RESILIENCE OF SAVANNA FOREST AFTER CLEAR-CUTTING IN THE CERRADO-AMAZON TRANSITION ZONE

RESILIÊNCIA DE CERRADÃO APÓS CORTE RASO DA VEGETAÇÃO NA TRANSIÇÃO CERRADO-AMAZÔNIA

Simone Matias REIS[1]; Beatriz Schwantes MARIMON[2]; Ben Hur MARIMON-JUNIOR[2]; Letícia GOMES[3]; Paulo Sérgio MORANDI[1]; Edson Galindo FREIRE[2]; Eddie LENZA[2]
1. Rede BIONORTE/UNEMAT, Programa de Pós Graduação em Biodiversidade e Biotecnologia, Campus Nova Xavantina, Mato Grosso, Brasil. simonematiasreis@gmail.com; 2. Universidade do Estado de Mato Grosso, Departamento de Ciências Biológicas, Campus Nova Xavantina, Mato Grosso, Brasil; 3. Universidade de Brasília, Departamento de Ecologia, Campus Universitário Darcy Ribeiro, Brasília, DF, Brasil.

ABSTRACT: The dynamics of the natural process of recuperation of the structure and diversity of native vegetation following anthropogenic disturbance has been the subject of a great deal of controversy in restoration ecology research. The present study evaluates the natural regeneration of savanna forest (*cerradão*) 32 and 36 years after the clear-cutting of the vegetation. We compared species diversity, and the structure and dynamics of the vegetation in two communities, one representing preserved *cerradão* (PC), and the other, the regenerating *cerradão* (RC), which was clear-cut in 1976. Surveys were conducted in 2008 and 2012, 32 and 36 years after clear-cutting, respectively. In 2008, we demarcated 81 permanent 10 m x 10 m plots, 50 in the RC and 31 in the PC, and measured all live plants with a diameter at soil level $\geq$ 5 cm. In 2012, the plots were resampled, including the original plants and all the recruits. The species were classified as specialists in savanna (SA) or forest habitat (FO), or as generalists (SA/FO). The RC presented the highest species richness and diversity, density, annual increment, and mortality rates. However, no significant differences were found between communities in the distribution of specialist or generalist species, or between years (2008 and 2012) in basal area or recruitment rates. While the species composition of the two communities is highly similar, the RC was characterized by a higher frequency of SA species, and was more similar to nearby savanna communities (cerrado *sensu stricto*). Trees in the RC were smaller and suffered higher rates of mortality than those in the PC, but also higher annual increments. While the RC demonstrated a high degree of resilience following clear-cutting, it was still found to be at an intermediate stage of succession, even after almost four decades, indicating that regeneration is a slow process.

KEYWORDS: Degraded areas. Natural regeneration. Species richness. Ecological succession.

INTRODUCTION

The Cerrado biome (RIBEIRO; WALTER, 2008) has the highest plant biodiversity of all the world's savannas (MENDONÇA et al., 2008), although the rapid, ongoing conversion of its natural habitats into pasture and plantations, especially on the agricultural frontiers of the Brazilian states of Mato Grosso and Goiás, has resulted in a steady decline in the extent of its original vegetation cover over the past few decades (SANO et al., 2010). The advance of the agricultural frontier in this region has a major impact on local biodiversity (BUENO et al., 2005), especially in the so-called "arc of deforestation", which straddles the interface between the Cerrado and Amazon biomes, reinforcing the need for the recuperation of degraded habitats. However, little is known of the regeneration capacity of the vegetation in this region, and more specific studies are required in order to understand this process and the potential for the recuperation of habitats.

The Cerrado is characterized by a mosaic of habitats, including grasslands, savannas, and forests. This diversity of vegetation types appears to be related to the characteristics of the soil (depth, texture, fertility, and water retention), as well as the occurrence of bushfires (COUTINHO, 1990; RIBEIRO; WALTER, 2008, ASSIS et al., 2011). In many cases, the clearing or burning of forest vegetation may lead to the formation of grassland or savanna (DURIGAN; RATTER, 2006; CARDOSO et al., 2009). The forest formations include the savanna forest (*cerradão*), which is closely associated with cerrado *sensu stricto*, and typically includes many savanna species (RIBEIRO; WALTER, 2008). Most *cerradão* has been converted into farmland because it grows on more fertile soil than the cerrado *sensu stricto*, and often on relatively flat terrain (RATTER, 1971; EITEN, 1972; OLIVEIRA-FILHO et al., 1994).

The long-term monitoring of woody plant communities can provide important insights into the dynamics of vegetation structure and composition (FELFILI, 1995; ARCE et al., 2000; CORRÊA; van

Received: 25/04/14
Accepted: 20/01/15

den BERG, 2002), including species turnover, growth rates, recruitment and mortality, as well as the influence of disturbances on community function (LIBANO; FELFILI, 2006). This monitoring provides an important baseline for the understanding of the resilience of communities following disturbance (MELO; DURIGAN, 2010).

The Cerrado appears to be relatively resilient to different types of disturbance (COUTINHO, 1990; REZENDE et al., 2005; ELIAS et al., 2013), such as the partial or complete removal of the vegetation, with ecological succession typically beginning with the establishment of savanna-type vegetation (cerrado *sensu stricto*), which is eventually replaced by species more typical of forest formations (see RATTER, 1992; DURIGAN; RATTER, 2006; CARDOSO et al., 2009). Succession is thus characterized by the substitution of species and shifts in community diversity, structure, and functioning.

The characteristics of this process, including its velocity, will depend on the intensity and duration of the impact, the natural regenerative capacity of each plant species, stem and root sprouting, and the capacity for vegetative reproduction (COUTINHO, 1990; AIDE et al., 1995; UHL et al., 1988; REZENDE et al., 2005). During the succession process, species richness may decrease as a result of the exclusion of typical Cerrado species, which are intolerant of shade (ABREU et al., 2011), while biomass tends to increase along a gradient from more open vegetation to denser habitats, such as the *cerradão* (MARIMON-JUNIOR; HARIDASAN, 2005; RIBEIRO; WALTER, 2008).

