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Original Paper

Anthropic disturbances as the main driver of a semideciduous seasonal forest fragment in Minas Gerais

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Abstract

The new environmental conditions imposed by disturbance events often create a mosaic of spots in different successional stages. Our objective was to describe the temporal variation of a semideciduous seasonal forest based on its anthropic disturbance history, verifying possible changes in forest dynamics and structure. We sampled the arboreal vegetation with a diameter at breast height (1.3 m above the ground; DBH) ≥ 5 cm in 15 permanent plots of 20 × 20 m where we performed four inventories (2003, 2005, 2007 and 2015). We observed a density decrease and a basal area increase, which indicates the late successional stage of the analyzed tree community. The phytosociological structure, richness and species diversity of the tree community did not show changes throughout the monitoring. However, the *Protium spruceanum* predominance may be a response to the environmental changes caused by the mining occurred in the area 250 years ago. The anthropic disturbances enduring influences make this type of work indispensable because it allows the ecological processes understanding, allowing a factual management of the forests by the its effective management and conservation.

Key words: floristic composition, forest dynamics, long-term ecological studies, phytosociological structure, tropical forest.

Resumo

As novas condições ambientais impostas por eventos de distúrbios criam um mosaico de manchas em diferentes estágios sucessionais. Nosso objetivo foi descrever a variação temporal de uma floresta estacional semidecidual em função do histórico de perturbação antrópica, verificando possíveis mudanças na dinâmica e estrutura da floresta. Nós amostramos a vegetação arbórea com diâmetro a 1,3 m do solo (DAP) ≥ 5 cm em 15 parcelas permanentes de 20 × 20 m onde realizamos quatro inventários (2003, 2005, 2007 e 2015). Nós verificamos uma diminuição da densidade e aumento da área basal, o que indica que a comunidade arbórea analisada se encontra em estágio tardio de sucessão. A estrutura fitossociológica, a riqueza e a diversidade de espécies da comunidade arbórea não apresentaram mudanças ao longo dos monitoramentos. Entretanto, o predomínio da espécie *Protium spruceanum* pode ser uma resposta às mudanças ambientais provocadas pela mineração que ocorreu na área há 250 anos. As influências duradouras dos distúrbios antrópicos tornam este tipo de trabalho imprescindível por permitir a compreensão dos processos ecológicos, possibilitando um gerenciamento factual das florestas pelo manejo e conservação efetivos.

Palavras-chave: composição florística, dinâmica florestal, estudos ecológicos de longa duração, estrutura fitossociológica, floresta tropical.

Introduction

The Human-biosphere interactions represent one of the current greatest threats to global biodiversity by changing the ecosystems dynamics around the world (Simberloff *et al.* 2013; Lewis *et al.* 2015). It is estimated that human activity had already changed 50% of terrestrial habitats in 1750 and reached values of 75% in 2000 (Ellis 2011). This global reality can be extended to the Brazilian Atlantic Domain through its deforestation

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history for conversion to agricultural areas and urban centers in the last three centuries (Haddad *et al.* 2015). The semidecidual seasonal forests call special attention in this context due to their degradation degree within the domain in relation to its other formations (Cunha & Silva-Júnior 2014; Ribeiro *et al*. 2009; Teixeira *et al*. 2009).

Although some disturbances are common events in nature and the ecosystems may present considerable resilience (Holling 1973), some of them can lead to durable changes in ecosystem status (Scheffer *et al.* 2001; Haddad *et al.* 2015) and increased vulnerability to degradation (Ghazoul *et al.* 2015; Seidl *et al.* 2016). As an example, the fragmentation disturbance may promote functional diversity deterioration (Benchimol & Peres 2015), increased tree mortality (Laurance *et al.* 2002), decreased carbon stocks (Pütz *et al.* 2014), species richness loss and floristic composition changes (Matos *et al.* 2017). On the other hand, the canopy gap disturbance is pointed out as decisive in species diversity maintenance by the modification in resources availability that drives ecological succession and dynamic cycles that favor biological heterogeneity (Bell *et al.* 2006; Machado & Oliveira-Filho 2010; Reyes *et al.* 2010).

The process of structural change that a specific forest suffers after a disturbance event that alters the biomass and organization of its tree community is called silvigenesis (Hallé *et al*. 1978). According to Oldeman (1983) in order to distinguish the regeneration phases of the tree community one of the main forms would be the analysis of the both density and basal area parameters. We then observe the suggestion of five phases: stability, in which there is no basal area and density change; degradation, showing a decrease in both basal area and density; initial construction with degradation, when there is a basal area decrease and density increase; initial construction, with both basal area and density increase; late construction, presenting basal area increase and density decrease.

