Original Article

FLORISTIC WOODY COMPOSITION OF REVEGETATED MINING SITES IN THE BRAZILIAN FEDERAL DISTRICT

COMPOSIÇÃO FLORÍSTICA LENHOSA DE JAZIDAS REVEGETADAS NO DISTRITO FEDERAL

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ABSTRACT: The extension degraded by mining in the Brazilian Federal District - BFD is proportionately five times larger than country's average. The restoration of plant communities at these sites is ecologically necessary and legally compulsory. Native woody species are commonly used for ecosystem restoration and this study aimed to identify the floristic composition of woody species introduced in BDF mining sites and discuss its outcomes. The floristic survey was conducted by sampling groups of one hundred individuals until sampling sufficiency was achieved. In total 4,500 plants were sampled in ten sites, which housed 92 autochthonous and 21 allochthonous woody species. Plant communities in the sites assembled between 13 and 62 species, planted at low density - 467 ± 222 plants ha^{-1}. The preferential use of autochthonous species in the revegetation projects resembles the standards recommended by successional restoration models, but the floristic diversity and plant density in initial communities fall below the values deemed as ideal. The 92 autochthonous species include representatives of various habitats, ecological groups and dispersal syndromes. These 92 species currently in use may be regrouped in initial plant communities denser and more diverse than those found in the revegetated sites. The surveyed plant communities were massively composed of arboreal species and such pattern may drive succession towards the formation of forest ecosystems where previously inhabited savanna formations.

KEYWORDS: Ecological restoration. Revegetation. Mining areas. Brazilian savanna.

INTRODUCTION

The Cerrado is the second largest Brazilian biome, occurs in fourteen out 26 states, occupies nearly 25% of the national territory and houses over twelve thousand species of vascular plants (MENDONÇA et al., 2008a). This biome consists of a mosaic of grassland, savanna and forest formations, which confers upon it a high diversity of habitats and the richest savanna in plant species in the world (MENDONÇA et al., 1998).

Studies report that agriculture, livestock breeding, urbanization and mining are responsible for the loss of more 50% of Cerrado native vegetation coverage (KLINK; MACHADO, 2005; MENDONÇA et al., 2008a). High degree of endemism, high biodiversity and significant human impacts on natural ecosystems have ranked the Cerrado biome amongst the 34 hotspots for global biodiversity conservation (IUCN, 2010). The Brazilian Federal District - BFD is located on the central part of Cerrado, where conflicts between conservation measures and economic activities are intense. In addition to the damage caused by agriculture and urbanization, almost 1% of the BFD's territory is taken by mines of clay, gravel, sand and limestone, a percentage five times higher than national average (CORRÊA et al., 2004; STARR et al., 2013).

The destruction of ecosystems by human activities has placed a number of species at risk of extinction. Conservationist plans recommend habitat restoration as a means of offsetting biodiversity losses (MARON; HOBBS, 2012), increasing carrying capacity, and lowering extinction risk (ANAND; DESROCHERS, 2004). The use of seedlings and seeds is the most viable alternative for the restoration of ecosystems that have lost most of resilience, like areas degraded by mining (DURIGAN, 2003; SILVA; CORRÊA, 2008). This practice began in Brazil almost two centuries ago (MARTINS, 1966), and the current use of native species in successional models aims to shorten the stages of natural succession by establishing trees in degraded areas that would be spontaneously colonized by herbs in the early stages of ecological succession (BARBOSA et al., 2003; REIS et. al., 2003; MARTINS et al., 2012).

The revegetation of a degraded area is currently considered the beginning of an ecosystem restoration, since ecological succession is the main course of restoration in tropical regions (CORLETT; HAU, 2000). Restoration projects aim to recover damaged ecosystems by creating conditions that will

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prompt communities to follow their natural pathways where ecological processes were destroyed (ANAND; DESROCHERS, 2004; SER, 2004). In this sense the recovery of biomass and biodiversity is considered necessary to restore and maintain ecosystem functioning (LYONS et al., 2005; MOKANY et al., 2008). Techniques involving facilitation, nucleation, keystone and umbrella species, and others have more recently been incorporated into successional restoration models (REIS et al., 2003; LYONS et al., 2005).

Tree plantation is the oldest and most common practice used for rehabilitation of lands degraded by human activities because trees provide a pronounced visual effect on the landscape (SINGH et al., 2002; RUIZ-JAEN; AIDE, 2005; SILVA; CORRÊA, 2008). Trees and shrubs also play a fundamental role in plant recruitment and ecological succession by increasing ecological structure and providing perches and food for fauna (CORLETT; HAU, 2000; KAGEYAMA et al., 2003; RUIZ-JAEN; AIDE, 2005; BARBOSA; PIZO, 2006). The appropriate assembly of plant species that will compose initial communities in degraded areas is essential for the success of restoration projects (MELO et al., 2004; STARR et al., 2013). In such view, this study aimed to identify the woody species assembled as initial plant communities in sites previously degraded by mining activities in the Brazilian Federal District - BFD and discuss outcomes of the floristic composition adopted.

