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Post-fire recovery of savanna vegetation from rocky outcrops

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ABSTRACT

The degree of stability of the Cerrado following burning is widely discussed in literature. However, little is known about the effects of fire on the resilience of savanna formations from rocky outcrops, known as "cerrado rupestre". We tested the hypothesis that floristic, structural, and dynamics parameters of a tree–shrub cerrado rupestre community have high stability following fire. We sampled the woody vegetation (plants with trunk diameter equal or larger than 3 cm as measured 30 cm above ground) in ten 20 m × 50 m plots before (2008) and after (2009, 2010, 2011, and 2012) an accidental burning in September 2008. Species richness and composition did not change. However, plant density and basal area were reduced after the fire, but began to increase in the second year after the fire. Recruitment rate was higher than mortality. Basal areal and half-life also increased, while time of duplication decreased. The community recovered relatively well from the fire, presenting high resilience to burning. However, it seemed not to have attained a complete restoration to the state prior to the fire after four years.

Introduction

Fire is a frequent and natural disturbance in formations of the Brazilian Cerrado (Coutinho, 1982; Klink and Machado, 2005; Moreira, 2000), owing to the seasonal rainfall (Miranda et al., 1996) and high amounts of inflammable herbaceous and grassy vegetation (Miranda and Sato, 2005; Miranda et al., 1993, 1996). These savanna formations, also known as cerrado *sensu stricto* (Ribeiro and Walter, 2008), have strong stability following fire, due to the high capacity of the floristic and structural properties of the vegetation to maintain (resistance) and recover (resilience) themselves after fire (Archer et al., 1996; Coutinho, 1990; Felfili et al., 2000). Several species typical of savanna formations tolerate fire (Hoffmann, 2005; Hoffmann et al., 2012; Moreira, 2000), due to several adaptive characteristics, namely: suberized trunks, high investment in root biomass (Hoffmann and Franco, 2003), underground organs, such as xylopodes, and low nutritional demand. Suberized trunks provide thermal protection against high temperatures (Hoffmann, 2005; Hoffmann et al., 2012), while a high investment in root biomass leaves a high stock of carbohydrates for sprouting (Hoffmann, 2005). Underground organs can develop right after the fire (Coutinho, 1990; Hoffmann, 1998), while the low nutritional demand of those plants allow for a high recovery following burning (Miranda et al., 2004).

There are several positive effects of burning on the Cerrado plant communities, for instance, an increase in soil nutrient availability (Frost and Robertson, 1987), flowering (Munhoz and Felfili, 2007), fructification (Conceição and Orr, 2012), dispersal (Coutinho, 1977), and seed germination (Tothill, 1969). However, the increase in burning frequency, intensity, and duration can also cause negative effects (Fiedler et al., 2004; Ribeiro et al., 2012), such as increase in mortality rates (Silva et al., 1996) – especially in the first diameter classes (Sato and Miranda, 1996) – decrease of the recruitment of woody species (Hoffmann, 2000), changes in floristic composition (Cochrane and Schulze, 1999; Moreira, 2000; Woods, 1989), and increase in the abundance of grassy species and their seed bank. The decrease in the recruitment of woody species leads to a reduction in species density, richness, and diversity (Coutinho, 1990). These factors reduce the survival of woody species seedlings and bring about changes in the floristic composition due to competition effects (D'Antonio and Vitousek, 1992).

The cerrado rupestre formation differs from the cerrado *sensu stricto* formation mainly due to its occurrence on shallow soils (Litholic Neosol) and on rocky outcrops, which are usually steep and

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hilly (Reatto et al., 2008). The conservation of cerrados rupestres is important for species of other cerrado formations, not only because of their species richness and endemism (Oliveira-Filho and Fluminhan-Filho, 1999), but also for their shallow and stony soil, which prevent intensive agriculture and livestock raising activities (Klink and Machado, 2005; Miranda et al., 2007). As a result, the cerrado rupestre functions also as refuge for plants of the cerrado *sensu stricto* (Gomes et al., 2011; Lenza et al., 2011; Santos et al., 2012).

The assessment of population dynamic parameters of plant communities, especially mortality, recruitment, and growth rates (Corrêa and Van Den Berg, 2002; Henriques and Hay, 2002; Oliveira-Filho et al., 1997), is crucial to understand in detail causes and consequences of long-term changes of the vegetation (Schiavini et al., 1998). Additionally, such data can allow predictions of responses of the vegetation to global climate changes (Condit et al., 1992). Recently, several systematic studies about floristics and the structural composition of the cerrado rupestre vegetation have been made (Abreu et al., 2012; Amaral et al., 2006; Gomes et al., 2011; Lenza et al., 2011; Lima et al., 2010; Maracahipes et al., 2011; Miranda et al., 2007; Moura et al., 2007; Pinto et al., 2009; Santos et al., 2012). But little is known about the effects of burnings on the resilience of the woody vegetation there and the best practices to manage wildfires. This lack of information results in part from the difficulty to predict when and where the burnings will occur, making large-scale studies impossible.