Thus, from the perspective that ecosystem changes express a “nature sequence” (Túndisi 2013) and that a time is needed for their expression (Strayer *et al.* 1986), several studies with a temporal approach were developed in brazilian semideciduous seasonal forests (Oliveira-Filho *et al.* 1997; Nascimento *et al.* 1999; Schiavini *et al.* 2001; Paula *et al.* 2004; Appolinário *et al.* 2005; Oliveira-Filho *et al.* 2007; Paiva *et al.* 2007; Higuchi *et al.* 2008; Silva & Araújo 2009; Machado & Oliveira-Filho 2010; Mews *et al.* 2011). However, these studies only covered two monitoring periods which may had limited the results analysis (Abreu *et al.* 2014), since very short or very long intervals may not be capable of showing tree community responses to disturbance events (Phillips 1996; Rolim *et al*. 1999; Oliveira-Filho *et al.* 2007).

The vegetation monitoring by consecutive inventories allows the meticulous analysis of spatial patterns of mortality, recruitment, growth and floristic changes, which allows the understanding of the ecological processes that drive the communities (Corrêa & van den Berg 2002). In addition, it is also possible to understand the life strategies employed by plant populations (Schiavini *et al.* 2001) and to recognize population changes and community oscillations in response to disturbances or successional transformations (Baker *et al.* 2003). In this sense, our objective was to describe the temporal variation of the arboreal community of a Semideciduous Seasonal Forest according to its anthropic disturbance history along 13 years of monitoring and four sampling intervals.

Material and Methods

Study area

The study area is a tropical forest fragment located in municipality of Bom Sucesso, Minas Gerais state, Brazil, under the geographic coordinates of 21º09’31.05”S, 44º54’10.84”W and with 840 m of altitude. The vegetation there is classified as semideciduous seasonal forests (IBGE 2012), and is inserted in the Atlantic Domain *lato sensu* approach (Oliveira-Filho & Fontes 2000; Eisenlohr & Oliveira-Filho 2015). The region climate is classified as Köppen Cwb (De Sá Júnior *et al*. 2012). The area underwent gold ore extraction during the XVIII century which resulted in the removal of soil up to 10 meters deep. In addition, the fragment lost about 30% of its total area in 2002 as result of Funil Hydroelectric Powerplant construction. The fragment current area is approximately 58 ha of native tropical forest (Appolinário *et al.* 2005).

In 2003, 15 permanent plots of 20 × 20 m (0.6 ha) were allocated, arranged from the lake margin towards the fragment interior in a systematic way (Fig. 1). We measured each one living arboreal individuals with a diameter at 1.30 m from the ground (Diameter at Breast Height - DBH) ≥ 5 cm and identified by specialists and marked with numbered aluminum platelets. Individuals with more than one stem were measured when the sum of squares of CBHs (forming the quadratic Circumference) reached the individual inclusion