MATERIAL AND METHODS

Study Area

The study was conducted in the Federal District of Brazil - BFD, which occupies 5,814 km^2 of the Brazilian Central Plateau. The region's topography varies from flat to gently slope, with average altitude of 1,100 m. Climate is Tropical of Savanna (Aw - Köppen-Geiger) with well-defined wet and dry seasons (PEEL et al., 2007), annual mean temperature of 21 - 24°C, and annual rainfall ranges from 1,200 to 1,600 mm, 84% of which precipitate in summer (INMET, 2012).

Floristic survey

Planted woody species were sampled in revegetated mining sites that were subject to restoration projects, namely the recovery of degraded ecosystems as close as possible to their original condition (Brazilian Federal Law Nr. 9.985/2000). All study sites were located in areas originally covered by savannic formations on either Oxisol or Inceptisol soils.

Sampling works in each site began soon after revegetation works, which occurred from 2005 to 2010. Based on Equations 1 and 2 (SNEDECOR; COCHRAN, 1989), four hundred plants were initially sampled in each site and then checked for sampling sufficiency through species rarefaction curves (GOTELLI; COLWELL, 2001). Sampling works were extended wherever necessary until sampling sufficiency was achieved in each revegetated site, which required the sampling of 400 to 900 individuals in each of the ten studied locations (Table 1).

$$n_0 = \frac{1}{E^2} \Rightarrow \frac{1}{0.05^2} = 400 \text{ individuals} \qquad \text{(Equation 1)}$$

$$n = \frac{N \ x \ n_o}{N + n_o} \qquad \text{(Equation 2)}$$

where,

n_0 = sample size for an infinite size population, at 5% confidential level

n = sample size for a known size population

N = population size

The floristic survey was done through traversal shaped scanning (PINHEIRO et al., 2009), using at least four sample groups of one hundred planted woody individuals each one (Equation 1). The starting point of each sample group was selected at random, and covered up a rectangle area from that point on until one hundred plants were sampled. The area occupied by every group of one hundred planted individuals was used for the estimation of planting density in each revegetated site. Part of plants from species not identified *in situ* were collected and pressed for subsequent identification through literature and comparison with exsiccates deposited in the University of Brasilia's herbarium. Taxonomic classification was based on The Angiosperm Phylogeny Group system (APG III, 2009), and taxa names were updated as *per* the nomenclature of the Missouri Botanical Garden (MOBOT, 2012).

Ten revegetated mining sites were sampled to achieve sampling sufficiency for the overall floristic woody composition introduced in these sites. Original soil type and vegetation formation of revegetated sites were determined based on surrounding areas, satellite images, and soil profiles. Geographic coordinates were recorded on the center of each study site, with a Garmin GPS 40 device, *datum* SAD 69 (Table 1).

Table 1. Some characteristics of study sites.

Location	Geographic coordinates (SAD 69)	Revegetated extension (ha)	Number of planted individuals	Number of species	Number of sampled individuals
1 - SHIS QI 29	15° 48' 44" S 47° 47'28" W	5.4	1,514	32	400
2 - Aeroporto JK	15° 52' 22" S 47° 53' 11" W	72.1	29,000	62	900
3 - REFESA	15° 47' 14" S 47° 57' 07" W	6.7	4,200	34	400
4 - Parna de Bsb	15° 44' 06" S 47° 55' 46" W	1.1	690	32	400
5 - Granja do Torto	15° 42' 43" S 47° 54' 36" W	16.4	5,410	21	400
6 - BR 060, Km 14,5	15° 56' 27" S 48° 09' 31" W	21.4	5,940	14	400
7 - DF 130, Km 8,5	15° 45'26" S 47° 39' 22" W	4.5	2,530	20	400
8- Arboreto UnB	15° 44' 20" S 47° 53' 02" W	4.9	1,350	16	400
9 - SMPW Q. 25	15° 54' 01'' S 47° 54' 58'' W	6.3	6,000	19	400
10 - DF 430	15° 40' 01" S 48° 10' 47" W	4.2	1,400	13	400

Data treatment

Number of individuals of each species was relativized according to the sample number in each revegetated site in order to determine the abundance of each species within the floristic composition. The frequency and abundance of species were calculated according to Dajoz (1983; 2005):

$$\text{Frequency - } F_i = \frac{\#\ of\ \ sites\ with\ species\ i}{total\ \#\ of\ \ sites} \times 100 \qquad \text{(Equation 3)}$$

$$\text{Abundance - } Ab_i = \frac{\#\ \ individuals\ of\ species\ i}{total\ number\ of\ individuals} \times 100 \qquad \text{(Equation 4)}$$

Identified woody species were classified according to origin (autochthonous or allochthonous), habit (tree or shrub), natural habitat (savanna or forest), ecological group (pioneer, secondary, climax), and dispersal syndrome (anemochory, autocory, hydrochory, zoochory), based on Durigan and Silveira (1999), Duboc (2004), Duboc and Guerrini (2007), Carvallho (2008), Mendonça et al. (2008b) and Corrêa (2009). Regression analyses were performed among number of species, number of individuals, frequency of species, and abundance of species by using Matlab software, version 2009.