It is crucial to understand the fire effects on the ecological dynamics of the cerrado vegetation, given the increase in fire frequency in this vegetation over the past decades. This kind of study provides information that could be used to develop strategies for fire management. With regard to such aims we assessed the effect of fire on the floristic, structural, and population dynamic parameters of the cerrado rupestre woody vegetation. Specifically, we stated and tested the following hypotheses: (1) the floristic parameters are maintained after the fire; (2) the structural parameters will recover to the status that existed before the fire; and (3) the community will regenerate following burning, due to its morphological characteristics that provide resistance to disturbances caused by fire.

Materials and methods

Study area

The Bacaba City Park is located in Nova Xavantina, Mato Grosso (14°41′ S; 52°20′ W). Despite of being a protected area since 1995 (Abad and Marimon, 2008), there are relatively frequent (e.g., in 2001, 2003 and 2008) accidental burnings in this area (B.S. Marimon; pers comm.). Even though the two first burnings destroyed only part of the Park, the third destroyed nearly 90% of the area, including forest vegetation types, such as savanna forest ("cerradão") and gallery forests, as well as open savannas, such as the cerrado rupestre. The cerrado rupestre in the Park is found around quartzitic rocky outcrops ("Litholic Neosol", Marimon et al., 1998; Marimon-Junior and Haridasan, 2005) at altitudes ranging from 339 to 406 m. The regional climate is Aw, tropical savanna, according to Köppen's classification (Peel et al., 2007), with two well-defined seasons: one dry and cold (April to September) and another rainy and warm (October to March; Silva et al., 2008). The annual average rainfall is about 1520 mm and the average temperature is around 24.8 °C (Abad and Marimon, 2008; Marimon-Junior and Haridasan, 2005).

We established 10 permanent plots of 20 m × 50 m, following Philip (1994), with a distance of at least 50 m from each other. The plots were arranged perpendicularly to the slopes of the rocky outcrops. Altogether, the area sampled comprised 1 ha. The plots were sampled in January 2008 (see Maracahipes et al., 2011). Later in this year there was an accidental wildfire (in September 2008) that destroyed the whole sampled area. We re-sampled the vegetation in the same plots as before in four censuses in January 2009, 2010, 2011 and 2012 using the same methodology used by Maracahipes et al. (2011).

We measured the diameters of all live and dead individuals with DAS_{30cm} (diameter at ground level) ≥ 3 cm. We identified the species by comparing them with herbaria vouchers from the NX Herbarium (State University of Mato Grosso, Nova Xavantina), and by consulting specialized literature. We used the APG III (2009) system for the family classification and confirmed the taxa in the List of Species of Brazilian Flora 2013 (http://floradobrasil.jbrj.gov.br/2013). All botanical material collected is deposited at the NX Herbarium.

Data analysis

We used a Detrended Correspondence Analysis (DCA; Kent and Coker, 1992; McCune and Grace, 2002) to ordinate the site by species matrix. To test for differences between the scores of axis 1 and 2, we used repeated-measures Multivariate Analysis of Variance (MANOVA), followed by Tukey's post hoc test (Zar, 2010).

We calculated density (ind. ha^{-1}) and basal area ($m^2\ ha^{-1}$) of each plot in each census using the software Mata Nativa 2.0 (Cientec, 2006). We used repeated-measures ANOVA, followed by Tukey's post hoc test (Zar, 2010) to compare the density and basal area between censuses. We determined the horizontal structure of the vegetation by the frequency distribution of individuals in diameter classes, using the following formula to calculate interval increment between classes (Spiegel, 1976): $I = A/K$, where A is the amplitude and "K" is a constant defined by the Sturge algorithm: $1 + 3.3 \times \log_{10} n$, where n is the total number of individuals sampled. We used repeated-measures MANOVA, followed by a Tukey's post hoc test (Zar, 2010) to compare each class of diameter between censuses. A Friedman's non-parametric test (Zar, 2010) was used to compare the density of individuals per plot between the years for species with more than 20 individuals in at least one of the years.

We calculated the population dynamic parameters (Table 1), such as average annual mortality rate and recruitment, half-life, and doubling time, and assessed the density and basal area of dead individuals and recruits. The half-life is the amount of years it takes for a community to reduce by 50% the number of individuals or basal area. The doubling time is the amount of years it takes to duplicate the number of individuals in a community. Stability values close to zero represent a stable community. Reposition time indicates how dynamic a community is. The lower this value, the more dynamic the community. We used a Friedman's test to compare these parameters between censuses (Zar, 2010). All analyses were performed in the R software (R Development Core Team, 2009).

Results

Floristic parameters

The species richness recorded before the fire in January 2008 (n = 85 species) decreased by 8.2% in January 2009 (n = 78) shortly after the fire, and slightly increased in the following years (2010 = 79; 2011 = 80; 2012 = 80). However, there were no significant differences in floristic composition between the years (F = 0.09; p = 0.99) when we compared DCA scores for the two axes. There were species colonizing and going locally extinct throughout the years (Table 2). For example, *Aspidosperma subincanum* (one individual in 2008), *Diospyros hispida* (two), *Eugenia punicifolia* (one),