direta (AIDs) dessa espécie, 11 áreas de influência indireta (AIIs) e 11 áreas controle (COs). Todas as espécies lenhosas ocorrentes nessas áreas foram amostradas. A riqueza, composição e abundância dos táxons foram determinados. Os efeitos de extratos foliares de *P. platycephala* na germinação e desenvolvimento inicial de *Dipteryx alata*, *Enterolobium gummiferum* e *Magonia pubescens*, que exibiram diferentes níveis de abundância sob sua copa, também foram avaliados. Em relação à assembleia de plantas, não foram detectadas diferenças para riqueza e abundância dos táxons lenhosos entre as áreas. Entretanto, verificou-se um gradiente de composição de espécies e dos níveis de abundância das áreas AIDs para COs. O número de plântulas também diferiu, com valores mais altos próximo a *P. platycephala*. As características edáficas foram similares entre as áreas, mas o sombreamento, a altura e o diâmetro das plantas diferiram. A melhor germinação de *M. pubescens* foi obtida em 25% do extrato foliar, enquanto 75% favoreceu o desenvolvimento inicial dessa espécie em termos de comprimento radicial. Esses resultados indicam que a presença de *P. platycephala* afeta a estrutura das assembleias de plantas adjacentes, possivelmente funcionando como facilitadora para algumas espécies em áreas em processo de restauração.
Palavras-chave: Cerrado, facilitação, extratos foliares.

1. INTRODUCTION

The Brazilian Savanna, locally known as “Cerrado”, is a world hotspot for biodiversity conservation [1]. This complex vegetation domain, however, has been subjected to profound transformations over the last decades due to the expansion of human activities, particularly deforestation and land conversion to agriculture and cattle raising [2, 3]. According to Strassburg et al. (2017) [4], almost 46% of its native vegetation has been lost. Given this situation, ecological restoration turns out to be an essential alternative to mitigate or reverse some of the negative effects in disturbed areas [5]. Environmental restoration has become a common and necessary practice in Brazil, considering the present levels of disturbance caused by different acitivities such as urbanization, agriculture, fires, illegal exploitation and commercialization of wood, among other factors [6].

Ecological restoration by managing pionner species may constitute a successful strategy, because these species present rapid growth and are efficient in terms of water and nutrient use [7], providing adequate conditions for the establishment of secondary and climax species. For this reason, it is important to understand the role of certain pioneer and secondary species when introduced into natural environments. Among the various restoration techniques used is nucleation, a method that promotes facilitation by means of microhabitat formation. This technique has been proven to be efficient in fomenting the formation of stable, integrated communities [8, 9]. Species that are able to promote these modifications have been denominated “foundation” and “nurse species” by Bruno et al. (2003) [10] and by Padilla and Pugnaire (2006) [11], respectively, because they provide conditions for the germination and growth of several other species. The planting of seedlings of target native species in disturbed sites is one of the techniques used to generate nucleus (nursing) effects capable of attracting greater biological diversity [8].

However, it is important to highlight that the presence of certain species can negatively affect the performance of neighboring plants in several ways. For example, pioneer species can act as strong competitors for resources or as inhibitors. Interspecific competition is one of the most common forms of interaction among plants, primarily during the process of community assembly, and quite often cause negative effects on diversity especially when there are dominant species [12]. Inhibitor species, in their turn, generally hinder the establishment of other species by competing for space and resources [13, 14], or by producing biochemicals that interfere in their germination or establishment (allelopathy) [15]. Studies carried out with tree species in the Cerrado savanna have demonstrated their inhibitory effects, but only in laboratory experiments where plant extracts (mostly from leaves) were used, whose phytotoxic activities were tested on the germination and growth of some species [16]. According to these authors, a number of scientists agree that such investigations (laboratorial) do not represent the natural conditions found in the ecosystem. Therefore, it is also important to evaluate, under field conditions, whether a species plays a positive, negative or neutral influence on the ability of a second species to invade and get established in a community [14].

In this study, we investigated community-level (assemblage structure) effects induced by a tree species commonly found in the Cerrado (*Parkia platycephala* Benth., Fabaceae), under the hypothesis that this tree works as a nurse species. In May 2006, 40 young individuals of *P. platycephala* were planted in a disturbed Cerrado area in the County of Porto Nacional, Tocantins, Brazil, so that the performance along their establishment in a natural environment could be evaluated. After planting the *P. platycephala* individuals in 2006, the area was abandoned, allowing natural colonization and dynamics, except for eventual domestic and wild animal grazing. The results revealed a high survival percentage and an outstanding growth capability of *P. platycephala* [17]. Moreover, this species has the largest crown among those planted in 2006. These traits (survival, growth and shading) suggest that *P. platycephala* may facilitate the establishment of other species, accelerating the restoration of disturbed areas [18, 19]. In light of the above, this study evaluated the influence of *P. platycephala* on plant assemblages under its crown and surrounding areas in a disturbed Brazilian savanna Cerrado undergoing a process of natural restoration.

We also investigated organism-level (seed germination and initial growth) effects induced by *P. platycephala* on other native species, under the hypothesis that this tree may affect the development of the neighboring plants. Although we have not found any evidence of allelopathic effects related to *P. platycephala* in the literature, a few studies have shown that other species of the genus *Parkia* such as *P. speciosa* [20], *P. clappertoniana* [21], *P. biglobosa* [22] and *P. pedula* [23] synthesize flavonoids, triterpenes, steroids and esters which have been associated with allelopathic activities. Thus, it is possible that these compounds are also present in the leaves of *P. platycephala* and exert some kind of influence on the germination and development of certain species under or near its crown. For this reason, under this hypothesis, a companion laboratory experiment tested the effects of *P. platycephala* aqueous leaf extracts on the germination and initial development of *Dipteryx alata*, *Enterolobium gummiferum* and *Magonia pubescens*, species that exhibited different abundance levels under the crowns of *P. platycephala*.

2. MATERIAL AND METHODS

2.1 Study area and target species

The study was carried out in a cerrado *sensu stricto* area at Fazenda São Judas Tadeu (10º48'31"S and 48º26'52"W) situated in the County of Porto Nacional, Tocantins, Brazil. The area is considered disturbed because it was used for animal grazing prior to the beginning of the study in 2006 [17]. The soil of the area is Concretionary and has medium texture [24].

