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VEGETATION SUCCESSION IN THE CERRADO–AMAZONIAN FOREST TRANSITION ZONE OF MATO GROSSO STATE, BRAZIL

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The occurrence of *cerrado* (as tree and shrub savanna is called in Brazil) and forest formations side by side is common at the southern margin of the Brazilian Amazonian Forest, and previous studies have demonstrated the advance of forests over *cerrado* areas. The aim of the present study is to provide an accurate documentation of the transition process between the two major biomes. Tree data (≥ 5 cm diameter at 0.3 m above soil level) from three plots of *cerrado sensu stricto* lying near three of *cerradão* (the taller, denser form of *cerrado*) were inventoried starting in 2002 in an area of 1.5 ha made up of 150 subplots of 10 × 10 m (50 in each area). This showed that the most important species of the *cerradão* were invading areas previously occupied by smaller, lower forms of *cerrado* (although it is sometimes difficult to define which are 'forest' and which '*cerrado*' species as many are flexible in size – for instance *Emmotum nitens* can often be intermediate, establishing in *cerrado* that develops into *cerradão* and on to forest). Some typical species such as *Eriotheca gracilipes* and *Emmotum nitens*, established since the first inventories, have increased their populations (between 27 and 210%). *Tachigali vulgaris*, a typical, weedy, adventive species of the Cerrado–Amazonian Forest transition, showed the largest increase in abundance in areas of *cerrado sensu stricto* (between 100 and 1200%), and is probably the most important pioneer species in the initial advance of the forest into *cerrado* at the Southern Amazonian border.

Keywords. Cerradão, *cerrado sensu stricto*, ecological succession, *Tachigali vulgaris*.

Introduction

At the southern edge of the Amazonian Forest, in eastern Mato Grosso, co-occurrence of savanna (called *cerrado* in Brazil) and forest formations is common (Ratter, 1971; Ratter *et al.*, 1973, 1978; Marimon-Junior & Haridasan, 2005; Marimon *et al.*, 2006). The transition between the two largest Brazilian plant biomes (Cerrado and

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Amazonian Forest) is a zone of ecological tension (ZET) (Radambrasil, 1982), where environmental factors, such as climatic seasonality, fire frequency and edaphic characteristics, determine the distribution of *cerrado sensu stricto* and *cerradão* (augmentative of *cerrado*, i.e. a dense and tall formation of savanna woodland with many characteristic species) (Ratter *et al.*, 1973; Ratter, 1992; Marimon-Junior & Haridasan, 2005; Marimon *et al.*, 2014), and the evergreen Amazonian Forest itself.

In 1967, 1968, 1972 and 1978, i.e. beginning nearly 50 years ago, Ratter (1971), Ratter *et al.* (1973) *et seq.* studied the floristic composition of the Cerrado–Amazonian Forest transition zone in Mato Grosso in the drainage of the rivers Araguaia and Xingu, and showed that the Amazonian Forest was advancing into the *cerrado* (a process already well understood by the few local inhabitants of the region at that time). Despite massive human destruction of the habitat, later studies, often carried out in protected areas (Ratter, 1992; Marimon *et al.*, 2006), confirmed the continued advance of the Amazonian Forest into *cerrado* vegetation, probably favoured by the current climatic conditions and supported by evidence of pollen paleo-stratigraphy (Mayle *et al.*, 2000; Behling, 2003; Cárdenas *et al.*, 2011) and the isotopic composition of soil organic carbon (Pessenda *et al.*, 2001). Marimon *et al.* (2006) give precise figures based on the position of the Xavantina-Cachimbo Expedition base camp (sited intentionally at the Cerrado–Amazonian Forest transition) in 1968, and the position of the transition area 36 years later when it had moved 7 km further into the *cerrado* (the continued existence of the ruined remains of the expedition base camp guaranteed the accuracy of this figure).