The lack of data on the effects of clear-cutting on different types of Cerrado vegetation emphasizes the need for the more systematic analysis of this process, which may not only provide vital information for the management and restoration of degraded areas, but also important insights into the successional dynamics of the mosaic of habitats found within the Cerrado-Amazon transition zone. In the present study, we evaluated the natural regeneration process in an area of *cerradão*, 32 and 36 years after the clear-cutting of the vegetation.

MATERIAL AND METHODS

The present study was conducted in two *cerradão* communities at different stages of succession in the Bacaba Municipal Park in the municipality of Nova Xavantina, in eastern Mato Grosso, Brazil. One community (14°42’02.3” S, 52°21’02.6” W) represents typical preserved *cerradão* (PC), while the other (14°41’40.42” S, 52°21’1.82” W) is an example of regenerating *cerradão* (RC). The predominant vegetation type in the region is cerrado *sensu stricto*, which is interspersed with areas of forest and *cerradão* (MARIMON-JUNIOR; HARIDASAN, 2005).

The region’s climate is of Köppen’s Aw type (SILVA et al., 2008), characterized by two well-defined seasons – one dry and cooler (April to September) and the other, hot and rainy (October to March). Mean monthly rainfall is 0–310 mm, and temperatures range from 20.5°C to 28.5°C (MARIMON-JUNIOR; HARIDASAN, 2005).

The communities monitored in the present study are located within the zone of ecological tension between the Cerrado and Amazon biomes, on a flat to slightly hilly terrain at altitudes of nearly 250 m (MARIMON-JUNIOR; HARIDASAN, 2005; ABAD; MARIMON, 2008). The soil is Red-Yellow Latosol, acid and dystrophic (MARIMON-JUNIOR; HARIDASAN, 2005). In the 1950s, both study communities formed part of a large, continuous area of *cerradão*, which was partially deforested for the construction of a Brazilian Air Force base.

The two communities are 700 m distant. The PC vegetation is very well preserved (MARIMON-JUNIOR; HARIDASAN 2005; FRANCZAK et al., 2011), while the RC was clear-cut, burned off, and had its stumps extracted between 1971 and 1973 (personal communication from Francisca O. Viana, habitant of the region since 1964). This area was subsequently planted with *colonião* grass (*Panicum maximum* Jacq) for livestock grazing over a two-year period, following which, it was abandoned. By the end of the present study, in 2012, the area had been regenerating naturally for 36 years, and the grassland had been replaced by arboreal vegetation.

Fifty contiguous permanent plots of 10 m x 10 m were established in each community, within which all live woody plants with a $DAS_{30\ cm}$ (diameter at ground level) $\geq$ 5 cm were sampled. The preserved *cerradão* (PC) was first surveyed in January, 2002 (MARIMON-JUNIOR; HARIDASAN, 2005), when all individuals were measured, identified, and marked with aluminum tags. In January 2005, 2008 (FRANCZAK et al., 2011), and 2012 (the present study), all surviving individuals were measured once again and those attaining the $DAS_{30\ cm} \geq 5$ cm criterion were included as recruits. The present study is based on the data from 2008, obtained from FRANCZAK et al. (2011) and our own survey, conducted in 2012. The regenerated *cerradão* (RC) was sampled in 2008 and 2012 following the same criteria and procedures in order to provide a comparative sample.

Some of the PC plots sampled in 2008 were burned accidentally in September, 2008, and these plots were identified and excluded from the present study. This left 31 PC plots for comparison and analysis, and 50 RC plots.

Species diversity was based on Shannon's index, H', Naperian base (MAGURRAN, 2004). Species richness and diversity were compared between communities (PC and RC) using a rarefaction approach, with 1,000 randomizations, run in Ecosim 7.0 (GOTELLI; ENTSMINGER, 2001). To avoid bias, the tests were run on the abundance data, as in Hortal et al. (2006). The Z test was then applied to the mean and variance using the vegan package (OKSANEN et al., 2010) in R 2.13 (R DEVELOPMENT CORE TEAM, 2011).

Species composition was compared between communities with Sørensen's (BROWER; ZAR, 1977) and Morisita's indices of similarity (MAGURRAN, 1988). The Chi-square test was used to compare the relative frequencies of all species and those exclusive to each community (ZAR, 2010). The same similarity indices were used to compare the PC and RC communities with two communities of typical cerrado (*cerrado típico*) vegetation also located in Bacaba Municipal Park – *cerrado típico* 1 (CT1: GOMES et al., 2011) and *cerrado típico* 2 (CT2: MEWS et al., 2011). This comparison was aimed in particular at evaluating the similarity between RC and savanna formations.

To evaluate successional stages, we classified each species as either a savanna specialist (SA), forest specialist (FO) or a habitat generalist, found in both savanna and forest (SA/FO). The species were classified through a review of the recent literature (SILVA-JÚNIOR et al., 2001; FELFILI et al., 2001; PEREIRA, 2002; MENDONÇA et al., 2008; SILVA-JÚNIOR; PEREIRA, 2009; SILVA-JÚNIOR, 2012). We used Chi-square, χ^2 (ZAR, 2010) to compare the relative frequencies of these species and individuals of these species between the two communities.

We compared the mean density of individuals, mean diameter, and mean basal area per plot between communities in each year (2008 and 2012) using the *t* test for independent samples (ZAR, 2010). For this, the homogeneity of the variances was evaluated using Levene's test (ZAR, 2010). We ran these analyses in the stats package in R 2.13 (R DEVELOPMENT CORE TEAM, 2011).