RESULTS

The sampling of 4,500 individuals along 143 hectares in ten surveyed sites was necessary to achieve stability tendency in the rarefaction curve (Figure 1). In this 143 hectares, which represents 4% of the extension degraded by mining in the Brazilian Federal District - BFD (CORRÊA et. al., 2004), there were 103 species of trees and 13 species of shrubs (Table 2). The survey of the first four sites assembled 92% of the species found in the study, while the survey of further six sites added nine species to the overall floristic composition.

Among the 116 species found, 92 (79%) are autochthonous to Cerrado biome. Seedlings planted in sites were distributed in 36 botanical families (Table 2). Fabaceae was the family with the highest species richness (33 species), followed by Bignoniaceae (11), Malvaceae (11) and Anacardiaceae (7). The remaining families were represented by up to four species each one. Species of Anarcadiaceae, Bignoniaceae and Fabaceae were present in all the investigated sites, with a total of 51 species, or 44% of the floristic richness.

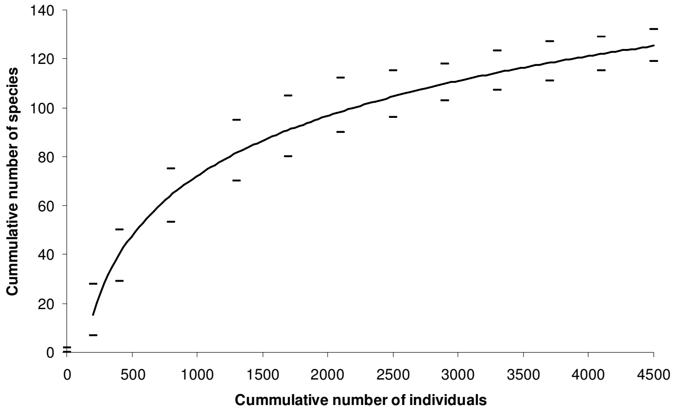

Figure 1. Species rarefaction curve for plants sampled in ten revegetated mining sites in the Brazilian Federal District - BFD.

Surveyed mining sites were revegetated with communities composed of 13 to 62 woody species (Table 1), with density of 467 ± 222 plants ha^{-1} or a spacing of 4 x 5 m among plants. Average number of species *per* revegetated site was of 26 ± 15, and only one project used more than 34 species (Table 1). The majority of projects (60%) employed between 13 and 21 woody species. Twenty one allochthonous species to Cerrado were found in the sites, which corresponded to 18% of the floristic composition. It was not possible to determine the species of three identified genus (Table 2). Among the 92 autochthonous species found, 47 occur naturally in forest and savanna formations of Cerrado, 37 occur exclusively in forest formations and eight species are exclusive to savannic formations (Table 2). About a quarter (26%) of the autochthonous species introduced in the sites are pioneer species, 37% are secondary and 3% are climax species. The remaining 34% of species have more than one ecological group classification (DURIGAN; SILVEIRA, 1999; DUBOC, 2004; DUBOC; GUERRINI, 2007; CARVALHO, 2008; MENDONÇA et al., 2008b; CORRÊA, 2009). More than half (51%) of the autochthonous species identified in the sites present zoochorous dispersal syndrome, while 45% are anemochorous species, and 4% disperse by either autocory or hydrochory.

Of the 116 species found in the ten surveyed locations, 61 occurred in only one of the revegetated sites (Fi = 10%), 21 species were recorded in two sites (Fi = 20%) and 15 species occurred in five or more sites (Fi ≥ 50%). Only *Myracrodruon urundeuva* Allemão was found in all revegetated sites, while *Anadenanthera macrocarpa* (Benth.) Brenan was present in 80% of the surveyed locations (Table 2).

Among the 4,500 individuals sampled in sites, 9.4% were *M. urundeuva*, followed in abundance by *A. macrocarpa* (5.6%) and *Triplaris brasiliana* Cham. (4.8%). The 16 most abundant species accounted for 55% of the number of sampled individuals. They were *M. urundeuva* (9.4%), *A. macrocarpa* (5.6%), *T. brasiliana* (4.8%), *Handroanthus albus* (Cham.) Mattos (3.8%), *Dipteryx alata* Vogel (3.4%), *Jacaranda macrantha* Cham**.** (3.3%), *Genipa americana* L. (3.1%), *Tabebuia roseoalba* (Ridl.) Sandwith (3.1), *Inga laurina* (Sw.) Willd. (3.0), *Myroxylon peruiferum* L. f. (2.9%), *Guazuma ulmifolia* Lam (2.4%), *Senegalia polyphylla* (DC) Britton. Rose (2.2%), *Dalbergia miscolobium* Benth. (2.1%), *Tabebuia aurea* Benth. & Hook. f. ex S. Moore (2.1%), *Inga cylindrica* (Vell.) Mart. (2.0%) and *Plathymenia reticulata* Benth. (2.0%). Of these, *J. macrantha* is allochthonous to Cerrado biome. Among the 15 most abundant autochthonous species eight are exclusive of forest formations, while seven occur in savannas and forests. Ten of these species have anemochorous dispersal syndrome, four are zoochorous, and four species are pioneers. Eight of the 16 most abundant species are Fabaceae, while other four are Bignoniaceae. The other four species among the 16 most abundant ones belong to four distinct families (Table 2). The other 45% of the individuals found in the sites are distributed among the other 100 species of 30 different families. The families with the largest numbers of plants were Fabaceae - 1,622 or 36%, Bignoniaceae - 719 or 16%, and Anacardiaceae, with 541 individuals or 12% of sampled plants (Table 2). The frequency of species in sites influenced species abundance ($R^2 = 0.66$; $P < 0.05$).