The establishment of dystrophic *cerradão* is sometimes related to soil texture in sites with higher clay levels retaining more water (Marimon-Junior & Haridasan, 2005) while increase in annual precipitation and average temperature also favours the expansion of forests into *cerrado* vegetation (Mayle *et al.*, 2000; Behling, 2003; Cárdenas *et al.*, 2011). On the other hand, the advance of forest into *cerrado* can be controlled by frequent fires because, as is well known to natives of such areas, forest species are relatively intolerant of them (Geiger *et al.*, 2011). In the absence of fire, however, succession of *cerrado* vegetation by forest species usually occurs (Durigan & Ratter, 2006; Geiger *et al.*, 2011).

The vegetation of the Cerrado–Amazonian Forest transition zone is under constant human disturbance and has been considered 'intrinsically hyperdynamic' and 'sensitive to shifting precipitation patterns' (Marimon *et al.*, 2014). Thus, the dynamics of forest expansion in the transition between the Cerrado and Amazonian Forest is a process that still requires further study. Thus, the aim of this study was to assess whether the colonisation of *cerrado* areas by *cerradão* and forest species continues. In particular, we want to determine which species contribute to the initial advance of the forest into the *cerrado* at the southern border of the Brazilian Amazonian Forest and how its speed may vary.

Materials and Methods

The study was conducted at the Bacaba Municipal Park, Nova Xavantina-MT (14°41′S, 52°20′W, 306 m.a.s.l.), a protected area of 500 ha in the Cerrado–Amazonian vegetation transition zone (Marimon *et al.*, 2014). The climate is Aw, according to the Köppen classification, with very marked rainy and dry seasons, average annual precipitation between 1300 and 1500 mm and average annual temperature of 25°C (Marimon *et al.*, 2010).

Tree data (≥ 5 cm diameter at 0.3 m above soil level) from three areas of *cerrado sensu stricto* situated approximately 800 m from *cerradão* were studied (Fig. 1). We evaluated 150 subplots of 10 × 10 m, 50 in each area, totalling 1.5 ha. Area 1 was first inventoried in 2002 (Marimon-Junior & Haridasan, 2005) and remeasured in 2006

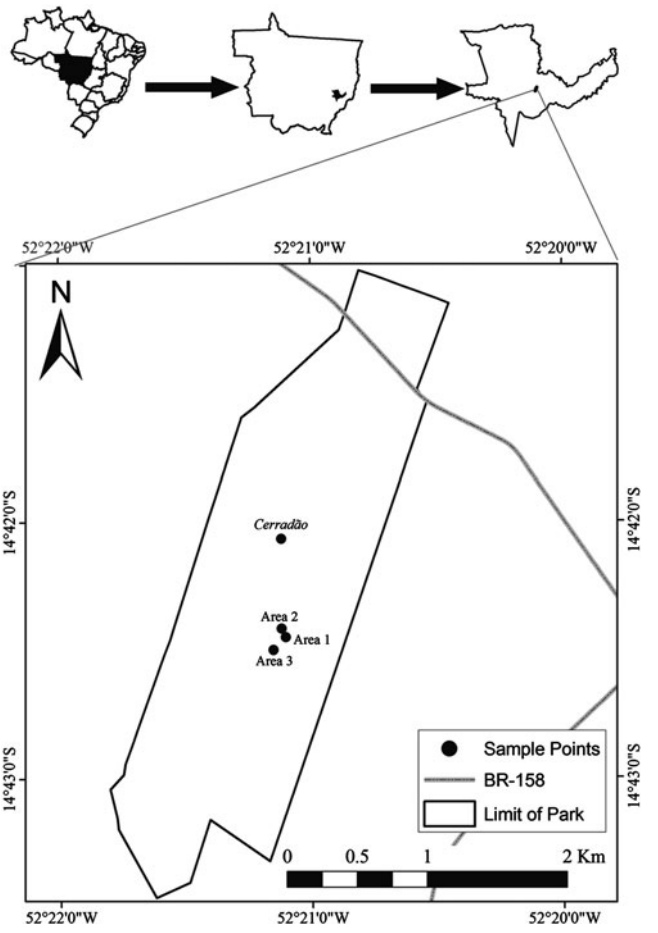

Fig. 1. Location of the study areas in Nova Xavantina, state of Mato Grosso, Brazil. Areas 1, 2 and 3 = *cerrado sensu stricto*.