From the data collected during the two years, we calculated, for each community, the periodic annual increment or PAI (ENCINAS et al., 2005), the mean annual rates of mortality ($M=\{1-[(N_0-N_m)/N_0]^{1/t}\}x100$) and recruitment ($R=[1-(1-N_r/N_t)^{1/t}]x100$) (SHEIL et al., 1995; 2000), as well as the loss ($P=\{1-[(AB_0-AB_m-AB_d)/AB_0]^{1/t}\}x100$) and gain ($G=\{1-[1-(AB_r+AB_g)/AB_t]^{1/t}\}x100$) of basal area (GUIMARÃES et al., 2008). Half-life ($T_{1/2}=Ln(1/2)/Ln[(N_0-N_m)/N_0]^{1/t}$), doubling ($T_2=Ln(2)/Ln[(N_0+N_r)/N_0]^{1/t}$) (SWAINE; LIEBERMAN, 1987), stability ($E=(T_{1/2}-T_2)$ and turnover times ($Rep=(T_{1/2}+T_2)/2$) (KORNING; BALSLEV, 1994) were also calculated, where *t* is the time elapsed between surveys, N_0 and N_t are the initial and final number of individuals, N_m and N_r are the number of dead individuals and recruits, AB_0 and AB_t are the initial and final basal area values, AB_m and AB_r are the basal area of dead individuals and recruits, and AB_d and AB_g are the decrement and increment in basal area, respectively.

These parameters were compared between RC and PC communities using the *t* test for independent samples (ZAR, 2010). Whenever the samples did not present homogeneity of variance (Levene's test), we applied the *t* test for different variances (ZAR, 2010). All analyses were run in R 2.13 (R DEVELOPMENT CORE TEAM, 2011) considering a significance level of 5%.

RESULTS

Controlling for the potential effects of sample size (number of individuals) by the rarefaction approach, the regenerating *cerradão* (RC) presented significantly higher species richness and diversity (H') than the preserved *cerradão* in both 2008 and 2012 (Table 1).

The mean density of individuals per plot was higher in the RC than the PC in both years (Table 1), although the mean diameter of individuals was higher in the PC plots. Even so, the mean basal area was similar in both communities in both years.

The similarity of the species composition of the two communities was also high in both years (Table 1). In 2008, a total of 125 species was recorded, of which 60 (48%) were common to both communities, 45 (36%) were exclusive to the RC, and 20 (16%) to the PC. In 2012, the number of species fell to 115, of which 59 (51%) were present in both communities, 39 (34%) were exclusve to the RC, and 17 (15%) to the PC. A significantly higher frequency of exclusive species was recorded in the RC plots in both 2008 ($\chi^2 = 6.35$, $p = 0.01$) and 2012 ($\chi^2 = 5.68$, $p = 0.02$).

Table 1. Characteristics of the woody vegetation ($DAS_{30\ cm} \geq 5$ cm) of the PC and RC plots in Bacaba Municipal Park, Nova Xavantina, Mato Grosso, Brazil, in 2008 and 2012. Richness and diversity are based on a rarefaction analysis considering the same number of individuals per community. CT1 = *cerrado típico* 1 (GOMES et al., 2011), CT2 = *cerrado típico* 2 (MEWS et al., 2011), SD = standard deviation, Z = result of the Z test for independent samples, t = result of the t test for independent samples, * = $p \leq 0.05$, ** = $p \leq 0.01$, n.s. = non-significant.

Parameter	**Regenerated *Cerradão* ± SD**	**Preserved *Cerradão***	**Statistic**
Species richness 2008	90 ± 8.01	80	Z = -3.634**
Species richness 2012	86 ± 7.88	77	Z = -3.211**
Shannon's diversity (H') 2008	3.80 ± 0.001	3.60	Z = -5.838**
Shannon's diversity (H') 2012	3.80 ± 0.001	3.50	Z = -8.953**
Mean density (ind. $plot^{-1}$) 2008	24.48	21.26	t = 2.413*
Mean density (ind. $plot^{-1}$) 2012	22.48	19.97	t = 2.166*
Mean basal area (m^2 $plot^{-1}$) 2008	0.24	0.25	t = n.s.
Mean basal area (m^2 $plot^{-1}$) 2012	0.24	0.25	t = n.s.
Mean diameter (cm) 2008	9.86	10.73	t = -3.306**
Mean diameter (cm) 2012	10.20	11.01	t = -2.772**
Species similarity	**Sørensen**	**Morisita**	
RC2008 and PC2008	0.65	0.60	
RC2012 and PC2012	0.67	0.62	
RC and CT1	0.58	0.14	
RC and CT2	0.61	0.20	
PC and CT1	0.50	0.06	
PC and CT2	0.53	0.08	

In the comparison between the communities analyzed in the present study (PC and RC) and those of *cerrado típico* (TC1 and TC2) from the same study area, relatively high levels of similarity were found in the case of Sørensen's index, whereas the values recorded for Morisita's index were very much lower (Table 1).

In both cases, however, the RC was consistently more similar to the TC plots than the PC. In both years (Table 2), most species were classified as habitat generalists (SA/FO), followed by savanna (SA) specialists and finally, forest (FO) species. There were clear differences between habitats, with forest species being relatively more abundant and savanna species relatively less abundant in the PC in comparison with the RC, and between years, with an increase in the abundance of forest species in 2012 in comparison with 2008.

Considering only the species exclusive to each community, 13 (35.1%) of the species found only in the RC were savanna species, 20 (54.1%) were generalists, and four (10.8%) were forest specialists. By contrast, three (23.1%) of the 13 species exclusive to the PC were savanna species, seven (53.8%) were generalists, and three (23.1%) were forest species. The proportion of exclusive species in each community was significantly different ($\chi^2 = 5.92$, $p = 0.05$).

The mortality rate was higher in the RC in comparison with the PC, but there was no difference in mean annual recruitment rates, half-life or doubling time, turnover rates or stability time. However, biomass mortality was higher in the PC, being reflected in a higher half-life time (Table 3).

Periodic annual increment was almost three times higher in the RC in comparison with the PC, which was reflected in the lower decrement in basal area and the tendency for high basal area recruitment. The accumulation of biomass (deduced from basal area) was also higher in the RC than the PC, resulting from higher growth rates, and the reduced decrement in the basal area of the individuals surviving between surveys, in addition to the recruitment of new individuals in the RC (Table 3).