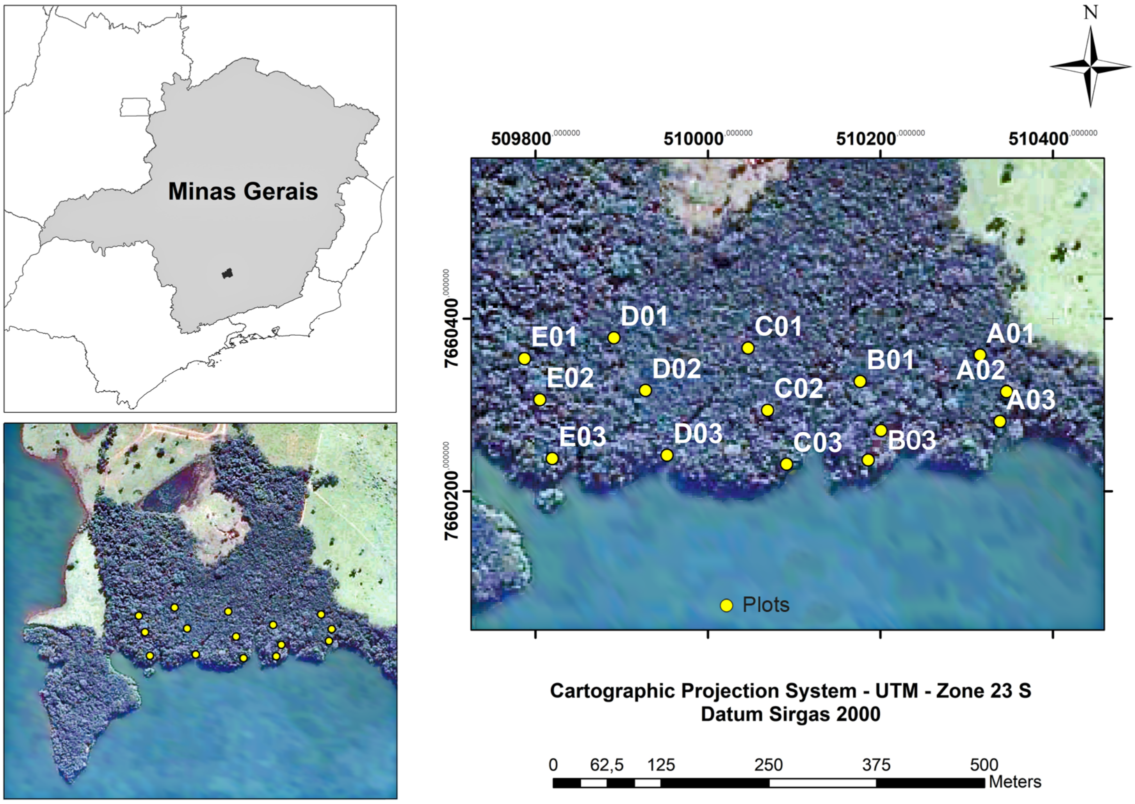

Figure 1 – Location of the fifteen permanent parcels in the Semideciduous Seasonal Forest located in Bom Sucesso, Minas Gerais state - Brazil. Source: Adapted from Google Earth, 2014.

criterion (Carvalho *et al.* 2007). In 2005, 2007 and 2015 teams of researches returned there for monitoring, when surviving individuals were remeasured, dead individuals were recorded and recruits (individuals that met the minimum inclusion criterion) were included.

Vegetation dynamic

The arboreal community dynamics was analyzed for the three sampling intervals (2003–2005; 2005–2007; 2007–2015) through the parameters: mortality (M) and recruitment (R) of individuals and loss (P) and gain (G) in the basal area, calculated according to the exponential expressions:

$$M = \{1 - [(N_0 - N_m)/N_0]^{1/t}\} \times 100 \qquad [1]$$

$$R = \{1 - [1 - (N_r/N_t)]^{1/t}\} \times 100 \qquad [2]$$

$$P = \left\{1 - \left[\left(Ab_0 - (Ab_d + Ab_m)\right)/Ab_0\right]^{1/t}\right\} \times 100 \qquad [3]$$

$$G = \{1 - [1 - (Ab_r + Ab_i/Ab_t)]^{1/t}\} \times 100 \qquad [4]$$

Where: t is the time interval among the inventories; N_0 and N_t are, respectively, the abundances of individuals in the beginning and final time; N_m is the number of dead trees; N_r is the number of recruited individuals; Ab_0 and Ab_t are, respectively, the initial and final basal areas of trees; Ab_m is the basal area of dead trees; Ab_r is the basal area of the recruited individuals; Ab_d and Ab_i correspond to the decrement and increment in basal area of surviving trees (Sheil *et al.* 1995, 2000). We disregard individuals of Arecaceae family in analysis because their lack of secondary growth (Welden *et al.* 1991).

Due to the temporal irregularity among intervals, the mortality and recruitment rates of the arboreal community were corrected according to Lewis *et al.* (2004), enabling the comparison of the inventories, being made by the formula:

$$\lambda' = \lambda \times t^{0,08} \qquad [5]$$

Where: λ' corresponds to the corrected dynamic rates; λ is equivalent to the dynamics rates observed; t refers to the time interval.