Parkia platycephala Benth., our target species, is a member of the Fabaceae family and is popularly known as "sabiú", "fava de bolota", or "badoqueiro". It is a native species distributed throughout the Brazilian North, Northeast and Central-west regions [25], found in areas of Cerrado, Caatinga and the Amazon Rainforest [25, 26]. According to MMA (2007) [18] and Sano et al. (2008) [19], this tree species could act as a facilitator species in the process of restoration of different ecosystems. It is a tree species of rapid growth, reaching from 8 to 18 meters in height, has a broad crown with decumbent branches which often touch the ground. In reforestation programs, its crown favors the development of late secondary species [27]. As stated by Bulhão and Figueiredo (2002) [28], *P. platycephala* is a facultative evergreen species and leaf abscission occurs late in the dry season after fruit production. It is economically important, e.g., timber industry, forage for ruminants and ornamental potential [27, 29]. Because it is a common plant throughout the State of Tocantins, it is recognized as the State tree [30].

2.2 Community-level effects

To investigate the effects of *P. platycephala* on plant assemblage structure, the study considered a gradient of its influence: (i) under *P. patycephala* crowns (direct influence), (ii) areas adjacent to its crowns (indirect influence), and (iii) areas free of its influence (absence of *P. platycephala*).

Out of the 40 individuals of *P. platycephala* planted in 2006 (for more information see Alves et al. 2016 [17]), 11 were selected for the present study. The selection considered that each *P. platycephala* individual was isolated from one another, with no overlapping crowns. The mean distance between individuals was 27.2 meters. For each individual, we delineated areas of direct influence (ADI) and areas of indirect influence (AII). The ADI corresponded to the horizontal crown projection of each individual on the ground as defined by two perpendicular axes whose radii were measured from the center of the tree trunk (Figure 1). The AII was defined on the basis of each radius of the ADI (the same values), projected immediately outside the crown. Eleven control areas (CO) were also delineated at least 30 meters away from any *P. platycephala* individual. The mean crown diameter, trunk diameter and height of the individuals were 11.8 m, 12.3 cm and 3.8 m, respectively. The size of the control areas was standardized as the average sizes of both ADI and AII combined, assuming these areas were in the shape of an ellipse. No *P. platycephala* individual was present in the control areas. We considered each area an independent sampling unity, totaling 11 samples/treatment and 33 samples in all. The three areas are relatively close to each other, so they were subjected to the same climate regime (humid tropical classified as Aw, according to Köppen [31], which is characterized by rainy Summers and dry Winters), environmental conditions and disturbance (animal grazing). Species were also classified according to their functional dispersion syndromes based on bibliographical research.

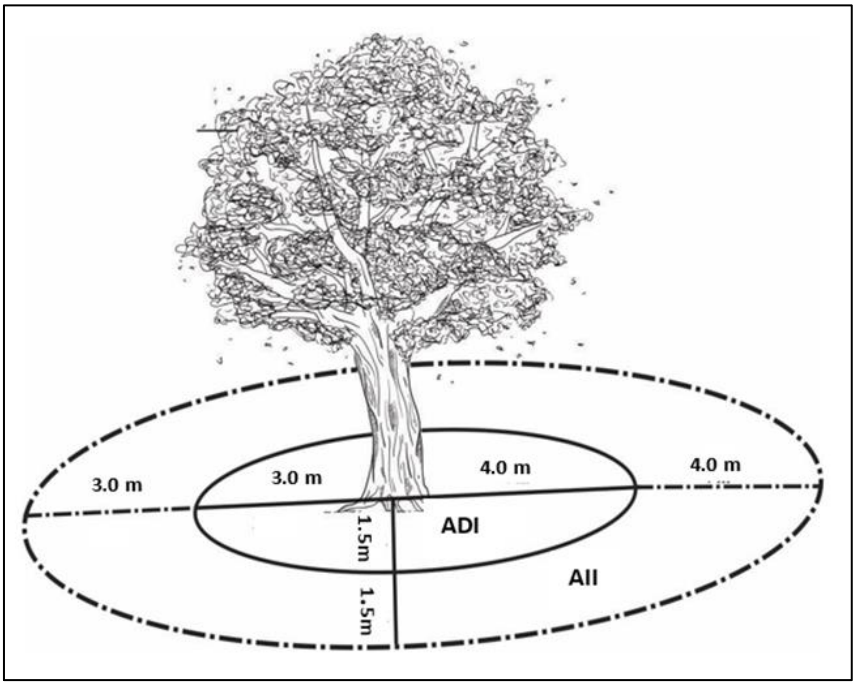

Figure 1: Schematic diagram of the areas of direct (ADI) and indirect (AII) influence of Parkia platycephala as calculated in the present study.

Data were collected from February to August 2016, ten years after the planting of *P. platycephala* individuals in the study area. All *P. platycephala* specimens selected for the study as well as the control areas were georeferenced. All woody specimens (including seedlings) in the three areas (ADI, AII and CO) were identified and measured for height (m) and diameter at ground level (mm). Most seedling species were identified in the field. When this was not possible, they were carefully removed with their roots and taken to the Tocantins Herbarium (HTO) for identification. Only seedlings of woody species were included in the analyses. Resprouts were considered adult individuals. Shading percentage was determined by randomly measuring the amount of light available one meter above ground level (three readings in each area) in relation to full sun, by means of a digital light meter (General Tools DLM2, New Jersey, USA). Readings were recorded on days with no clouds during the month of June. In order to compare soil chemical and physical properties (pH, macronutrient, aluminum and organic matter contents, and texture), we collected four samples (at 0-20 cm depth) per *P. platycephala* individual (two from the ADI and two from the AII) and four samples from each control area. These samples were analyzed in the Soil Analysis Laboratory of the Federal Institute of Tocantins.

2.3 Effects of *P. platycephala* leaf extracts on germination and seedling development

Laboratory experiments were conducted to investigate the effects of aqueous extracts of *P. platycephala* leaves on the germination and initial development of other Cerrado plant species. Three species were selected for these experiments: *Dipteryx alata* Vog. (Fabaceae), *Enterolobium gummiferum* (Mart.) J. F. Macbr. (Fabaceae) and *Magonia pubescens* St. Hil. (Sapindaceae). Selection was based on their relative abundance under *P. platycephala* crowns (ADI) according to the species abundance rank (Figue 5): low (*D. alata* ranked 23rd), intermediate (*E. gummiferum* ranked 9th) and high abundance (*M. pubescens* ranked 2nd). In addition, this selection was based on seed availability at the time of the experiments.