Among the individuals sampled, 90.4% were of autochthonous trees, 1.7% were autochthonous shrubs and the remaining 7.9% were trees or shrubs allochthonous to Cerrado. The individuals of autochthonous species from forest formations totaled 46.1% of sampled plants, while those from savanna formations accounted for 4.6% of the same. Plants that occur naturally in forest and savanna formations amounted to 41.4% of the total sampled individuals. Autochthonous pioneer species represented 21.3% of the individuals sampled, and 21.7% were secondary species. Climax species accounted for 5%, and 44.1% of the individuals had more than one classification for ecological group. Regarding dispersal syndrome, 53.5% of sampled individuals were of anemochorous species, 33.3% of zoochorous species, and 5.3% were individuals of either autochorous or hydrochorous species (DURIGAN; SILVEIRA, 1999; DUBOC, 2004; DUBOC; GUERRINI, 2007; CARVALHO, 2008; MENDONÇA et al., 2008b; CORRÊA, 2009).

Table 2. Taxon, frequency (Fi), abundance (Abi) and some characteristics of the woody species found in study sites.

Taxon	Fi (%)	Abi (%)	Habit	Habitat	Ecological group	Dispersal syndrome
ANACARDIACEAE						
Anacardium occidentale L.	10	< 0.1	T	S, F	p, s, c	z
Astronium fraxinifolium Schott ex Spreng	20	0.7	T	S, F	p, s	a
Astronium graveolens Jacq.	20	0.8	T	F	s	a
Lithraea molleoides Engl.	10	0.3	T	F	p	z
† *Myracrodruon urundeuva* Allemão	100	9.4	T	F	s, c	a
Schinus terebinthifolius Raddi	10	0.1	T	F	p, s	z
Tapirira guianensis Aubl.	50	0.9	T	S, F	p, s	z
ANNONACEAE						
Xylopia aromatica (Lam.) Mart.	20	0.4	T	S	p	z
APOCYNACEAE						
Aspidosperma macrocarpon Mart.	30	0.5	T	S, F	s	a
Aspidosperma subincanum Mart.	10	0.1	T	F	s	a, z
†*Hancornia speciosa* Gomez	30	0.4	T	S, F	s	z
**Nerium oleander* L.	10	< 0.1	Sb	exotic		
ARALIACEAE						
**Schefflera actinophylla* (Endl.) Harms	10	< 0.1	T	exotic		z
BIGNONIACEAE						
Cybistax antisyphilitica (Mart.) Mart.	40	1.7	T	S, F	s	a
Jacaranda macrantha Cham.	40	3.3	T	exotic	p	a
Handroanthus albus (Cham.) Mattos	70	3.8	T	S, F	c	a
Handroanthus chrysotrichus (Mart.ex DC) Mattos	30	0.4	T	F	s	a
† *Tabebuia aurea* Benth. & Hook. f. ex S. Moore	70	2.1	T	S, F	s	a
Tabebuia impetiginosa (Mart. ex DC.) Standl.	30	0.7	T	F	s	a