Table 2. Occurrence of habitat specialist and generalist tree species (number of species and individuals with $DAS_{30\ cm} \geq 5$ cm) in the PC (preserved *cerradão*) and RC (regenerated *cerradão*) communities in the Bacaba Municipal Park, Nova Xavantina, Mato Grosso, Brazil. SA = savanna specialist, FO = forest specialist, SA/FO = generalist. ** = $p < 0.01$, n.s. = non-significant.

	Number (%) of species in:				**Ind.ha^{-1} (%) in:**			
Category	RC/2008	PC/2008	RC/2012	PC/2012	RC/2008	PC/2008	RC/2012	PC/2012
SA	27 (27.0)	14 (19.7)	22 (23.4)	12 (16.9)	236 (9.7)	97 (4.7)	186 (8.3)	62 (3.1)
SA/FO	67 (67.0)	52 (73.2)	65 (69.1)	53 (74.6)	2054 (84.4)	1840 (88.2)	1886 (84.3)	1.735 (88.4)
FO	6 (6.0)	5 (7.1)	7 (7.5)	6 (8.5)	144 (5.9)	148 (7.1)	166 (7.4)	166 (8.5)
χ^2	RC08 x PC08 - n.s.		PC12 x CN12 - n.s.		RC08 x PC08 – 43.14**		RC12 x PC12 – 50.51**	

Table 3. Dynamic parameters of the woody vegetation ($DAS_{30\ cm} \geq 5$ cm) in the PC and RC communities in the Bacaba Municipal Park, Nova Xavantina, Mato Grosso, Brazil. Mean values () in the same line followed by different letters are significantly different, based on the *t* test for independent samples.

Parameter	**Number of individuals (mean per plot^{-1})**		**Basal Area (mean per plot^{-1})**	
	Regenerated *Cerradão*	Preserved *Cerradão*	Regenerated *Cerradão*	Preserved *Cerradão*
Mortality rate (% year^{-1})	5.64 (5.16^a)	4.36 (3.86^b)	0.73 (3.91^a)	0.93 (2.30^b)
Recruitment rate (% year^{-1})	3.35 (3.15^a)	2.67 (2.60^a)	0.84 (0.007^a)	0.64 (0.006^a)
Half-life time (years)	14.96 (19.50^a)	19.45 (22.24^a)	19.70 (32.76^b)	32.97 (69.49^a)
Doubling time (years)	30.92 (34.45^a)	37.34 (39.65^a)	105.96 (122.03^a)	140.48 (151.90^a)
Turnover rate (% year^{-1})	22.94 (23.60^a)	28.40 (23.50^a)	62.84 (64.44^b)	86.72 (84.36^a)
Stability (years)	15.97 (15.26^a)	17.89 (19.11^a)	86.27 (88.52^a)	107.51 (84.40^a)
Rate of gain (% year^{-1})			1.27 (1.28^a)	1.06 (1.19^a)
Rate of loss (% year^{-1})			4.34 (3.94^a)	2.69 (2.41^b)
Increment in basal area (m^2 ha^{-1})			0.21 (0.004^a)	0.13 (0.004^a)
Decrement in basal area (m^2 ha^{-1})			0.02 (0.0003^b)	0.03 (0.0008^a)
Basal area of recruits (m^2 ha^{-1})			0.40 (0.007^a)	0.19 (0.006^a)
Dead individuals basal area (m^2 ha^{-1})			1.95 (0.035^a)	0.78 (0.024^a)
Annual increment (m^2 ha^{-1} year^{-1})			0.43 (0.0004^a)	0.16 (0.0002^b)

DISCUSSION

The higher species richness and diversity (H') recorded in the regenerating *cerradão* (RC) in both years appear to be related to a greater degree of overlap between savanna and forest species. The relative abundance of exclusive species in the RC also appears to reflect its link with the savanna formations, which was reinforced by its greater similarity with the *cerrado típico* plots, and that 35.1% of these exclusive species were typical of savanna, whereas only 23.1% of the exclusive species in the PC were savanna species. The lower densities of forest species in the RC also indicate that it was at an intermediate stage of succession. In more advanced stages of succession, savanna species are progressively excluded as the canopy becomes denser (ABREU et al., 2011), leading to an overall reduction in species diversity, as observed in the PC. The higher mortality in the RC would also have contributed to the formation of gaps in the canopy, creating conditions for the establishment of savanna species (EITEN, 1972).

Bruelheide et al. (2011) concluded that the lower species richness and diversity of communities at more advanced successional stages is related to increasing competition for resources, which may become scarcer as succession advances. The reduction in density resulting from the increase in size of the surviving individuals may also contribute to reduced richness and diversity in late successional and climax systems. This was confirmed in the present study, in which a higher density of smaller individuals was recorded in the RC.

Despite these differences in species richness and diversity, the species composition of the two communities was highly similar, and even increased by the end of the study. This similarity is probably related to the typical resprouting capacity of most Cerrado woody plant species (COUTINHO, 1990; MIRANDA et al., 1996), which would have contributed to the autochthonous recuperation of species richness in the RC. In addition, the spatial proximity between communities may have favored seed dispersal from the PC to the RC, which would have supported the colonization of the RC by forest species (ABREU et al., 2011) and contributed to the increasing similarity of the two communities.

Generalist species predominated in both communities. This is probably related to the ecological plasticity of many species in relation to the variable conditions of luminosity (ABREU et al., 2011). The predominance of typical savanna species, which are generally heliophilous, was probably related to the disappearance of individuals of pioneer species, such as *Tachigalli vulgaris* (FRANCZAK et al., 2011). The forest habitats of the Cerrado/Amazon transition zone appear to be characterized by their highly dynamic nature, provoking certain imbalances in the vegetation structure (MARIMON et al., 2013).