The extracts were prepared according to Gatti et al. (2004) [32] and Grisi et al. (2011) [33]. Young and adult leaves of *P. platycephala* were collected from five individuals. They were washed in running water for approximately five minutes for debris removal and then dried for 96 hours in an oven set to 45º C. Following that, the leaves were ground in a knife-type mill (Marconi - MA 340, São Paulo, Brazil). An aqueous extract was obtained using deionized water as the solvent, and a crude extract (100 g of dry leaves in 1 L of deionized water) was prepared. This crude extract was kept at 5º C for one hour and then vacuum-filtered through one layer of filter paper to obtain the most concentrated extract (100%). From this extract, three dilutions were made using deionized water, resulting in the following concentrations: 75%, 50% and 25%. We evaluated the effects of these extract concentrations in addition to pure deionized water (control treatment) on the germination and initial development of the three species mentioned above.

A completely randomized experimental design was carried out. For *D. alata* and *E. gummiferum* there were five repetitions, each consisting of 10 seeds laid on double-layer filter paper disks placed in 11-cm glass Petri dishes (n=50). For *M. pubescens*, whose seeds are much larger, there were 10 repetitions, each consisting of 5 seeds (n=50). The Petri dishes (containing the filter paper disks) were autoclaved at 120º C and 105 kPa for 15 minutes before the addition of 25 mL of the extracts, and then followed by seed sowing. Prior to sowing, seeds were surface sterilized with 50% (v/v) commercial bleach (2.5% active chlorine) in deionized/autoclaved water solution for 15 minutes, followed by two 15-minute rinses in deionized/autoclaved water. The Petri dishes containing the seeds were kept in a growth room at 27 ± 1º C under a 16-hour photoperiod provided by cool-white fluorescent lamps (Empalux, Brazil) at 30-35 µmol m^{-2} s^{-1} (measured by a digital light meter - General Tools DLM2, New Jersey, USA). Five days after the beginning of the experiment, 15 mL of the extracts were added to each Petri dish.

2.4 Statistical analyses

To examine community-level effects, we investigated woody plant assemblage structure in the three areas (ADI, AII and CO) considering variations in plant density (individuals/m^2), species density (species/m^2), total richness and composition of woody taxa. To investigate patterns in total richness, we calculated rarefaction curves (95% confidence intervals) based on the number of individuals sampled [34]. For this analysis, we considered only taxa identified to the genus or species levels (excluding morpho-species). We applied non-parametric Anova (Kruskal-Wallis) to investigate differences in individual (abundance) and species densities, average height, average diameter and shading percentage among areas. The Dunn's test was applied to verify differences among means. We applied the same protocol to investigate variation in the physical and chemical characteristics of the soil.

Variations in assemblage composition (based on taxon densities) were investigated using four different analyses. First, non-metric multidimensional scaling (NMDS) was applied to graphically depict variations in assemblage composition, based on Bray-Curtis distance. Second, significant differences in composition were tested with one-way Analysis of Similarity (ANOSIM), considering treatments (areas) as groups. Third, a Similarity Percentage (SIMPER) analysis was applied to partition the relative contribution of each species to the overall dissimilarity observed among treatments. Finally, we compared variations in taxon abundance ranks (relative abundance, %). For this, we considered species that summed 90% of the abundance in the ADI areas (all samples pooled), and then plotted their abundances for the three areas.

To evaluate the effect of the extracts on seed germination, the following variables were used: germination percentage and mean germination rate, according to Ranal et al. (2009) [35]. Seeds were considered germinated when 2-3 mm of the radicle was visible. Germinated seedlings were transferred to individual plastic pots (7 cm height × 6 cm basal diameter) containing a 4:1 mix of Cerrado soil (collected from CO areas) and Bioplant (Minas Gerais, Brazil). Initial development was analyzed by assessing plant height, number of leaves, stem diameter, longest root length, and shoot and root dry matter 30 days after transferring seedlings to the pots. At the moment of transfer and at 10-day intervals, seedlings were irrigated with 15 mL of the extracts. They were irrigated daily with tap water until the substrate reached the saturation point. Differences in germination and development among treatments were evaluated by the analysis of variance (one-way ANOVA, and the means were compared by the Tukey test at the 5% probability level. Percentage results were arcsine transformed to normalize variation. The experiments were repeated twice. The results represent the average of the two repetitions.

The statistical analyses in both community and organism-level experiments were carried out in Sisvar 5.6 [36] and PAST 1.75b [34]. Statistical significance implied P <0.05.

3. RESULTS AND DISCUSSION

3.1 Community-level effects

Overall, 1,540 individuals of 108 woody species and 34 plant families were sampled in the study area. Seventy-six taxa were identified to the species level, while the remaining were identified to the genus, family or morphospecies levels. Many individuals at seedling stage could not be identified. In the ADI areas, we recorded 237 individuals, 56 species and 23 families; in the AII, 639 individuals, 79 species and 29 families; in the CO, 664 individuals, 67 species and 26 families (Table 1). The most predominant families were Fabaceae (18 species - 16.5%), Myrtaceae (9 species - 8.3%), Malpighiaceae (8 species -7.3%), Bignoniaceae (7 species - 6.4%) and Apocynaceae (6 species - 5.5%). Thirty-one species (28.70%) were common to the three treatment areas. Ten species (9.25%) were observed only in the ADI areas. Twenty species (18.51%) were present only in AII, while 18 (16.67%) were exclusive to the CO areas.

Table 1: Species, their respective abundance and dispersal syndromes recorded in areas under the influence of Parkia platycephala *and in control areas in a cerrado* sensu stricto *in Porto Nacional, Tocantins, Brazil. ADI = areas under direct influence; AII = areas under indirect influence; CO = control areas (*P. platycephala *absent), DS = dispersal syndrome; ANE = anemochoric; ZOO = zoochoric; AUT = autochoric; IND = indeterminate.*

Families	Species	DS	ADI	AII	CO
Anacardiaceae	*Anacardium occidentale* L.	ZOO	1	6	6
	Anacardium sp.	ZOO		1	2
	Astronium fraxinifolium Schott	ANE		3	9
	Myracrodruon urundeuva Allemão	ANE		1	
Annonaceae	*Annona coriacea* Mart.	ZOO	4	3	2
	Annona sp.	ZOO	2		13
	Annona sylvatica A. St.-Hil.	ZOO	1	1	
	Xylopia aromatica (Lam.) Mart.	ZOO		4	2
Apocynaceae	*Aspidosperma macrocarpon* Mart.	ANE		13	4
	Aspidosperma nobile Müll. Arg.	ANE			6
	Aspidosperma sp.	ANE		1	
	Aspidosperma tomentosum Mart.	ANE	4	4	2
	Hancornia speciosa Gomes	ZOO	1	3	
	Himatanthus obovatus (Müll. Arg.) Woodson	ANE	2	12	3
Arecaceae	*Syagrus* sp.	ZOO			1
Asteraceae	*Tilesia baccata* (L. f.) Pruski	ZOO	6	1	
Bignoniaceae	*Anemopaegma arvense* (Vell.) Stellfeldex de Souza	ANE	2	2	
	Cybistax antisyphilitica (Mart.) Mart.	ANE	1		
	Fridericia sp.	ANE		1	
	Handroanthus ochraceus (Cham.) Mattos	ANE	1	7	16
	Handroanthus serratifolius (Vahl) S. Grose	ANE	1	1	
	Jacaranda brasiliana (Lam.) Pers.	ANE		2	
	*Tabebuia aurea (*Silva Manso) Benth. & Hook. f. ex S. Moore	ANE	4	8	3
Bixaceae	*Cochlos permumregium* (Mart. exSchrank) Pilg.	ANE		1	
Calophyllaceae	*Kielmeyera coriacea* Mart. &Zucc.	ANE	1	1	5
Caryocaraceae	*Caryocar brasiliense* Cambess.	ZOO		7	17