The tree community restructuring in terms of abundance and biomass (inferred from the basal area) was estimated by calculating the Doubling time and Half-life time (Korning & Balslev 1994) by the formulas:

$$T_{1/2} = \ln 0{,}5 / \ln\ (1 + M) \quad [6]$$

$$T_2 = \ln 2 / \ln\ (1 + R) \quad [7]$$

$$T_{1/2} = \ln 0{,}5 / \ln\ (1 + P) \quad [8]$$

$$T_2 = \ln 2 / \ln\ (1 + G) \quad [9]$$

In which: $T_{1/2}$ e T_2 are equivalent respectively to time intervals for Half-life and Duplication; M and R correspond to dynamic rates of mortality and recruitment of individuals; P and G correspond to dynamic rates of basal area loss and gain. The stability was obtained through the inequalities between the times, for which we adopt values more distant from zero as less stable (Korning & Balslev 1994).

We also performed the distribution of both abundance and basal area in four diameters classes for the four monitoring moments. We used the following classes: from 5 to 10, from 10.1 to 20, from 20.1 to 40 and greater than 40 cm in diameter. We defined increasing amplitude in order to reduce the effect of specimens accumulation in the lower classes (Oliveira-Filho *et al.* 2001).

Phytosociology and floristic composition

We performed the tree community description for the four monitoring moments through phytosociological analysis and floristic composition. Thus, we calculate the absolute and relative parameters of frequency, density and dominance, that formed the Importance Value (IV) (Ellenberg & Mueller-Dombois 1974; Brower & Zar 1984). In order to verify which species were more abundant over time, we developed abundance rank curves for the four inventories.

In order to evaluate aspects related to floristic composition, the richness and species diversity patterns of the tree community were analyzed graphically with estimates EstimateS software, version 8.2 (Colwell 2011). We developed then two graphs of rarefaction in relation to individual's abundance (Gotelli & Colwell 2011), one for species richness and other for Shannon diversity index (H'). We compared the curves through the confidence intervals (estimated value ± standard error) achieved by 999 randomizations per measurement. The Pielou equability index (J') was used to estimate the tree community uniformity (Brower & Zar 1984).

Results

Vegetation dynamic

The individual's mortality rate was higher than recruitment rate in all considered intervals and presented long instability periods. This imbalance in favor of mortality resulted in the occurrence of shorter half-live times and longer doubling times. However, half-life and doubling times were more balanced in the period 2005–2007 due to more similar numbers of dead individuals and recruits, which resulted in a stability value close to zero (Tab. 1). For the basal area, gains were greater than losses at all intervals considered. This imbalance in favor of the basal area gain rate resulted in longer half-live times and shorter doubling times. Although this pattern also occurs in the other measurements, in the period of 2003–2005 the half-life time and the doubling time presented close values and thus more balanced (Tab. 1).

The observed species abundance disposition in diametric classes presented the reversed exponential (J-inverted) form in all inventories (Fig. 2a), characterized by low values in the upper classes that increase towards the lower classes. The area basal distribution classes presented a normal pattern (Fig. 2b).

Phytosociology and floristic composition

We recorded 1.341 individuals and 142 species over the 13 years of monitoring, of which 359 individuals (27%) belonging to the Burseraceae, 188 (14%) to Fabaceae, 161 (12%) to Myrtaceae and 108 individuals (8%) to Rubiaceae, in sequence. The other families reached no more than 5% of representation of the total tree community, seven of them consisting of only one individual (Asteraceae, Cannabaceae, Lamiaceae, Malpighiaceae, Sapotaceae, Symplocaceae and Theaceae).

For the phytosociological structure, the species that stood out hierarchically in IV terms in 2003 were *Protium spruceanum* (Benth.) Engl., *Copaifera langsdorffii* Desf., *Protium widgrenii* Engl., *Myrcia pulchra* (O.Berg) Kiaersk., *Ixora brevifolia* Benth., *Clethra scabra* Pers.,

Table 1 – Dynamics parameters for the three periods (2005, 2007 and 2015) in the Semideciduous Seasonal Forest fragment located in Bom Sucesso, Minas Gerais state - Brazil.

	2005	2007	2015
Mortality rate (%.yr^{-1})	3.00	2.22	3.62
Recruitment rate (%.yr^{-1})	1.58	1.95	2.46
Half-life time N (yr)$^{-1}$	23.44	31.60	19.48
Doubling time N (yr)$^{-1}$	44.24	35.81	28.57
Stability N (yr)$^{-1}$	20.8	4.21	9.09
Loss rate (%.yr^{-1})	3.42	2.85	1.96
Gain rate (%.yr^{-1})	3.55	5.21	2.74
Half-life BA (yr)$^{-1}$	20.63	24.64	35.63
Doubling time BA (yr)$^{-1}$	19.86	13.64	25.62
Stability BA (yr)$^{-1}$	0.77	11.00	10.01