The higher density of individuals in the RC is another characteristic of succession. As succession advances, density tends to decrease, while basal area normally increases. This pattern has been recorded in a deciduous forest in southern Brazil (VACCARO et al., 1999) and in deciduous (WERNECK et al., 2000) and semi-deciduous forests (FONSECA; RODRIGUES, 2000) in southeastern Brazil. In the present case, in *cerradão*, this pattern also corresponds to the transition from a predominance of savanna to forest species. The lower density recorded in the PC is the result of self-thinning (OLIVEIRA-FILHO et al., 1997; MACHADO; OLIVEIRA-FILHO, 2010), reflecting the increased competition for space in more advanced stages of succession (PUIG, 2008). As succession progresses, some individuals die off, while surviving trees accumulate biomass (MACHADO; OLIVEIRA-FILHO, 2010).

However, the similarity in the basal area of the two communities indicates that the RC had apparently recovered with regard to this parameter 32 years after clear-cutting. In a recuperated subtropical forest in Puerto Rico, which had been pasture 40 years previously, Aide et al. (1996) also found a basal area similar to that of undisturbed forest. In cerrado *sensu stricto*, by contrast, Rezende et al. (2005) found no recuperation of basal area 11 years after clear-cutting. Obviously, then, recuperation of basal area is a slow process, although the high annual increment recorded for the RC may contribute to its capacity to recover from disturbance.

Despite the recuperation of basal area in the RC, mean tree diameter was higher in the PC, representing a more advanced stage of succession. The greater density of smaller trees recorded in the RC indicates that this community had yet to reach a mature stage of regeneration, even after 36 years of recuperation. A similar pattern was observed in a cerrado *sensu stricto* community 30 years after clear-cutting (SILVA-JÚNIOR; SILVA, 1988).

The higher mortality rates recorded in the RC were to be expected given the smaller size (stem diameter) of the individuals in this community (BRAGA; REZENDE, 2007), reinforced by the higher density of individuals, which generates increased competition for space and resources

(SCHORN; GALVÃO, 2009), especially among smaller individuals (BRAGA; REZENDE, 2007). The progressive reduction in luminosity may be one of the most important factors determining mortality in the smaller individuals during the succession process (FELFILI, 1995).

The considerable similarities in the dynamic parameters of the two communities (Table 3) indicates that the RC is close to reaching a pattern of population dynamics comparable to that of the original forest cover. However, the relative high mortality rate, low turnover rate and half-life period, and the higher annual rate of loss of basal area recorded in the RC all indicate that certain functional processes weren't yet re-established. Overall, the results of the present study emphasize the complexity of the response of *cerradão* communities to deforestation, reinforcing the need for further studies in order to better understand the processes involved in the recovery of fundamental ecological functions, such as biogeochemical cycles.

CONCLUSIONS

The composition of the two communities was enough similar, but the RC was more similar to neighboring savanna communities than the PC, and was characterized by higher densities of savanna species. These results indicate that the RC was still successional even after almost 40 years of recuperation from clear-cutting.

Higher densities, smaller tree size (trunk diameter), and the resulting higher mortality all reflect the more dynamic nature of the RC. Perhaps more importantly, this study showed that the *cerradão* is able to regenerate spontaneously from clear-cutting, showing considerable resilience. Even so, recuperation appears to be a relatively slow process, given that, even after 36 years, major differences persisted in parameters such as species richness and diversity, and habitat structure between the RC and the PC community.

Some characteristics of the regenerating *cerradão* represent an intermediate stage in the succession process, with more savanna elements than found in the well-preserved *cerradão*.

ACKNOWLEDGMENTS

We thank the Nova Xavantina Plant Ecology Laboratory team for their great help in the field. We also thank the National Council for Scientific and Technological Development (CNPq), through projects PELD (Project *Transição Cerrado-Floresta Amazônica: bases ecológicas e sócio ambientais para a conservação*, process No. 558069/2009-6) and PROCAD UnB/UNEMAT (National Program for Academic Cooperation, University of Brasília and Mato Grosso State University, process No. 109/2007) and the Higher Education Training Program (CAPES) for granting an academic scholarship to S.M. Reis, L. Gomes and P.S. Morandi and CNPq for granting a Research Productivity fellowship to E. Lenza, B.S. Marimon and B.H. Marimon-Junior.

RESUMO: A dinâmica de recuperação da diversidade e estrutura da vegetação nativa, a partir de processos naturais, após distúrbios antrópicos, tem sido objeto de controvérsias em estudos de ecologia da restauração. Nosso objetivo foi avaliar a regeneração natural de cerradão em 32 e 36 anos, após corte raso da vegetação. Comparamos os parâmetros florísticos e estruturais e a dinâmica da vegetação (entre 2008 e 2012) de duas comunidades de cerradão, sendo uma de cerradão preservado (CP) e outra em regeneração desde 1976 (CR). Demarcamos em 2008, 81 parcelas permanentes (10 x 10 m), sendo 50 no CR e 31 no CP e medimos todas as plantas vivas com diâmetro a altura do solo $\geq$ 5 cm. Em 2012, reamostramos todas as plantas e incluímos os recrutas. Classificamos as espécies como especialistas em habitats savânicos (SA), florestal (FO) ou generalistas em habitats savânicos e florestais (SA/FO). O CR apresentou maior riqueza e diversidade de espécies, densidade de indivíduos, incremento periódico anual e taxa de mortalidade. Porém, as duas áreas não apresentaram diferenças na distribuição das espécies entre os habitats (SA, FO, SA/FO) e área basal (em 2008 e 2012) e taxa de recrutamento (entre 2008 e 2012). Apesar do CR e CP apresentarem elevada similaridade florística, o CR apresentou maior frequência de indivíduos de espécies com habitat SA bem como maior similaridade com duas outras comunidades savânicas (cerrado sentido restrito) próximas. Ainda, o CR possui indivíduos com menores diâmetros e consequentemente maiores taxas de mortalidade e incremento periódico anual. Apesar da resiliência do cerradão em relação ao corte raso esse ainda se encontra em estágio intermediário de sucessão, mesmo quase quatro décadas após o distúrbio, indicando que a regeneração é um processo lento.

PALAVRAS-CHAVE: Áreas degradadas. Regeneração natural. Riqueza de espécies. Sucessão ecológica.