(Mews *et al.*, 2011), 2008, 2011 and 2013. The first inventory of Area 2 was made in 2008 (E. A. Oliveira, unpublished data) with later measurements in 2011 and 2013. Area 3 (the present study) was inventoried in 2011 and 2013.

This work was also based (species list, Importance Value Index (IVI) and description of the advance of the forest species into the *cerrado*) on studies by Ratter (1971, 1992), Ratter *et al.* (1973, 1978), Marimon-Junior & Haridasan (2005), Marimon *et al.* (2006) and Franczak *et al.* (2011) in areas of the Cerrado–Amazonian Forest transition (e.g. *cerradão* and seasonal evergreen forests). Whether the most important species (i.e. those with the highest IVI) of the *cerradão* were advancing and/or increasing population density in adjacent areas of *cerrado sensu stricto* was investigated and their average diameter and height, basal area and IVI were recorded, as were their habitat preferences using the overall species list of Mendonça *et al.* (2008). A Partition Chi-square (χ^2) test was also used to check differences between the categories in the proportion of individuals recruited in each inventory.

Results

Typical forest/*cerradão* species, such as *Eriotheca gracilipes* (K.Schum.) A.Robyns and *Emmotum nitens* (Benth.) Miers, and typical transition species between forest and *cerrado*, such as *Roupala montana* Aubl. and *Guapira graciliflora* (Mart. ex Schmidt) Lundell, have established in the areas studied since the first inventory, and are gradually increasing (Table 1). They have doubled their populations in at least one of the areas studied and have also been recorded among the most important in a nearby *cerradão* (Marimon-Junior & Haridasan, 2005). They can grow into large trees dominating the vegetation and outcompeting the smaller typical *cerrado* species (Fig. 2). In contrast to this is *Tachigali vulgaris* L.F.Gomes da Silva & H.C.Lima (syn. *Sclerolobium paniculatum* Vogel), a typical species of the Cerrado–Amazonian Forest transition (Ratter *et al.*, 1973), which showed the largest increase in abundance in our last two inventories (between 100 and 1200%) (Table 1). It is an extremely fast-growing, short-lived, massively fruiting tree that is probably usually monocarpic (some of its congeners are certainly always monocarpic) and its seed production is enormous.

Besides density, it was noted that the average diameter and IVI values of species are increasing, especially in Area 1. In addition, some species have increased their IVI positions (PIVI), particularly *Tachigali vulgaris*, which increased to positions 52 and 48 in Areas 2 and 3, respectively, and *Emmotum nitens*, which rose by 26 positions in Area 1 (Table 1).

Considering only subplots with *Tachigali vulgaris* present, young plants of all species entering the community in each inventory are typical of forest or transitional formations, while *cerrado* species are decreasing ($\sum\chi^2$ between partitions = 92.59; 26.48; 40.99 and overall $P < 0.001$ for Areas 1, 2 and 3, respectively) (Fig. 2).