Families	Species	DS	ADI	AII	CO
Celastraceae	*Peritassa campestris* (Cambess.) A. C. Sm.	ZOO	9	8	31
	Salacia elliptica (Mart. exSchult.) G. Don	ZOO		1	
	Salacia sp.	ZOO	1	2	1
Chrysobalanaceae	*Couepia grandiflora* (Mart. &Zucc.) Benth.	ZOO	1		10
Connaraceae	*Connarus suberosus* Planch.	ZOO	3	12	19
	Rourea induta Planch.	ZOO	11	32	46
Dilleniaceae	*Curatella americana* L.	ZOO	3	11	5
	*Davilla elliptica*A. St.-Hil.	ZOO			1
Ebenaceae	*Diospyros hispida* A. DC.	ZOO	14	23	53
Erythroxylaceae	*Erythroxylum* sp.	ZOO		1	9
	Erythroxylum suberosum A. St.-Hil.	ZOO	4	18	32
Fabaceae	*Andira cujabensis* Benth.	ZOO	5	7	19
	Andira sp.	ZOO		1	1
	Bauhinia acuruana Moric.	AUT	27	70	4
	Bauhinia sp.	AUT	1	3	
	Bowdichia virgilioides Kunth	ANE			1
	Cenostigma macrophyllum Tul.	AUT	5	30	56
	Dipteryx alata Vogel	ZOO	3	3	
	Enterolobium gummiferum (Mart.) J. F. Macbr.	AUT/ZOO	8	5	
	*Galactia glaucescens*Kunth	AUT			3
	Hymenaea stigonocarpa Mart. exHayne	ZOO	1	1	1
	Inga laurina (Sw.) Willd.	ZOO	1		
	Leptolobium dasycarpum Vogel	ANE	1		
	Plathymenia reticulata Benth.	ANE		5	8
	Pterodon emarginatus Vogel	ANE	1	7	13
	Stryphnodendron adstringens (Mart.) Coville	AUT/ZOO	12	78	9
	Tachigali aurea Tul.	ANE	5	6	1
	Tachigali vulgaris L. G. Silva & H. C. Lima	ANE			1
	Vatairea macrocarpa (Benth.) Ducke	ANE		5	25
Hypericaceae	*Vismia guianensis* (Aubl.) Choisy	ZOO	1	15	
Lamiaceae	*Aegiphila verticillata*Vell.	ZOO		1	
Lythraceae	*Lafoensia pacari* A. St.-Hil.	ANE	3	18	9
	Physocalym mascaberrimum Pohl	ANE			1
Malpighiaceae	*Banisteriopsis* sp.	ANE		1	
	Byrsonima crassifolia (L.) Kunt	ZOO		2	2
	Byrsonima pachyphylla A. Juss.	ZOO		1	3
	Byrsonima sp.	ZOO		1	
	Byrsonima verbascifolia (L.) DC.	ZOO	1	1	4
	Heteropterys byrsonimifolia A. Juss.	ANE	3	13	
	Heteropterys sp.	ANE			12
	Malpighiaceae sp	-			1
Malvaceae	*Eriotheca gracilipes* (K.Schum.) A. Robyns	ANE	1	2	4
	Pseudobombax tomentosum (Mart. &Zucc.) A. Robyns	ANE			1
Melastomataceae	*Miconia albicans* (Sw.) Triana	ZOO			1
	Mouriri pusa Gardner	ZOO		2	3
Moraceae	*Brosimum gaudichaudii* Trécul	ZOO		1	
Myrtaceae	*Eugenia dysenterica* (Mart.) DC.	ZOO			1
	Myrcia multiflora (Lam.) DC.	ZOO	2	2	8
	Myrcia sp1	ZOO	8	10	4
	Myrcia sp2	ZOO	1	1	1
	Myrcia splendens (Sw.) DC.	ZOO		3	21
	Psidium myrtoides O. Berg	ZOO	10	27	7
	Psidium sp.	ZOO		5	
	Myrtaceae sp1	-	1		
	Myrtaceae sp2	-			2
Ochnaceae	*Ouratea spectabilis* (Mart.) Engl.	ZOO		6	10
Rubiaceae	*Cordiera sessilis* (Vell.) Kuntze	ZOO			1
	Tocoyena formosa (Cham. &Schltdl.) K. Schum.	ZOO	8	10	18
Salicaceae	*Casearia sylvestris* Sw.	ZOO	10	15	17
Sapindaceae	*Magonia pubescens* A. St.-Hil.	ANE	15	30	8

Families	Species	DS	ADI	AII	CO
Sapotaceae	*Pouteria ramiflora* (Mart.) Radlk.	ZOO		10	21
Simaroubaceae	*Simarouba versicolor* A. St.-Hil.	ZOO			2
Solanaceae	*Solanum lycocarpum* A. St.-Hil.	ZOO		1	
	Solanum paniculatum L.	ZOO		4	
	Solanum sp.	ZOO		1	
Vitaceae	*Cissus campestris* (Baker) Planch.	ZOO	1		
Vochysiaceae	*Qualea grandiflora* Mart.	ANE			2
Undetermined 1	Morphospecies 1			1	
	Morphospecies 2			1	
	Morphospecies 3		2		
	Morphospecies 4		1	1	
	Morphospecies 5			2	
	Morphospecies 6		2	1	
	Morphospecies 7			1	
	Morphospecies 8		1		
	Morphospecies 9		1		
	Morphospecies 10		7		
	Morphospecies 11		4		
	Morphospecies 12			2	
	Morphospecies 13			3	
Undetermined 2	Morphospecies 14				1
	Morphospecies 15				1
Total			**237**	**639**	**664**

ADI areas totaled 200.59 m^2 (mean 18.24), AII totaled 601.76 m^2 (mean 54.71) and CO 660 m^2 (mean 60.00). Rarefaction curves showed similar behaviors, with a weak indication of more species in AII and CO, considering the 95% confidence intervals (Figure 2). We also observed no difference in plant abundance and species densities among treatment areas (Table 2). These results suggest that the presence of *P. platycephala* does not affect the number of species and plant abundance in local assemblages, which indicate co-existence between this tree species and other plants living under its crowns and adjacent areas.