REFERENCES

ABAD, J. C. S.; MARIMON, B. S. **Caracterização e diagnóstico ambiental do Parque Municipal do Bacaba, Nova Xavantina-MT**. In: SANTOS, J. E.; GALBIATI, C. (Eds.). Gestão e Educação Ambiental: Água, Biodiversidade e Cultura 1. São Carlos: RiMa, 2008. p. 23-56.

ABREU, R. C. R. D.; DE ASSIS, G. B.; FRISON, S.; AGUIRRE, A.; DURIGAN, G. Can native vegetation recover after slash pine cultivation in the Brazilian Savanna? **Forest. Ecol. Manag.**, Amsterdam, v. 262, n. 8, p. 1452-1459, 2011.

AIDE, T. M.; ZIMMERMAN, J. K.; HERRERA, L.; ROSARIO, M.; SERRANO, M. Forest recovery in abandoned tropical pastures in Puerto Rico. **Forest. Ecol. Manag.**, Amsterdam, v. 77, p. 77-86, set. 1995.

AIDE, T. M.; ZIMMERMAN, J. K.; ROSARIO, M.; MARCANO, H. Forest recovery in abandoned cattle pastures along an elevational gradient in northeastern Puerto Rico. **Biotropica**, Maldem, v. 28, p. 537-548, dec. 1996.

ARCE, J. E.; FELFILI, J. A.; GAIAD, D.; REZENDE, A. V.; SANQUETTA, C. R. **Avaliação do crescimento da vegetação arbórea em uma área de cerrado *sensu stricto*, em Brasília, DF**. In: COLÉGIO DE INGENIEROS DEL PERU. Capítulos de Ingenieria florestal (LOMBARDI, I.; Org.). Congresso Florestal Latinoamericano. Tomo III, 2000.

ASSIS, A. C. C.; COELHO, R. M.; PINHEIRO, E. S.; DURIGAN, G. Water availability determines physiognomic gradient in an area of low-fertility soils under Cerrado vegetation. **Plant Ecol**., Dordrecht, v. 212, p. 1135-1147, 2011.

BRAGA, F. M. S.; REZENDE, A. V. Dinâmica da vegetação arbórea da mata de galeria do Catetinho, Brasília, DF. **Cerne**, Lavras, v. 13, p. 138-148, abr./jun. 2007.

BROWER, J. E.; ZAR, J. H. **Field and laboratory methods for general ecology**. Iowa: Brown Company Publishers, 1977. 194 p.

BRUELHEIDE, H.; BÖHNKE, M.; BOTH, S. et al. Community assembly during secondary forest succession in a Chinese subtropical Forest. **Ecol. Monogr.**, USA, v. 81, p. 25-41, fev. 2011.

BUENO, L. F.; GALBIATTI, J. A.; BORGES, M. J. Monitoramento de variáveis de qualidade da água do Horto Ouro Verde, Conchal - SP. **Eng. Agríc.**, Jaboticabal, v. 25, p. 742-748, set./dez. 2005.

CARDOSO, E.; MORENO, M. I. C.; BRUNA, E. M.; VASCONCELOS, H. L. Mudanças fitofisionômicas no cerrado: 18 anos de sucessão ecológica na estação ecológica do panga, Uberlândia-MG. **Caminhos de Geografia**, Uberlândia, v. 10, n. 32, p. 254-268, 2010.

CORRÊA, B. S.; van den BERG, E. Estudo da dinâmica da população de *Xylopia brasiliensis* Sprengel em relação a parâmetros populacionais e da comunidade em uma floresta de galeria em Itutinga, MG, Brasil. **Cerne**, Lavras, v. 8, p. 1-12, 2002.

COUTINHO, L. M. Fire ecology of the Brazilian cerrado. In: GOLDAMMER, J. G. (Ed.). **Fire in the tropical biota**. Berlin: Springer-Verlag, 1990, p. 82-105. http://dx.doi.org/10.1007/978-3-642-75395-4_6

DURIGAN, G.; RATTER, J. A. Successional changes in cerradão and cerrado/forest ecotonal vegetation in western São Paulo State, Brazil, 1962-2000. **Edinb. J. Bot.**, Edinburgh, v. 63, p. 119-130, 2006.

EITEN, G. The Cerrado Vegetation of Brazil. **Bot. Rev.**, Bronx, v. 38, n. 2, p. 201-341, 1972.

ELIAS, F.; MARIMON, B. S.; GOMES, L.; FORSTHOFER, M.; ABREU, M. F.; REIS, S. A.; LENZA, E.; FRANCZAK, D. D.; MARIMON-JUNIOR, B. H. Resiliência de um cerradão submetido a perturbações intermediárias na transição Cerrado-Amazônia. **Biotemas**, Florianópolis, v. 26, n. 3, p. 49-62, 2013. http://dx.doi.org/10.5007/2175-7925.2013v26n3p49

ENCINAS, J. M. I.; SILVA, G. F.; PINTO, J. R. R. **Idade e crescimento das árvores. Brasília**: Comunicações técnicas florestais, v. 7, 2005. 43 p.

FELFILI, J. M.; MENDONÇA, R. D.; WALTER, B. M. T.; SILVA JÚNIOR, M. D.; NÓBREGA, M. G. G.; FAGG, C. W.; SOUZA-SILVA, J. C. **Flora fanerogâmica das matas de galeria e ciliares do Brasil Central**. In: RIBEIRO, J. F.; FONSECA, C. E. L; SOUZA-SILVA, J. C. (Eds.). Cerrado: caracterização e recuperação de Matas de Galeria. Planaltina: Embrapa-CPAC, 2001. p. 195-263.

FELFILI, J. M. Diversity, structure and dynamics of a gallery forest in central Brazil. **Vegetatio**, Bélgica, v. 117, p. 1-15, mar. 1995.

FONSECA, R. C. B.; RODRIGUES, R. R. Análise estrutural e aspectos do mosaico sucessional de uma floresta semidecídua em Botucatu, SP. **Sci. Forestalis**, Piracicaba, v. 57, p. 27-43, jun. 2000.