TABLE 1. Phytosociological parameters of five species typical of the Cerrado–Amazonian Forest transition that have increased their populations

			Tachigali vulgaris	*Eriotheca gracilipes*	*Emmotum nitens*	*Roupala montana*	*Guapira graciliflora*
			Categories				
Site	Year	Parameter	T	F	F	T	T
Area 1	2002	NI	–	9	7	37	30
		D	–	11.7	7.3	11.8	7.7
		H	–	5.6	4.6	5.3	4.1
		BA	–	0.24	0.06	1.02	0.31
		IVI	–	3.9	2	13.7	6.6
		PIVI	–	28	46	3	16
	2006	NI	–	12	9	48	41
		D	–	12	7.8	11.5	8
		H	–	6.1	4.3	5.4	4.5
		BA	–	0.35	0.10	1.29	0.46
		IVI	–	4.3	2.5	14.4	7.4
		PIVI	–	25	36	3	11
	2008	NI	–	13	13	61	45
		D	–	12.4	8.6	11.2	8.7
		H	–	6.5	5.1	5.6	4.5
		BA	–	0.40	0.17	1.56	0.59
		IVI	–	4.5	3.2	16	8
		PIVI	–	23	34	3	9
	2011	NI	12	17	18	111	61
		D	6.1	11.8	9.7	9.3	8.8
		H	4.9	5.9	5.3	4.8	4.1
		BA	0.07	0.48	0.31	2.00	0.82
		IVI	2.3	4.7	4	19.5	9.8
		PIVI	39	19	28	2	6

TABLE 1. (*Cont'd*)

			Tachigali vulgaris	*Eriotheca gracilipes*	*Emmotum nitens*	*Roupala montana*	*Guapira graciliflora*
			Categories				
Site	Year	Parameter	T	F	F	T	T
	2013	NI	36	17	19	115	65
		D	8.4	13.1	12	10	9.5
		H	6.5	6.7	6.1	5.4	4.8
		BA	0.43	0.58	0.48	2.31	1.01
		IVI	6	4.8	4.6	19.9	10.2
		PIVI	15	19	20	2	5
Area 2	2008	NI	–	20	11	44	63
		D	–	12.2	15.1	9.6	7
		H	–	6.4	6	5.3	3.8
		BA	–	0.55	0.53	0.86	0.54
		IVI	–	8	5.7	13.4	12.9
		PIVI	–	9	18	3	4
	2011	NI	2	22	12	60	107
		D	5.8	12.2	13	9	6.8
		H	5.5	5.8	5.7	5.3	3.9
		BA	0.01	0.62	0.46	1.02	0.85
		IVI	0.5	8.2	4.8	15.4	18.7
		PIVI	75	8	23	2	1
	2013	NI	26	25	14	71	114
		D	6.3	11.7	12.6	9	7.2
		H	6	6.5	6.5	5.6	4.3
		BA	0.17	0.66	0.50	1.20	1.00
		IVI	5	8.4	5	16.4	19.2
		PIVI	23	7	19	2	1

TABLE 1. (*Cont'd*)

			Tachigali vulgaris	*Eriotheca gracilipes*	*Emmotum nitens*	*Roupala montana*	*Guapira graciliflora*
			Categories				
Site	Year	Parameter	T	F	F	T	T
Area 3	2011	NI	4	32	12	43	64
		D	5.5	13.8	16.2	7.6	8
		H	4.4	6.2	6.2	4.3	3.8
		BA	0.02	1.16	0.63	0.46	0.72
		IVI	0.6	10.6	4.6	8.1	10.5
		PIVI	74	6	24	9	7
	2013	NI	23	32	13	49	67
		D	6.5	14.4	16.4	8.2	8.7
		H	5.5	6.8	6.4	4.8	4.3
		BA	0.16	1.23	0.69	0.59	0.88
		IVI	4	10.3	4.8	9	11
		PIVI	26	7	20	9	5

T = typical transition species; F = typical forest species; NI = number of individuals; D = average diameter (cm); H = average height (m); BA = basal area; IVI = Importance Value Index; PIVI = position of the species in the community related to the IVI. Dashes (–) indicate that the species was not recorded in this inventory.