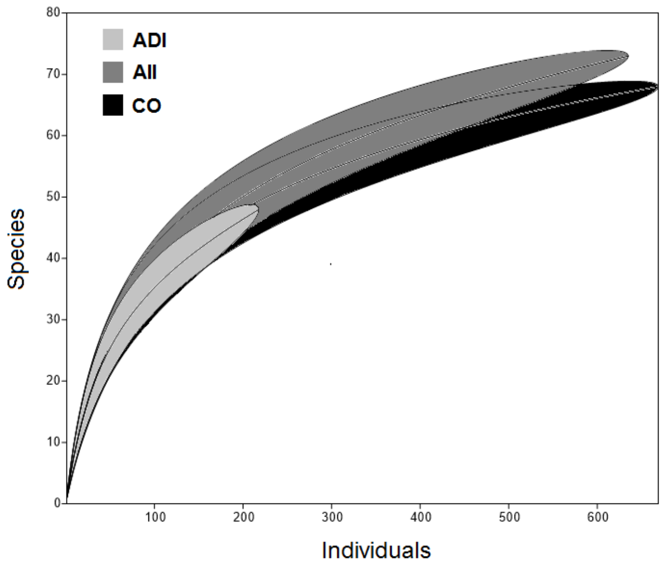

Figure 2: Species rarefaction curves (95% confidence intervals) controlling for sampling effort (individuals) of plants recorded in areas under the influence of Parkia platycephala *and in control areas in a cerrado* sensu stricto *in Porto Nacional, Tocantins, Brazil. Curves were calculated separately for each area. ADI = areas under direct influence of* P. platycephala*; AII = areas under indirect influence; CO = control areas (*P. platycephala *absent).*

The floristic composition and vegetation structure on local scales may be associated, among other factors, with physicochemical properties of the soil [37, 38]. The edaphic characteristics (Table 2) showed that soil of the three areas are medium-textured and acidic (pH 4.3 to 4.6). Phosphorous levels were very low in all areas; K values were considered moderate, and Ca, Mg and base saturation were considered low in all areas. Organic matter was medium at ADI and within an adequate range at AII and CO. CTC was within adequate limits in all areas [39]. In general, soil analyses revealed that the areas were similar in terms of macronutrients and soil texture, indicating that edaphic conditions did not vary substantially among the areas. Although other studies in Cerrado areas have demonstrated that soil physical and chemical traits affect floristic composition [38, 40], the present study indicated that edaphic properties possibly played a minor role in determining differences in plant diversity among areas directly and indirectly influenced by *P. platycephala* and control areas.

Table 2: Plant assemblage attributes and soil characteristics in areas under the influence of Parkia platycephala *and in control areas in a cerrado* sensu stricto *in Porto Nacional, Tocantins, Brazil. ADI = areas under direct influence; AII = areas under indirect influence; CO = control areas (*P. platycephala *absent). Differences among areas (bold letters) were tested with non-parametric Anova (Kruskal-Wallis), complemented with Dunn's test at the 5% probability level. Values followed by the same letters (lines) are not significantly different.*

	ADI		**AII**		**CO**		**K-Wallis**
	X	**SD**	**X**	**SD**	**X**	**SD**	**p-value**
Assemblage attributes							
Species density (species. m^{-2})	0.820	0.515	0.573	0.328	0.357	0.093	0.075
Abundance (individual. m^{-2})	1.452	1.030	1.427	0.891	1.006	0.494	0.438
Average height (m)	0.710$^{\mathbf{a}}$	0.314	0.915$^{\mathbf{a}}$	0.224	1.335$^{\mathbf{b}}$	0.202	**0.001**
Average diameter (mm)	2.164$^{\mathbf{a}}$	1.747	2.128$^{\mathbf{a}}$	0.408	3.124$^{\mathbf{b}}$	0.548	**0.002**
Shading percentage	83.31$^{\mathbf{a}}$	8.911	77.27$^{\mathbf{ab}}$	7.539	63.44$^{\mathbf{b}}$	9.122	**0.0002**
Seedling density (plant. m^{-2})	0.527$^{\mathbf{a}}$	0.513	0.396$^{\mathbf{a}}$	0.201	0.138$^{\mathbf{b}}$	0.183	**0.010**
Seedling relative abundance (%)	31.95$^{\mathbf{a}}$	20.95	29.41$^{\mathbf{a}}$	5.38	11.73$^{\mathbf{b}}$	8.61	**0.003**
Soil chemical and physical properties							
pH in H_20	4.582	0.354	4.364	0.223	4.654	0.464	0.113
Phosphorous (P) (mg. dm^{-3})	1.800	0.577	2.360	0.980	2.000	1.177	0.346
Potassium (K) (mg. dm^{-3})	30.636	9.403	27.727	8.624	41.818	17.403	0.086
Calcium (Ca) ($cmol_c dm^{-3}$)	0.282	0.072	0.336	0.098	0.736	1.263	0.388
Magnesium (Mg) ($cmol_c.dm^{-3}$)	0.300	0.060	0.264	0.098	0.309	0.254	0.508
Aluminum (Al) ($cmol_c dm^{-3}$)	0.682	0.204	0.754	0.227	0.591	0.254	0.334
Potential acidity(H+Al) ($cmol_c dm^{-3}$)	3.768	1.285	3.625	0.739	4.036	1.117	0.709
Cation Exchange Capacity (T) ($cmol_c dm^{-3}$)	4.424	1.333	4.294	0.778	5.186	1.780	0.589
Base saturation (%)	15.816	3.833	15.921	3.803	18.864	14.647	0.907
Organic matter (%)	1.841	0.365	2.232	0.822	2.475	0.724	0.098
Sand (%)	63.456	5.325	63.628	6.424	62.096	4.273	0.800
Clay (%)	25.454	4.498	27.394	4.598	27.2700	4.176	0.385
Silt (%)	11.092	3.724	8.892	2.773	10.635	3.487	0.336