FRANCZAK, D. D.; MARIMON, B. S.; MARIMON-JUNIOR, B. H.; MEWS, H. A.; MARACAHIPES, L.; OLIVEIRA, E. A. Changes in the structure of a savanna forest over a six-year period in the Amazonia-Cerrado boundary, Mato Grosso state, Brazil. **Rodriguésia**, Rio de Janeiro, v. 62, p. 425-436, mar. 2011.

GOMES, L.; LENZA, E.; MARACAHIPES, L.; MARIMON, B. S.; OLIVEIRA, E. A. Comparações florísticas e estruturais entre duas comunidades lenhosas de cerrado típico e cerrado rupestre, Mato Grosso, Brasil. **Acta Bot. Bras.**, Feira de Santana, v. 25, p. 865-875, out./dez. 2011.

GOTELLI, N. J.; ENTSMINGER, G. L. **EcoSim: Null models software for ecology.** Acquired Intelligence Inc.; Kesey-Bear [7.0], 2001.

GUIMARÃES, J. C. C.; VAN DEN BERG, E.; CASTRO, G. C.; MACHADO, E. L. M.; OLIVEIRA-FILHO, A. T. Dinâmica do componente arbustivo-arbóreo de uma floresta de galeria aluvial no planalto de Poços de Caldas, MG, Brasil. **Rev. Bras. Bot.**, São Paulo, v. 31, p. 621-632, out./dez. 2008.

HORTAL, J.; BORGES, P. A. V.; GASPAR, C. Evaluating the performance of species richness estimators: sensitivity to sample grain size. **J. Anim. Ecol.**, Britânia, v. 75, p. 274-287, jan. 2006.

PEREIRA, B. A. S. **Árvores do Brasil Central**: Espécies da região geoeconômica de Brasília. Rio de Janeiro: IBGE/Diretoria de Geociências, 2002. 417 p.

KORNING, J.; BALSLEV, H. Growth rates and mortality patterns of tropical lowland tree species and the relation to forest structure in Amazonia Ecuador. **J. Trop. Ecol.**, Cambridge, v. 10, p. 151-166, fev. 1994.

LIBANO, A. M.; FELFILI, J. M. Mudanças temporais na composição florística e na diversidade de um cerrado *sensu stricto* do Brasil Central em um período de 18 anos (1985-2003). **Acta Bot. Bras.**, Feira de Santana, v. 20, p. 927-936, out./dez. 2006.

MACHADO, E. L. M.; OLIVEIRA-FILHO, A. T. Spatial patterns of tree community dynamics are detectable in a small (4 ha) and disturbed fragment of the Brazilian Atlantic forest. **Acta Bot. Bras.**, Feira de Santana, v. 24, p. 250-261, jan./mar. 2010.

MAGURRAN, A. E. **Ecological diversity and its measurement.** London: England, Croom Helm, 1988. 179 p. http://dx.doi.org/10.1007/978-94-015-7358-0

MAGURRAN, A. E. **Measuring biological diversity**. Oxford: Blackwell Science, 2004. 256 p.

MARIMON, B. S.; FELDPAUSCH, T.; MARIMON-JUNIOR, B. H.; SANTOS, C. O.; MEWS, H. A.; LOPEZ-GONZALES, G.; FRANCZAK, D. D.; ALMEIDA-OLIVEIRA, E.; MARACAHIPES, L.; MIGUEL, A.; LENZA, E.; PHILLIPS, O. Disequilibrium and hyperdinamic tree turnover at the forest-savanna boundary zone in southern Amazonia. **Plant Ecol. Divers.**, London, v. 7, p. 281-292, set. 2013.

MARIMON-JUNIOR, B. H.; HARIDASAN, M. Comparação da vegetação arbórea e características edáficas de um cerradão e um cerrado *sensu stricto* em áreas adjacentes em solos distróficos no leste de Mato Grosso, Brasil. **Acta Bot. Bras.**, Feira de Santana, v. 19, p. 913-926, dez. 2005.

MELO, A. C. G.; DURIGAN, G. Impacto do fogo e dinâmica da regeneração da comunidade vegetal em borda de Floresta Estacional Semidecidual (Gália, SP, Brasil). **Rev. Bras. Bot.**, São Paulo, v. 33, p. 37-50, jan./mar. 2010.

MENDONÇA, R. C.; FELFILI, J. M.; WALTER, B. M. T.; SILVA-JÚNIOR, M. C.; REZENDE, A. V.; FILGUEIRAS, T. S.; NOGUEIRA, P. E. **Flora Vascular do Cerrado**. In: SANO, S. M.; ALMEIDA, S.P. (Eds.). Cerrado: ambiente e flora. Planaltina: Embrapa-CPAC, 2008. p. 289-556.

MEWS, H. A.; MARIMON, B. S.; MARACAHIPES, L.; FRANCZAK, D. D.; MARIMON-JUNIOR, B. H. Dinâmica da comunidade lenhosa de um Cerrado Típico na região Nordeste do Estado de Mato Grosso, Brasil. **Biota Neotrop.**, São Paulo, v. 11, p. 73-82, jan./mar. 2011.

MIRANDA, H. S.; ROCHA E SILVA, E. P.; MIRANDA, A. C. **Comportamento do fogo em queimadas de campo sujo**. In: MIRANDA, H. S.; SAITO, C. O.; DIAS, B. F. S. (Eds.). Impactos de queimadas em áreas de cerrado e restinga. Universidade de Brasília, Brasília, 1996. p. 1-10.

OKSANEN, J.; BLANCHET, F. G.; KINDT, R.; LEGENDRE, P.; O'HARA, R. B.; SIMPSON, G. L.; SOLYMOS, P.; STEVENS, M. H. H.; WAGNER, H. **Vegan**: Community Ecology Package. R package version 1.17-2. 2010. Disponível em: <http://CRAN.R-project.org/package=vegan>. Acesso em: 12 jan. 2014.