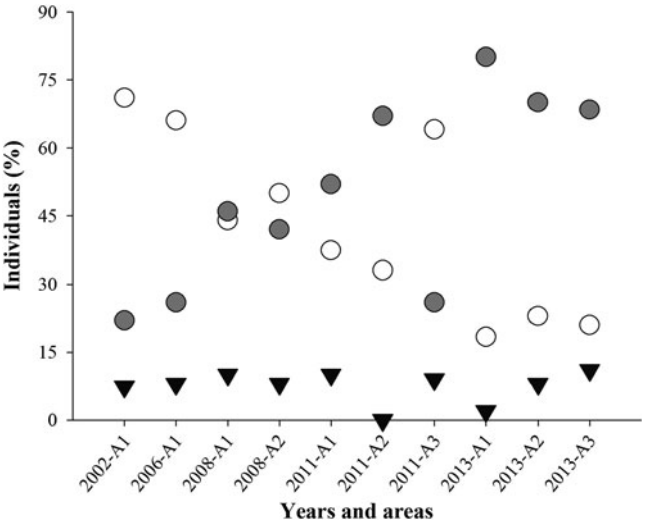

FIG. 2. Proportion of individuals of the *cerrado*, transition and forest species in three areas of *cerrado sensu stricto* (considering only plots with *Tachigali vulgaris* present), Nova Xavantina-MT. Open symbols (○): *cerrado* species; grey symbols (●): transitional species; black symbols (▼): forest species. A1, A2 and A3 = Areas 1, 2 and 3.

DISCUSSION

This study showed the succession of typical *cerrado* species by those characteristic of forests or transitions, as also recorded in other Brazilian states, such as São Paulo (Durigan & Ratter, 2006), Distrito Federal (Ratter, 1992; Geiger *et al.*, 2011), and Mato Grosso (Marimon *et al.*, 2006), and similar to the succession in African savannas (e.g. Khavhagali & Bond, 2008), where areas protected from fire were colonised by forest species. Besides the absence of disturbance, nowadays the increase in average precipitation and temperature may also be contributing to forest expansion of the *cerrado* (Mayle *et al.*, 2000; Behling, 2003; Cárdenas *et al.*, 2011).

Tachigali vulgaris is the most successful species in terms of recruitment in the areas already occupied by *cerrado* vegetation and is important in the beginning of the succession process in *cerrado sensu lato* and *cerradão* at the southern Amazonian border (Franczak *et al.*, 2011). Ratter (1992) also reported the occurrence of *Tachigali vulgaris* in Cerrado–Amazonian Forest transition areas in Northeastern Mato Grosso, in addition to *cerrado* species such as *Curatella americana* in *cerradão* dominated by *T. vulgaris*. In another study conducted in an ecotone in Amazonia, *Tachigali vulgaris* was registered at the forest margin and in open areas, and was recognised as a bioindicator of the advance of forest into open areas (Vidotto *et al.*, 2007).

In this case, we suggest that *Tachigali vulgaris* may facilitate the growth and development of other plants (Connell & Slatyer, 1977) by settling in a *cerrado* where it grows rapidly in more open areas (Roitman *et al.*, 2008), accumulating litterfall

(B. Oliveira, unpublished data) including its own, partly as a result of its monocarpic life cycle. During the succession process, some species provide enhancement of the habitat quality under their canopies, such as the increase of litter layer and nutrients, adding to the likelihood of other species colonising the site (Connell & Slatyer, 1977; Passos *et al.*, 2014). Large trees of *Eriotheca gracilipes*, *Emmotum nitens*, *Roupala montana* and *Guapira graciliflora*, typical *cerradão* and transitional species, can also facilitate establishment of other species.

Thus, the initial advance of the forest into the *cerrado* at the southern edge of the Amazonian Forest occurs (Ratter *et al.*, 1973; Marimon *et al.*, 2006; Franczak *et al.*, 2011) leading to the establishment of forest species (e.g. *Emmotum nitens*) and transition species (e.g. *Roupala montana*), and especially *Tachigali vulgaris* itself.

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