Tabebuia ochracea (Cham.) Standl.	10	< 0.1	T	S, F	s	a
Tabebuia roseoalba (Ridl.) Sandwith	70	3.1	T	F	s	a
**Tabebuia* sp.	10	0.8	Sb	exotic		
*† *Stenolobium stans* (L.) Seem	20	0.2	Sb	exotic		
Zeyheria montana Mart.	10	< 0.1	Sb	S, F	p	a
BORAGINACEAE						
Cordia sellowiana Cham.	10	0.3	T	F	p	a
CALOPHYLLACEAE						
Calophyllum brasiliense Cambess.	30	1.1	T	F	s, c	h, z
† #*Kielmeyera coriacea* Mart. & Zucc.	20	< 0.1	T	S, F	p	a
CARYOCARACEAE						
† #*Caryocar brasiliense* Cambess.	30	0.3	T	S, F	p, s, c	z
CELASTRACEAE						
† *Plenckia populnea* Reissek	10	< 0.1	T	S, F	p	a
CHRYSOBALANACEAE						
Couepia grandiflora (Mart. & Zucc.) Benth. ex Hook. f.	10	0.1	T	S, F,	s	z
CLUSIACEAE						
Clusia sp.	20	0.1	T			
COMBRETACEAE						
Terminalia argentea Mart.	30	1.2	T	S, F	p	a, h
Terminalia fagifolia Mart.	10	0.3	T	S, F	s	a
Terminalia phaeocarpa Eichler	10	< 0.1	T	F	p	a
DILLENIACEAE						
Curatella americana L.	10	< 0.1	T	S, F	c	z
ERYTHROXYLACEAE						
# *Erythroxylum suberosum* A. St.-Hil.	10	< 0.1	Sb	S	s	z
EUPHORBIACEAE						
Margaritaria nobilis L.f.	10	< 0.1	T	F	s	t, z
*† *Ricinus communis* **L.**	10	< 0.1	Sb	exotic		
Sapium glandulatum (Vell.) Pax	10	< 0.1	Sb	S, F	p	z
FABACEAE						
Amburana cearensis (Allemão) A.C. Sm.	10	0.2	T	F	s	a
† Anadenanthera macrocarpa (Benth.) Brenan	80	5.6	T	F	s, c	a
† *Bauhinia* sp.	10	0.9	T			
**Caesalpinia echinata* Lam.	10	0.1	T	exotic		
**Calliandra* sp.	10	0.2	Sb	exotic		
Copaifera langsdorffii Desf.	60	1.8	T	F	s, c	z
† #*Dalbergia miscolobium* Benth.	60	2.1	T	S, F	p	a
†*Dimorphandra mollis* Benth.	10	< 0.1	T	S	p	z
Dipteryx alata Vogel	50	3.4	T	S, F	s, c	t, z

Enterolobium contortisiliquum (Vell.) Morong	20	0.5	T	F	p, s	t, z
Enterolobium gummiferum Benth.	10	< 0.1	T	S, F	p, s	t, z
Erythrina verna Vell.	20	< 0.1	T	S, F	s	a, z
Hymenaea courbaril var. stilbocarpa (Hayne) Y.T. Lee & Langenh.	60	1.9	T	F	s, c	t, z
†*Hymenaea stigonocarpa* Mart. ex. Hayne	70	1.2	T	S, F	s, c	t, z
Inga cylindrica (Vell.) Mart.	30	2.0	T	F	p	h, z
Inga edulis var. edulis	20	0.5	T	F	s	h, z
Inga laurina (Sw.) Willd.	70	3.0	T	F	s	h, z
*† *Leucaena leucocephala* (Lam.) de Wit.	10	< 0.1	T	exotic		
**Libidibia ferrea* Mart.	30	1.5	T	exotic		
†*Machaerium opacum* Vogel	10	< 0.1	T	S, F	p, s	a
† *Mimosa claussenii* Benth.	10	< 0.1	Sb	S	p	t
Mimosa sp.	10	< 0.1	Sb			
Myroxylon peruiferum L. f.	50	2.9	T	F	s, c	a
Ormosia stipularis Ducke	10	0.3	T	F	s, c	t, z
Piptadenia gonoacantha (Mart.) Macbr.	10	1.5	T	F	p	t
† *Plathymenia reticulata* Benth.	20	2.0	T	S, F	p, s, c	a
Platypodium elegans Vogel	10	0.6	T	F	s	a
†*Pterodon pubescens* (Benth.) Benth.	10	< 0.1	T	S, F	s, c	a
Pterogyne nitens Tul.	10	0.4	T	exotic		
#Sclerolobium paniculatum Vogel	10	< 0.1	T	S, F	s	a,z
Senegalia polyphylla (DC) Britton. Rose	40	2.2	T	S, F	p	t
† *#Stryphnodendron adstringens* (Mart.) Coville	20	0.4	T	S	p, s	t
**Tamarindus indica* L.	10	0.1	T	exotic		
ICACINACEAE						
Emmotum nitens (Benth.) Miers	10	0.1	T	S, F	s	z
LAMIACEAE						
Aegiphila lhotskiana Cham.	10	1.3	T	S	p	z
LECYTIDACEAE						
Cariniana estrellensis (Raddi) Kuntze	30	1.0	T	F	s, c	a
LYTHRACEAE						
Physocalymma scaberrimum Pohl	10	0.6	T	S, F	p	a
MALVACEAE						
Apeiba tibourbou Aubl.	10	0.1	T	F	p, s	z
Chorisia speciosa A. St.-Hil.	20	0.9	T	F	s	a
Eriotheca gracilipes (K. Schum.) A. Robyns	20	0.3	T	S, F	s	a