OLIVEIRA-FILHO, A. T.; MELLO, J. M.; SCOLFORO, J. R. Effects of past disturbance and edges on tree community structure and dynamics within a fragment of tropical semideciduous forest in south-eastern Brazil over a five-year period (1987-1992). **Plant Ecol.**, Dordrecht, v. 131, p. 45-66, jul. 1997.

OLIVEIRA-FILHO, A. T.; VILELA, E. A.; CARVALHO, D. A.; GAVILANES, M. L. Effects of soils and topography on the distribution of tree species in a tropical riverine forest in south-eastern Brazil. **J. Trop. Ecol.**, Cambridge, v. 10, p. 483-508, 1994.

PUIG, H. **A floresta tropical úmida**. São Paulo: UNESP, Imprensa Oficial do Estado de São Paulo, 2008. 493 p.

R DEVELOPMENT CORE TEAM. **R: A language and environment for statistical computing**. R Foundation for Statistical Computing. Vienna, Austria, 2011. ISBN 3-900051-07-0. Disponível em: <http://www.R-project.org>. Acesso em: 12 dez. 2013.

RATTER, J. A. **Some notes on two types of cerradão occurring in northeastern Mato Grosso**. In: FERRI, M. G. (Ed.). III Simpósio Sobre o Cerrado. São Paulo: EDUSP/Edgard Blücher, 1971. p. 110-112.

RATTER, J. A. **Transitions between cerrado and Forest vegetation in Brazil**. In: FURLEY, P. A.; PROCTOR, J.; RATTER, J. A. (Eds.). Nature and dynamics of Forest – Savanna boundaries. London: Chapman & Hall, 1992. p. 417-430.

REZENDE, A. V.; SANQUETTA, C. R.; FIGUEIREDO FILHO, A. Efeito do desmatamento no estabelecimento de espécies lenhosas em um cerrado *sensu stricto*. **Floresta**, Curitiba, v. 35, n. 1, 2005.

RIBEIRO, J. F.; WALTER, B. M. T. **As principais fitofisionomias do Bioma Cerrado**. In: SANO, S. M.; ALMEIDA, S. P.; RIBEIRO, J. F. (Ed.). Cerrado: ecologia e flora. Planaltina: Embrapa-CPAC, 2008. p. 151-212.

SANO, E. E.; ROSA, R.; BRITO, J. L. S.; FERREIRA Jr., L. G. Land cover mapping of the tropical savanna region in Brazil. **Environ. Monit. Assess.**, Berlin, v. 166, p. 113-124, jun. 2010.

SCHORN, L. A.; GALVÃO, F. Dinâmica do estrato arbóreo em três estádios sucessionais de uma floresta ombrófila densa em Blumenau, SC. **Cerne**, Lavras, v. 159, p. 221-235, abr./jun. 2009.

SHEIL, D.; BURSLEM, D. F. R. P.; ALDER, D. The interpretation and misinterpretation of mortality rate measures. **J. Ecol.**, London, v. 83, p. 331-333, out. 1995.

SHEIL, D.; JENNINGS, S.; SAVILL, P. Long-term permanent plot observations of vegetations dynamics in Budongo, a Ugandan rain Forest. **J. Trop. Ecol.**, Cambridge, v. 16, p. 765-800, nov. 2000.

SILVA JÚNIOR, M. C; PEREIRA, B. S. **Mais 100 árvores do cerrado – Matas de Galeria**: guia de campo. Brasília: Rede de Sementes do Cerrado, 2009. 288 p.

SILVA JÚNIOR, M. D.; FELFILI, J. M.; WALTER, B. M. T.; NOGUEIRA, P. E.; REZENDE, A. V.; MORAIS, R. D. O.; SOUZA-SILVA, J. C. **Análise da flora arbórea de Matas de Galeria no Distrito Federal**: 21 levantamentos. In: RIBEIRO, J. F.; FONSECA, C. E. L.; SOUSA-SILVA, J. C. (Eds.). Cerrado: caracterização e recuperação de Matas de Galeria. Planaltina: EMBRAPA Cerrados, 2001. p. 142-191.

SILVA, F. A. M.; ASSAD, E. D.; EVANGELISTA, B. A. **Caracterização climática do Bioma Cerrado**. In: SANO, S. M.; ALMEIDA, S. P.; RIBEIRO, J. F. (Ed.). Cerrado: ecologia e flora. Planaltina: Embrapa-CPAC, 2008. p. 69-88.

SILVA-JUNIOR, M. C. **100 árvores do cerrado sentido restrito**: guia de campo. Brasília: Distrito Federal: Rede de Sementes do Cerrado, 2012. 360 p.

SILVA-JÚNIOR, M. C.; SILVA, A. F. Distribuição de diâmetros dos troncos das espécies mais importantes do Cerrado na Estação Florestal de Experimentação de Paraopeba (EFLEX)-MG. **Acta Bot. Bras.**, Feira de Santana, v. 2, p. 107-126, dez. 1988.

SWAINE, M. D.; LIEBERMAN, D. Note on the calculation of mortality rates. **J. Trop. Ecol.**, Cambridge, v. 3, p. 2-3, nov. 1987.

UHL, C.; BUSCHBACHER, R.; SERRAO, E. A. S. Abandoned pastures in eastern Amazonia. I. Patterns of plant succession. **J. Ecol.**, London, v. 76, p. 663-681, set. 1988.

VACCARO, S.; LONGHI, S. J.; BRENA, D. A. Aspectos da composição florística e categorias sucessionais do estrato arbóreo de três subseres de uma floresta estacional decidual, no município de Santa Tereza - RS. **Ci. Fl.**, Santa Maria, v. 9, p. 1-18, 1999.

WERNECK, M. S.; FRANCESCHINELLI, E. V.; TAMEIRÃO-NETO, E. Mudanças na florística e estrutura de uma floresta decídua durante um período de quatro anos (1994-1998), na região do Triângulo Mineiro, MG. **Rev. Bras. Bot.**, São Paulo, v. 23, p. 401-413, dez. 2000.

ZAR, J. H. Biostatistical Analisys. 4th ed. New Jersey: Pearson, Upper Saddle River, 2010. 944 p.