However, we detected significant differences in shading percentage, plant height and diameter among the three areas (Table 2). Shading was higher in ADI and AII compared to CO, and no significant difference existed between the first two areas, or between AII and CO. Regarding plant height and diameter, plants sampled in CO areas exhibited greater values when compared with those sampled in both ADI and AII. These differences may result in specific environmental conditions in areas under the influence of *P. platycephala*, especially related to the shading regime. According to Zanine and Santos (2004) [41], aspects related to the crown, such as height and thickness, may dictate coexistence patterns in plant assemblages. The shading regime may act as a limiting factor for the development of some trees and shrubs under or near *P. platycephala*, especially if they require higher light availability. On the other hand, it may facilitate the establishment of plants that are more tolerant or even demand shaded environments [42, 43], as required by intermediate and climax species. According to Vásquez-Yánes and Orozco-Segovia (1994) [44], the amount of available light directly affects plant biomass, and light quality controls physiological processes, promoting or inhibiting germination, flowering, stem growth and leaf expansion and orientation. Although light quality was not evaluated, *P. platycephala* probably influences the light regime and its properties, affecting the germination and growth of other species.

Plant composition differed among areas. The ordination (NMDS, stress value = 0.27) tended to group CO samples (Figure 3), with high within-group dissimilarity in areas under the influence of *P. platycephala* (ADI and AII). Similarly, ANOSIM indicated that CO differed significantly from other groups ($R = 0.25$; $P<0.0001$) and SIMPER analysis showed high dissimilarity among groups (average dissimilarity = 82.49). This latter analysis also showed that, among the species that most contributed to overall dissimilarity, the majority tended to decline from ADI to CO areas. These results indicate that assemblage composition is particular and more heterogeneous in areas under the influence of *P. platycephala*, with a gradient of taxon composition and densities between ADI and CO. Shading provided by crowns of *P. platycephala* can explain these patterns, considering that this tree forms broad, but not so dense crowns. Passos et al. (2014) [5] reported that facilitator species such as *Solanum lycocarpum* enhance environmental heterogeneity under their crowns due to partial shading, which can provide favorable conditions for species with different light requirements. In addition, they showed that this species also worked in a nucleation process.

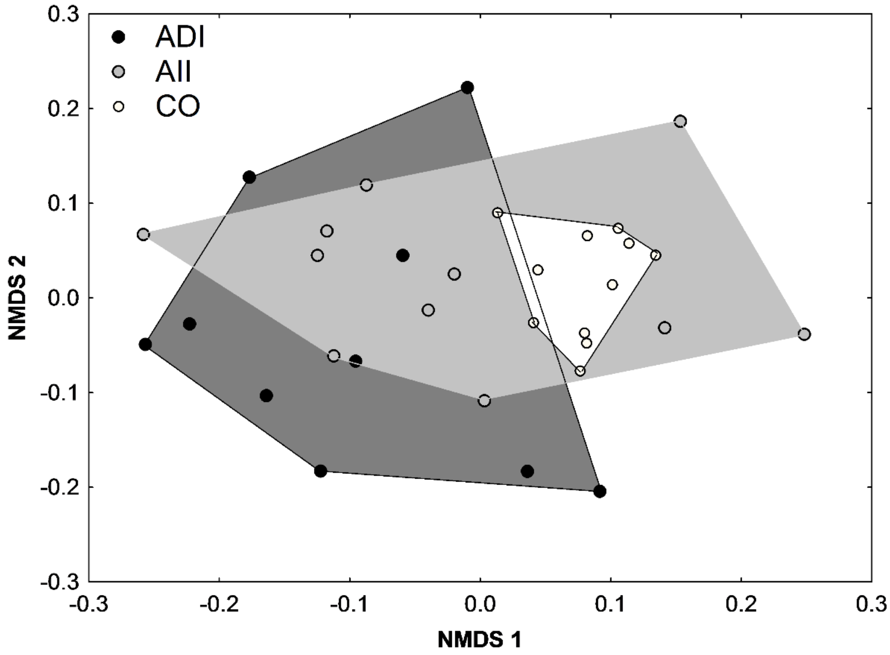

Figure 3: Non-Metric Multidimensional Scaling (NMDS) showing variation in plant assemblage structure (abundance and composition; Bray-Curtis distance) in areas under the influence of Parkia platycephala *and in control areas in a cerrado* sensu stricto *in Porto Nacional, Tocantins, Brazil. ADI = areas under direct influence; AII = areas under indirect influence; CO = control areas (*P. platycephala *absent).*

Considering that soil characteristics were similar among areas, it is likely that differences and variation in the shading regime create dynamic environmental filters, including light and soil moisture. Another aspect that might have influenced the observed results may possibly be related to seed dispersal by arboreal animals or birds that could be using the nurse trees as perches. Seed banks might also have affected the obtained outcome. Most woody species studied by Kuhlmann and Ribeiro (2016) [45] in the Cerrado exhibited zoochoric dispersal syndrome. These authors included Myrtaceae in the list of the most representative families recorded in their study, and this family was the second most predominant in the present study. Anderson and Pinto (1985) [46] reported that gum exudates from *P. bicolor* and *P. biglobosa*, and gum from the seed pods of *P. pendula,* may be related to mechanisms of seed dispersal associated with the genus *Parkia*. Although we have not collected or analyzed gum exudates from *P. platycephala* in our study, this species most likely serves as perches for birds or attracts other arboreal animals, as mentioned above, who aid seed dispersal. Indeed 62.2 % of the species exhibit zoochoric dispersal (Table 1).

Abundance ranks (considering taxa that summed 90% of total abundance in the ADI treatment, S = 28 taxa) showed contrasting distributions between areas under the influence of *P. platycephala* and the control treatment (Figure 4). For example, rank distributions were roughly similar between ADI and AII areas, and most taxa recorded in ADI were also recorded in AII (27 shared). Differently, the most abundant taxa in CO ranked 12th (*Qualea parviflora*) and 15th (*Cenostigma macrophyllum*) at ADI, and only 23 out of 28 taxa were recorded in CO areas (summing 62% of total abundance). The five main species at ADI (*Bauhinia acuruana*, *Magonia pubescens*, *Diospyros hispida*, *Stryphnodendron adstringens* and *Rourea induta*) totaled 36% of total abundance in ADI and AII, but only 18% in CO areas. Therefore, these results indicate environmental effects of *P. platycephala* on the structure of local assemblages, supporting the existence of a gradient of composition and abundance from ADI to CO areas.