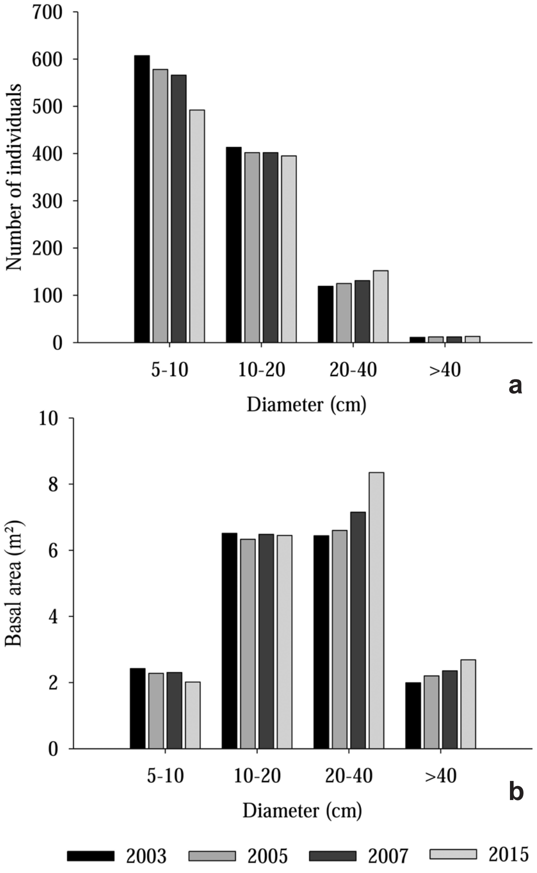

Figure 2 – a-b. Classes of diameters in the four inventories (2003, 2005, 2007 and 2015) in the Semideciduous Seasonal Forest fragment located in Bom Sucesso, Minas Gerais state, Brazil – a. by observed abundances; b. by registered basal area.

Machaerium villosum Vogel, *Trichilia pallida* Sw., *Lamanonia ternata* Vell. and *Siphoneugena crassifolia* (DC.) Proença & Sobral (Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.9892379.v1>). The species *Protium spruceanum* (Benth.) Engl., *Copaifera langsdorffii* Desf. and *Protium widgrenii* Engl. did not change their position in the IV rank in the other inventories, whereas *Ixora brevifolia* Benth., *Clethra scabra* Pers., *Machaerium villosum* Vogel, *Trichilia pallida* Sw. and *Siphoneugena crassifolia* (DC.) Proença & Sobral alternated their hierarchical position without leaving the top ten species (Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.9892379.v1>). We observed the predominance of *Protium spruceanum* (Benth.) Engl. and *Copaifera langsdorffii* Desf. in all the inventories, even verifying an abundance reduction of both that was more discreet in *Copaifera langsdorffii* Desf. (Fig.3).

The low IV species underwent some changes in their hierarchical position throughout the monitoring events. Occurred the outputs of *Erythroxylum citrifolium* A.St.-Hil., *Ocotea laxa* (Nees) Mez and *Myrcia guianensis* (Aubl.) DC. in 2005; *Lithrea molleoides* (Vell.) Engl., *Erythroxylum pulchrum* A.St.-Hil., *Dalbergia frutescens* (Vell.) Britton, *Casearia decandra* Jacq. and *Allophylus edulis* (A.St.-Hil., Cambess. & A.Juss.) Hieron. *ex* Niederl. in 2007; *Ocotea velutina* (Nees) Rohwer, *Miconia latecrenata* (DC.) Naudin, *Myrsine guianensis* (Aubl.) Kuntze,

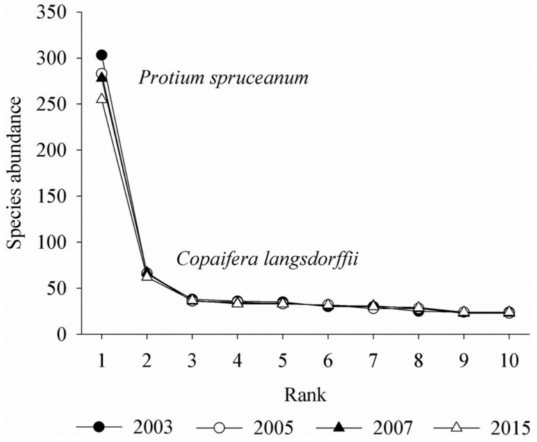

Figure 3 – Tree species abundance ranks over 13 years of monitoring conducted on a Semideciduous Seasonal Forest located in Bom Sucesso, Minas Gerais state, Brazil.