†*Eriotheca pubescens* (Mart. & Zucc.) Schott & Endl.	10	0.7	T	S, F	s	a
†*Guazuma ulmifolia* Lam	30	2.4	T	S, F	p	a, z
†*Luehea divaricata* Mart.	30	1.8	T	F	p, s	a
Luehea grandiflora Mart.	10	0.1	T	F	s	a
Ochroma pyramidale (Cav. ex Lam.) Urb.	10	< 0.1	T	exotic		
Pseudobombax longiflorum (Martius & Zuccarini) A. Robyns	20	0.2	T	S, F	s	a
Pseudobombax tomentosum (C. Martius & Zuccarini) Robyns	20	1.1	T	S, F	c	a
Sterculia striata A. St.-Hil. & Naudin	20	1.0	T	F	s, c	z
MELASTOMATACEAE						
† *Tibouchina stenocarpa* (DC.) Cogn.	40	0.6	T	S, F	p, s	a
MELIACEAE						
Cedrela fissilis Vell.	20	1.6	T	F	s, c	a
Melia azedarach L.	20	1.0	T	exotic		
Swietenia macrophylla King	10	0.3	T	exotic		
MORACEAE						
Ficus benjamina L.	10	0.2	T	exotic		
Morus nigra L.	10	0.2	T	exotic		
MYRTACEAE						
Blepharocalyx salicifolius (Kunth) O. Berg	40	0.7	T	S, F	s	z
†*Eugenia dysenterica* DC.	30	0.9	T	S, F	s	z
Eugenia uniflora L.	10	0.2	T	exotic		
Psidium guianense Sw.	10	0.2	T	F	s	z
† *Psidium myrsinoides* O. Berg	10	0.8	Sb	S	s	z
NYCTAGINACEAE						
† #*Guapira noxia (Netto) Lundell*	10	< 0.1	T	S, F	p	z
OCHNACEAE						
Ouratea castaneifolia (DC.) Engl.	10	< 0.1	T	S, F	s	z
† #*Ouratea hexasperma (A. St.-Hil.) Baill.*	10	< 0.1	T	S, F	p	z
POLYGONACEAE						
Triplaris brasiliana Cham.	50	4.8	T	F	p	a
PROTEACEAE						
Grevillea robusta A. Cunn. ex R. Br.	10	< 0.1	T	exotic		
† #*Roupala montana* Aubl.	10	< 0.1	T	S, F	p, s	t, a
RHAMNACEAE						
Hovenia dulcis Thunb.	10	0.1	T	exotic		
Rhamnidium elaeocarpum Reissek	10	0.6	T	S, F	s	z
ROSACEAE						
Cydonia oblonga Mill.	20	0.1	Sb	exotic		
RUBIACEAE						

Alibertia macrophylla K. Schum.	10	0.5	T	S, F	s	z
Amaioua guianensis Aubl.	10	0.1	T	F	p, s	z
Genipa americana L.	60	3.1	T	F	s, c	h, z
RUTACEAE						
Zanthoxylum rhoifolium Lam.	10	1.1	T	F	p, s, c	z
SAPINDACEAE						
Dilodendron bipinnatum Radlk.	10	< 0.1	T	F	p	z
Magonia pubescens A. St.-Hil.	20	0.6	T	S, F	s	a
Sapindus saponaria L.	20	< 0.1	T	F	p, s	t, z
SOLANACEAE						
† *Solanum lycocarpum* A. St.-Hil.	10	0.4	Sb	S, F	p	t, z
URTICACEAE						
†*Cecropia pachystachya* Trécul	30	0.3	T	S, F	p	z

*allochthonous (exotic) species to Cerrado biome; †Species capable of spontaneously establishing in mine sites in Cerrado (CORRÊA et al., 2007); **Habit**: T (tree), Sb (schrub). **Habitat**: S (savanna), F (forest). **Ecological group**: p (pioneer), s (secondary), c (clímax). **Dispersal syndrome**: a (anemochory), t (autocory), h (hydrochory), z (zoochory); Sources: Durigan and Silveira (1999), Duboc (2004), Duboc and Guerrini (2007), Carvallho (2008), Mendonça et al. (2008b), Corrêa (2009).

DISCUSSION

The floristic survey in the revegetated mining sites confirmed the pattern of conspicuous use of autochthonous tree species, which were grouped into assemblies of low (13 species) and medium (62 species) species richness (BARBOSA et al., 2003; 2012). The average number of woody species planted in sites was of 26 ± 15, which is less than half the species richness naturally present in Cerrado's savannic formations - 65 to 162 woody species ha^{-1} (EITEN, 1994). A small proportion of individuals of allochthonous species were found in the revegetated sites (7.9%), which suggests the accidental use (DAJOZ, 1983; 2005) of 20 out the 21 allochthonous species identified. Only *J. macrantha*, an allochthonous species to the Cerrado, presented a consistent pattern of intentional use, as it appeared in 40% of the surveyed locations and was the sixth most abundant species among the 116 found in the study sites (Table 2).