Seedling abundance differed among areas. We recorded 369 seedlings, distributed as follows: 95 in the ADI, 183 in the AII and 91 in the CO. Seedling density and relative abundance showed higher values under the crowns of *P. platycephala* and adjacent areas (Table 2), indicating a possible nursing effect. This target species is a large tree with broad crowns (a characteristic that is not so common among tree species in cerrado *sensu stricto* areas), that provides specific abiotic conditions (i.e., shading), probably favoring seed germination and establishment of shade-tolerant species. Moreover, seed dispersers (e.g., birds) are regularly observed visiting *P. platycephala.* It would increase propagule pressure in the neighboring areas, maintaining the rhythm of secondary and late succession [8]. Therefore, the combined effect of shading and dispersal may explain the higher abundance of seedlings around *P. platycephala*.

3.2 Effects of *P. platycephala* leaf extracts on germination and initial development

The results regarding the influence of aqueous extracts of *P. platycephala* leaves on the germination and initial development of *Magonia pubescens*, *Enterolobium gummiferum* and *Dipteryx alata* are shown on Table 3. We verified that germination of *M. pubescens* was greatest at 25% (but not significantly different from the control treatment) and decreased at higher concentrations. At this concentration, germination percentage and mean germination rate were superior to and significantly higher (P<0.05) than the control treatment, respectively, although germination did not differ significantly from the control treatment. Both variables were inhibited at higher extract concentrations. No significant differences were detected for the germination of *E. gummiferum* among the treatments, although mean germination increased at 25% of the crude extract and decreased at higher concentrations. Similar results were obtained for *D. alata* except for the fact that the germination percentage was significantly inhibited by the crude extract. In general, the results obtained showed that the extracts did not exert a strong influence on the germination of *D. alata* and *E. gummiferum*. Souza Filho et al. (2005) [23] reported that the secondary metabolites (two phenolic compounds and a terpenoid) produced by *Parkia pendula* exhibited low inhibitory potential on the germination of *Mimosa pudica* and *Senna obtusifolia* seeds, both also members of the Fabaceae family. In relation to *M. pubescens*, however, the germination rate was significantly higher at 25%, indicating a significant positive effect. It is possible that during the rainy season, rainwater washes the leaves of *P. platycephala* and carries some leaf compounds (at very low concentrations) to the soil, which positively influence the germination of *M. pubescens*. It is worth noting that *M. pubescens* showed a strong gradient of abundance in the field study, ranking 2nd in the ADI, 5th in the AII and 25th in the control areas.

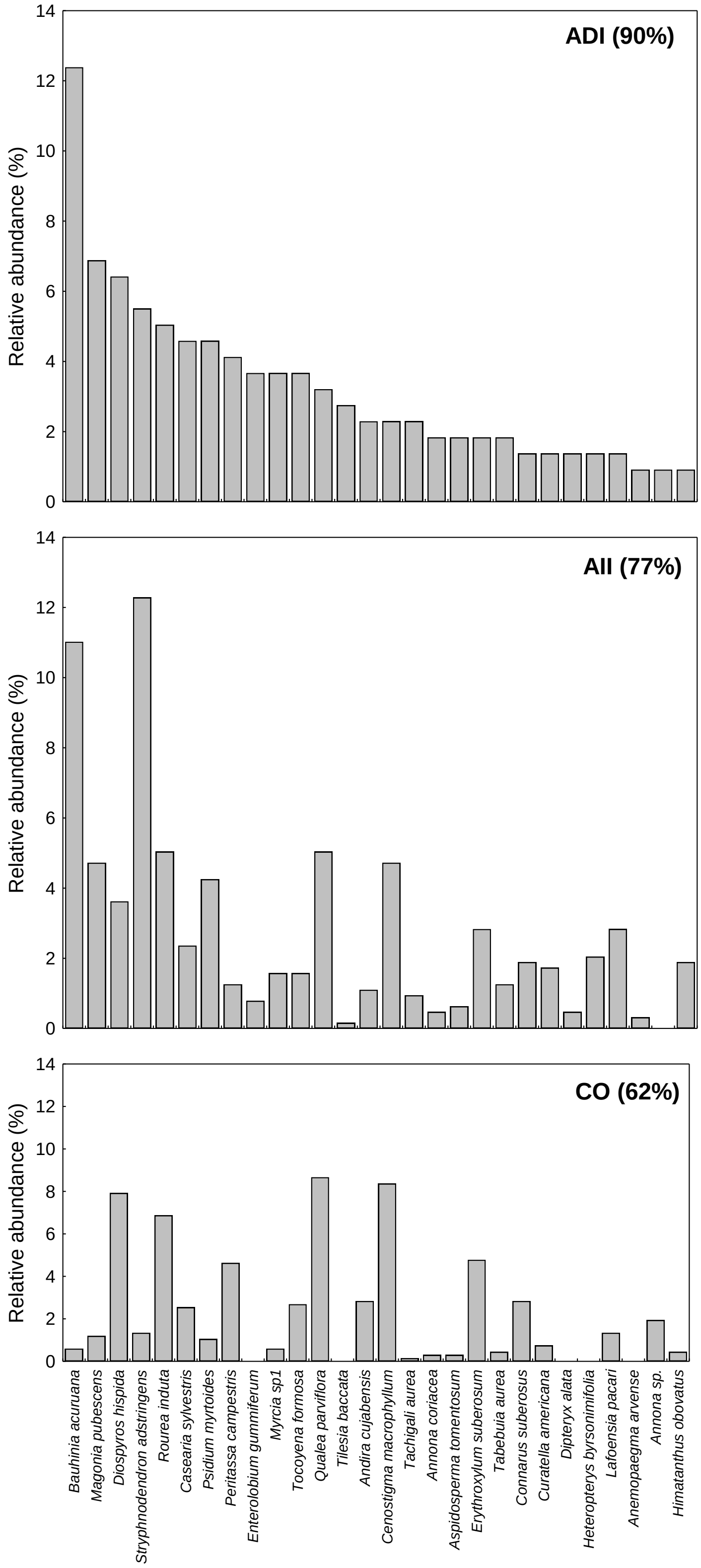

Figure 4: Abundance ranks of plant taxa recorded in areas under the influence of Parkia platycephala *and in control areas in a cerrado* sensu stricto *in Porto Nacional, Tocantins, Brazil. We plotted taxa that totaled 90% of total abundance in the ADI treatment. ADI = areas under direct influence; AII = areas under indirect influence; CO = control areas (*P. platycephala *absent). (%) Percentage contribution of these taxa to total abundance in each area.*

Table 3: Effects of different concentrations of aqueous extracts of Parkia platycephala *leaves on the germination and initial growth of* Dipteryx alata, Enterolobium gummiferum *and* Magonia pubescens. *G = germination percentage; MGM = mean germination rate; PH = plant height; SD = stem diameter; LRL = longest root length; ADM = plant aerial dry matter; RDM = root dry matter. Values followed by the same letter (lines) are not significantly different according to the Tukey's test at the 5% probability level.*