Ocotea odorifera (Vell.) Rohwer and *Vitex polygama* Cham. in 2015 (Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.9892379.v1>). On the other hand, was first recorded: *Miconia trianae* Cogn., *Ocotea odorifera* (Vell.) Rohwer and *Allophylus edulis* in 2005; *Vernonanthura divaricata* (Spreng.) H.Rob., in 2007; *Annona coriacea* Mart., *Annona* sp., *Senna multijuga* (Rich.) H.S.Irwin & Barneby, *Ficus enormis* Mart. *ex* Miq., *Calyptranthes clusiifolia* O.Berg, and two undetermined species (Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.9892379.v1>) in 2015. The last monitoring event was the one with higher number of new species recorded.

The lack of changes over time in species richness and diversity was observed through rarefaction curves (Fig. 4a-b), since the confidence intervals of the estimates from the randomizations were overlapped. Similar behaviors were recorded for the Pielou equability (J), which was 0.75 in 2003, 0.76 in 2005 and 0.77 for both 2007 and 2015.

Discussion

The found tree community temporal pattern of decreasing density and increasing basal area is a worldwide trend of tropical forests (Lewis *et al.* 2009). In relation to phytosociological structure and floristic composition, Atlantic semideciduous seasonal forests commonly present 33% to 40% of species with abundance varying from one to two individuals (Paula *et al.* 2004) and both dominance and density concentrated in a few populations (Fonseca *et al.* 2013).

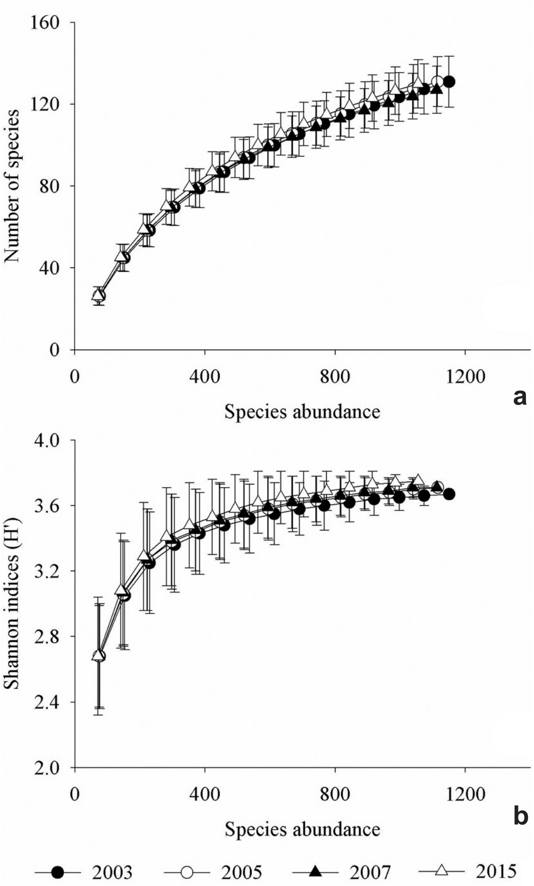

Figure 4 – a-b. Rarefaction curves for the tree community over 13 years of monitoring conducted on a Semideciduous Seasonal Forest located in Bom Sucesso, Minas Gerais state, Brazil – a. for species number; b. for Shannon diversity index.

Vegetation dynamic

Imbalances between recruitment rates and mortality of individuals, as well as rates of loss and gain of the basal area, are common for fragments of semideciduous tropical forests and are always related to the silvigenic silvicultural cycle of forests reconstruction (Oliveira-Filho *et al.* 2007; Machado & Oliveira-Filho 2010; Mews *et al.* 2011). In addition, different disturbances such as droughts, landslides, floods, fire, storms, canopy gaps opening, and human interventions (Condit *et al.* 1995; Damasceno-Junior *et al.* 2004) are generally the main agents in forest dynamics (Condit *et al.* 1995; Baker *et al.* 2005).