The preferential use of native species complies with successional models for ecological restoration (ENGEL; PARROTTA, 2003; RODRIGUES et al., 2009; MARTINS et al., 2012). However, high diversity of plant species in initial communities of successional models is reported as the most ecologically efficient approach for ecosystem restoration, because an elevated species richness (80 - 90 species) may include species of various ecological groups, architectures and dispersal syndromes (BARBOSA et al. 2003; 2012; RODRIGUES et al., 2009). High diversity communities also provide high structural diversity, perches and food for animals, maximize interaction networks, ecological functions and ensure the growth and maintenance of ecological processes in revegetated sites (BARBOSA et al., 2003; 2012; ENGEL; PARROTTA, 2003; REIS et al., 2003; 2010; RODRIGUES et al., 2009). Among the surveyed sites, only one presented a number of species deemed close to ideal (80 - 90) in its initial plant community (BARBOSA et al. 2003) (Table 1).

Current successional restoration models are based on spontaneous changes in plant communities established by man (ENGEL; PARROTTA, 2003). Species diversity and planting density are factors that strongly influence ecological succession in recovering ecosystems that start off from planted communities (BARBOSA et al., 2003; 2102; LYONS et al., 2005; MOKANY et al., 2008). The reduced species richness in the study sites was accompanied by a low planting density (467 ± 222 plants ha^{-1}), which falls short to the lower limit of woody plant density in savannic formations of Cerrado (660 - 1,990 woody plants ha^{-1}) (EITEN, 1994; 2001). Based on species richness and plant density, the initial plant communities established in the mining sites are most probably ineffective for ecosystem restoration (BARBOSA et al., 2003; MOKANY et al., 2008; BARBOSA et al., 2012).

Biodiversity is an all-encompassing term and from the standpoint of ecosystem functioning, functional diversity rather than taxonomic diversity is the most relevant component of biodiversity (NAEEM, 2006). Ecological groups and dispersal syndromes of plant species are essential functional traits in ecological restoration projects (ENGEL; PAROTTA, 2003; KAGEYAMA et al., 2003; REIS et. al., 2003; BARBOSA; PIZO, 2006; ARAÚJO; REIS, 2009). Cerrado's autochthonous species from all ecological groups, dispersal syndromes, forest and savanna formations were found in the revegetated sites (Table 2). In this sense, the use of plant species with different traits and functions dominates the current restoration model applied to the mine sites in the Brazilian Federal District - BFD.

But the presence of species with varied functional traits alone may not guarantee the success of a restoration project (BARBOSA et al., 2003), because species evenness must portray the functional diversity of a plant assembly (MOKANY et al., 2008). Half (51%) of the 92 autochthonous species identified in the studied sites is dispersed by fauna but only 33.3% of sampled individuals were of zoochorous species, while 53.5% of individuals presented anemochorous dispersal syndrome. Thus, the number of plant species dispersed by animals in the revegetated sites does not reflect the intensity of interactions between fauna and flora due to the relatively low number of zoochorous individuals in the initial plant communities. Respect to the number of individuals, there was a fair proportion among plants of species from different ecological groups: the number of plants of pioneer and secondary species was similar, and 44.1% of sampled plants had more than one classification for ecological group (Table 2).

The mass ratio hypothesis argues that ecosystem processes in communities are largely shaped by the functional traits of dominant species (MOKANY et al., 2008). Abundance exerts a strong influence on species dominance (DAJOZ, 1983; 2005) and the 16 most abundant species in the sites, which were generally the most frequent species in the surveyed locations, amounted to 55% of the number of sampled individuals (Table 2). These species, which are likely to be shaping the evolution of the initial communities introduced in the sites, are trees, being 15 of them naturally occurring in forest formations of Cerrado and one species is allochthonous to the Cerrado biome - *J. macrantha*. Fabaceae and Bignoniaceae accounted for 52% of all sampled individuals (Table 2) and 11 species that were planted in more than half of the surveyed sites (Fi ≥ 50%) are among the 16 most abundant species. Based on values of frequency and abundance, there are 19 autochthonous species to the Cerrado biome and one allochthonous to it that have been systematically used in restoration projects of mine sites in the BFD.

Some studies claim that ecosystem functioning precludes the need for complete taxonomic diversity and can be maintained with a reduced number of species that present a large number of interspecific interactions (NAEEM, 2006; GUIMARÃES JR., 2009). Under such view, the use of low number of plant species for ecological restoration (Table 1) would not be a problem as long as the assembled plants provide a dense ecological web. However, tropical ecosystems are highly diverse to properly function with a small number of species (ANAND; DESROCHERS, 2004) and most species exists at low abundance levels in natural communities, like in Cerrado formations (EITEN, 1994; 2001; DAJOZ, 2005; LYONS et al., 2005). As such, the contribution of rare, keystone and less common species cannot be neglected in restoration projects because they aggregate as a whole measurable benefits to ecosystem functioning and diversity (LYONS et al., 2005). Rare and low abundance species also create ecosystem own identity, discriminate a community from other communities, and increase the various levels of diversity as a result (DAJOZ, 2005).