Variables	**Control (H_2O)**	**25%**	**50%**	**75%**	**100%**
		Dipteryx alata			
G (%)	93.3 a	91.1 a	93.3 a	82.2 a	66.6 b
MGR(seeds day^{-1})	0.151 a	0.162 a	0.142 a	0.139 a	0.138 a
PH (cm)	7.87 a	9.11 a	10.07 a	10.11 a	6.71 b
SD (mm)	2.65 a	2.93 a	2.94 a	3.03 a	2.72 a
LRL (cm)	13.02 a	11.81 a	12.49 a	11.86 a	9.98 a
ADM (g)	0.433 a	0.447 a	0.593 a	0.632 a	0.398 a
RDM (g)	0.087 a	0.103 a	0.116 a	0.099 a	0.079 a
		Enterolobium gummiferum			
G (%)	100 a	98.3 a	95.0 a	96.65 a	93.3 a
MGR (seeds hour^{-1})	0.02 a	0.035 a	0.021 a	0.016 a	0.015 a
PH (cm)	5.62 a	7.00 a	6.76 a	6.63 a	5.90 a
SD (mm)	2.16 a	2.17 a	2.19 a	2.02 a	2.16 a
LRL (cm)	7.74 a	7.95 a	5.56 a	6.00 a	5.15 a
ADM (g)	0.197 a	0.166 a	0.177 a	0.175 a	0.164 a
RDM (g)	0.012 a	0.013 a	0.012 a	0.012 a	0.012 a
		Magonia pubescens			
G (%)	84.0 a	94.0 a	74.0 ab	70 ab	57.5 b
MGR (seeds day^{-1})	0.203 b	0.260 a	0.197 b	0.200 b	0.172 b
PH (cm)	9.20 a	9.81 a	11.34 a	10.08 a	10.23 a
SD (mm)	2.37 a	2.28 a	2.14 a	2.17 a	2.22 a
LRL (cm)	10.60 b	12.9 ab	12.94 ab	15.20 a	12.22 ab
ADM (g)	2.389 a	2.281 a	2.304 a	2.306 a	2.540 a
RDM (g)	0.160 a	0.155 a	0.130 a	0.153 a	0.152 a

Extracts at 75% significantly favored the initial development of *M. pubescens* seedlings in terms of root length (Table 3). This is evidence that this concentration was beneficial to root growth in length, probably by favoring cell division and extension [47]. Similar results were reported by Rosa et al. (2011) [48] and Martinelli and Silva (2018) [49] upon studying the effects of leaf extracts of *Panicum maximum* on the radicle length of *Peltophorum dubium* seedlings, and the influence of aqueous extracts of *Secale cereale* on the growth of *Beta vulgaris* roots, respectively. No marked influence was observed in terms of stem diameter and dry matter buildup in roots. For *E. gummiferum,* at 25% of the extract plants were 21.6% higher than the control treatment. No pronounced effects were detected for the other variables although the concentrations of 25 and 50% generally provided higher values, except for aerial dry matter. All variables assessed in *D. alata,* apart from root length, were positively influenced by the extracts (50 and 75% concentrations). A possible explanation for the stimulus of seedling growth in height, as observed in the three species, can be related to the action of the extract on their endogenous hormonal production [50], which in this case could be primarily associated with an increase in the synthesis of gibberellins. This group of hormones is known to stimulate extension of cells of plant stems [51, 52].

Taken together, these results point to the trend that the extracts at low and moderate concentrations (25-75% of the crude extracts) exhibited a tendency to favor germination percentage of *M. pubescens* as well as growth and development of the species assessed. In fact, the 25% concentration aqueous extract increased the germination rate of all three species. This is a possible indication, as mentioned above, that rainwater containing trace amounts of certain leaf compounds might favor seed germination and promote the development of these species, thus contributing to the observed abundance in areas under direct and indirect influence of *P. platycephala* in the field experiment. *Magonia pubescens* and *E. gummiferum* were ranked second and fifth in terms of abundance in the areas under direct and indirect influence of *P. platycephala*, respectively. Ferreira and Aquila (2000) [53] stated that plants synthesize secondary metabolites and that these compounds can promote or inhibit physiological processes of other species, depending on their sensitivity. It is also important to mention that *E. gummiferum* and *D. alata* were not present in the control areas, which probably suggest that other than shading, they might have benefitted from some chemical cue associated with the presence of *P. platycephala*. Another aspect that deserves to be raised is the fact that several *Parkia* species are nitrogen fixers (54, 55). Although we have not found specific information related to *P. platycephala* we believe it can be included in this group of *Parkia* species. This characteristic enhances the development of neighboring species facilitating their development [56, 57].

4. CONCLUSIONS

This study provided evidence that the presence of *Parkia platycephala* affects the structure of neighboring plant assemblages, possibly working as a nurse for some species in the area. We recorded a gradient of species composition and abundance ranks from the areas of direct influence (ADI) to the control (CO) areas, with a higher abundance of seedlings near *P. platycephala*, indicating a possible nursing role for some species. Considering that soil characteristics were similar among areas, it is likely that differences and variation in the shading regime provided by *P. platycephala* created heterogeneous conditions and dynamic environmental filters. These factors must affect the establishment of other plants, especially shade-tolerant species. Because this tree grows rapidly (in height and diameter) and is resistant and resilient to disturbances, it likely plays a role during initial phases of succession, serving as a nurse species. It is important to emphasize that these findings refer to a 10-year period after the experimental establishment of *P. platycephala* in the area. Further studies addressing, for example, direct seeding and/or manipulated plant introductions at ADI and AII, as well as the effects on the water-holding capacity of the soil, should help unveil additional details regarding its role in the plant community under its crown and in surrounding areas.

The laboratory experiment that investigated the effects of aqueous extracts of *P. platycephala* leaves provided support that this tree possibly affects other species via chemical compounds. It revealed that the extracts favored the germination of *M. pubescens* at intermediate concentrations but exerted negative effect on *D. alata* and *E. gummiferum* at the highest concentration. These results point to the possibility that, in the natural environment, rainwater leaches certain compounds from leaf tissues (at much lower concentrations when compared to the extracts used in the present study) and reaches the soil near the crowns of *P. platycephala*, aiding seed germination and the development of some species. Future studies aiming to test the effect of leaf extracts on other Cerrado species, as well as to identify the chemical nature of such compounds will certainly shed more light on our present findings.

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