The general pattern of decreasing abundance and increasing basal area is a trend of tropical forests in post-disturbance recovery (Crow 1980; Lewis *et al.* 2009). In this situation, there is a high mortality rate in smaller diameter classes (Felfili 1995; Kellman *et al.* 1998) and a basal area increase of individuals of the largest diameter classes (Werneck & Franceschinelli 2004). These two situations are justified by the low competition capacity of individuals of smaller diameter classes in relation to large arboreal individuals occupying higher strata and the greater longevity (Felfili 1995; Mews *et al.* 2011). The competition influence occurs through resources availability changes by disturbances that promote competitive interactions in site (Reyes *et al.* 2010). Thus, the interaction between arboreal individuals in a site can lead to high individuals mortality and basal area increase, characterizing a moment of forest community self-thinning (Higuchi *et al.* 2008).

Phytosociology and floristic composition

The most representative families are typical of structure and composition of Sub-Montana and Montana Atlantic Forests of Brazilian Southeastern region (Oliveira-Filho & Fontes 2000), with the exception of Burseraceae. The Burseraceae great expression is due to *Protium spruceanum,* which has its occurrence related to Atlantic and Amazon Rain forests and to Cerrado riparian forests (Rodrigues *et al.* 2003), being classified as a dominant species in well or poorly drained environments and of good fertility (Marques *et al.* 2003; Silva *et al.* 2007; Teixeira *et al.* 2008). This high representativeness is probably associated the anthropic disturbance occurred in the 18th century and the successional advance of the forest. This disturbance promoted stirring the soil up to 10 meters deep (Appolinário *et al.* 2005) and created deep ravines along the fragment that allowed water inlet (Appolinário *et al.* 2005), thus creating humid sites suitable for the establishment and development of this species.

The high *Copaifera langsdorffii* representativeness is probably related to its generalist habitat behavior (van den Berg & Oliveira-Filho 1999). In the study area, the condition of higher humidity does not affect all plots and the general character of this species makes it possible to occur in flooded environments (Lobo & Joly 2000; Brito *et al.* 2006) and not flooded (Sampaio *et al.* 1997; Felfili 1998). Besides, this species is identified as one of the most abundance species in most forest fragments in the Center-South region of the state of Minas Gerais (Oliveira-Filho *et al.* 1994). In addition, the ripening of the forest provides a decline in the availability of light that favors the establishment of species constituting more advanced serials, such as *Protium spruceanum* (Connell & Slatyer 1977; Amaral *et al.* 2013) and *Copaifera langsdorffii* (Nunes *et al.* 2003; Aquino & Barbosa 2009).

In contrast, the species that left and entered the sample showed abundances ranging from one to two individuals. The characteristic of there are few very abundant species and many little abundant species is considered common in tropical forests (Hartshorn 1980; Felfili & Felfili 2001). Species with few individuals may reappear in other moments by migration, seed bank individuals recruitment, seedlings growth or by the growth of individuals that did not meet the minimum inclusion criteria in previous inventories (Swaine *et al.* 1987).

The behaviors demonstrated by the rarefaction curves for both species richness and diversity show a stability increase in relation to floristic composition oscillations patterns, which confirm the phytosociological structure (Gotelli & Colwell 2011). The absence of variation in both richness and Shannon diversity index occurs due to the compensation between the number of species with low abundance they arrived and leaved the tree community (Paiva *et al.* 2007). The value of Pielou equability (J) is justified by the concentration of both dominance and density in few populations (Gonzaga *et al.* 2008; Moreira & Carvalho 2013).

The results suggest the mining influence on the formation of community patterns, selecting species through the creation of new conditions. However, there were no differences in temporal behavior that could be attributed to the past occurrence of this disturb. We believe that the time elapsed since the mining closure was enough for the community to reach a climax stage associated with the new conditions (Whitaker 1974), in which a structure and composition molded by the disturbance vary in time due to the forest dynamics characteristic oscillations (Korning & Balslev 1994; Carvalho & Felfili 2011). Thus, the community would have reached a dynamic equilibrium status characterized by stability of general patterns of structure and composition, added to temporary fluctuations of biomass and entry and exit of species.

Our work was one of the first to monitor Atlantic semideciduous seasonal forests through successive inventories. Thus it contributes to recognition of tree community oscillations and to the understanding of successional transformations and population changes resulting from anthropic disturbances effects (mining) by community dynamics, phytosociological structure and floristic composition. Studies with these properties are essential because they offer a substantial contribution to conservation science and to implementation of effective forest ecosystem conservation policies, since anthropogenic disturbances show long-term effects (Haddad *et al.* 2015).

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