High diversity plant communities established on degraded sites has shown to be an effective concept for ecosystem restoration (BARBOSA et al., 2003; 2012; RODRIGUES et al., 2009). But researches have proposed the replacement of restoration concepts based on high diversity of species (BARBOSA et al., 2003; 2012) by the selection of a reduced number of species that could stimulate and accelerate ecological succession (REIS et al., 2003; 2010). Among the 92 autochthonous species identified (Table 2), *Inga* spp., *Cecropia pachystachya* Trécul, *Solanum lycocarpum* A. St.-Hil., and *Genipa americana* L. have been reported to stimulate succession due to their vegetative characteristics and the large number of animal species that use them (REIS et al. 2003; 2010; CORRÊA, 2009).

Generalist species for habitat, ecological group and dispersal/pollination syndrome exhibit interaction networks wider than specialist species (GUIMARÃES JR., 2009) and may be more adequate for restoration projects from the practical point of view. More than half of autochthonous species planted in the surveyed sites occur naturally in forest and savanna formations of Cerrado, 34% had more than one classification for ecological group, 51% interact with fauna to disperse and 1/5 of them are dispersed by more than one agent type

(Table 2). These generalist traits can facilitate the restoration of interspecific relationships in recovering ecosystems (GUIMARÃES JR., 2009), although richer and denser plant assemblies are necessary in the studied sites (BARBOSA et al., 2003; 2012; LYONS et al., 2005; RODRIGUES et al., 2009). The 92 autochthonous woody species currently in use in restoration projects (Table 2) can compose functionally better plant communities than those found in the revegetated sites.

The studied scenario has shown that more than 90% of the individuals sampled in the sites were arboreal, being half of them of species exclusively found in forest formations (Table 2). The plant communities studied showed only six autochthonous shrub species accounting for only 1.7% of the sampled individuals. Thus, the initial communities established in the sites may be driving succession to pathways that unlikely will end up in similar savanna ecosystems (ENGEL; PAROTTA, 2003) as intended for restoration projects (Brazilian Federal Law Nr. 9.985/2000). Tree plantation based on the use of autochthonous species is still the main model for ecological restoration in Brazil (MARTINS et al., 2012) and so it is in the BFD (CORRÊA, 2009). But tree species represent a part of the organisms in tropical ecosystems, including forests (ENGEL; PAROTTA, 2003; KAGEYAMA et al., 2003). Tree establishment in areas of grasslands and savannas is considered a common mistake of restoration projects in Cerrado (ENGEL; PAROTTA, 2003). A considerable portion of the current knowledge on forest restoration does not apply to grassland and savanna formations, which makes the restoration of these ecosystems even more challenging (DURIGAN, 2003; DURIGAN; ENGEL, 2012).

CONCLUSIONS

The initial plant communities established in the study sites resemble the standards recommended by successional restoration models, but the floristic diversity and plant density fall below the values considered ideal.

There were 92 autochthonous species in the study sites, but only 19 of them were systematically used in the revegetation works. Among the 92 species there are representatives of various habitats, ecological groups and dispersal syndromes, and this set can be rearranged into initial communities denser and functionally more diverse than those established in surveyed locations.

Plant communities were composed almost exclusively of arboreal species, and they will probably lead succession towards the formation of forest ecosystems where previously inhabited savanna formations.

Plant communities found in each site will hardly drive succession towards the original ecosystems, chiefly due to the adopted floristic composition, low species diversity and reduced planting density.

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RESUMO: A extensão minerada no Distrito Federal - DF é proporcionalmente cinco vezes superior à média nacional. A restauração das comunidades vegetais nesses locais é necessária e obrigatória, e o plantio de espécies lenhosas é prática comum de restauração. Dessa forma, este trabalho visou identificar e avaliar a composição florística lenhosa introduzida em jazidas mineradas no DF como meio de restaurar o ecossistema natural. O levantamento florístico nas áreas selecionadas foi realizado por meio da amostragem de grupos de cem indivíduos, até se obter suficiência amostral. Foram amostradas 4.500 plantas em dez jazidas, que abrigavam 92 espécies lenhosas autóctones e 21 alóctones. As comunidades vegetais levantadas eram formadas por 13 a 62 espécies, plantadas a uma baixa densidade - 467 ± 222 plantas ha^{-1}. O uso preferencial de espécies autóctones nos projetos de revegetação os assemelham aos padrões recomendados pelos modelos sucessionais de restauração, mas a diversidade florística e densidade de plantas nas comunidades iniciais estão abaixo dos valores considerados ideais. Entre as 92 espécies identificadas há representantes de variados habitats, grupos ecológicos e síndromes de dispersão. Portanto, essas 92 espécies podem ser reagrupadas em comunidades iniciais mais densas e diversas do que as verificadas nos projetos executados. As comunidades vegetais nos locais investigados eram predominantemente compostas por espécies arbóreas e tal padrão pode levar à formação de ecossistemas florestais onde antes havia formações savanânicas.

PALAVRAS-CHAVE: Restauração ecológica. Revegetação. Áreas mineradas. Cerrado.

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