# Abundance of epigaeic arthropods in a Brazilian savanna under different fire frequencies

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ABSTRACT. Fire is a major determinant of structure and dynamics in savannas, and the rapid increase of human activities in this biome has changed the natural burning regime. The effects of fire on the fauna of the cerrado (Brazilian savanna) are still poorly understood, and studies comparing sites frequently and infrequently burned are scarce. In this study, the abundance of epigaeic arthropod orders and trophic guilds was assessed in cerrado sites located in the Brazilian Central Plateau that were subjected to three burning frequencies: frequent (HighFi), intermediary (MidFi), and infrequent (LowFi). In general, we found a positive relationship between the abundance of epigaeic arthropods and fire frequency. When arthropods were analyzed by orders, the abundance of Collembola and Orthoptera was lower in the LowFi site, while for Hemiptera, it was higher in the MidFi site. No significant differences were found for Hymenoptera, Coleoptera, and Araneae. The abundance of detritivores and herbivores decreased from HighFi to LowFi, but did not change significantly for omnivores and predators. These results indicate that some arthropod groups may not only be resilient to fire effects, but actually might benefit from fire effects in the cerrado. Characterizing arthropod responses to burning frequency at high taxonomic or functional levels is important for applied studies. Based on the results of the current study, springtails and ants seem to be particularly appropriate focal groups for further exploratory studies on the effects of fire at the species level.

KEY WORDS. Arachnida; burning; cerrado; Insecta; trophic guilds.

Originally covering around 2 million km², the Brazilian cerrado is the largest savanna region in the Americas (GOTTSBERGER & SILBERBAUER-GOTTSBERGER 2006). The fauna and flora of this region are the most diverse of the world's savannas (MITTERMEIER et al. 2004), comprising about 7,000 vascular plant species (CASTRO et al. 1999) and an estimated 90,000 insect species (DIAS 1992). However, current threats to its biodiversity are daunting, because 70% of the region has already been converted into disturbed landscapes (MITTERMEIER et al. 2004).

Fire is a major natural disturbance in the cerrado that determines its structure and dynamics and influences vegetation physiognomy and plant composition (MOREIRA 2000), soil temperature (MIRANDA et al. 2002), and plant nutrient use efficiency (NARDOTO et al. 2006). Fire stimulates the resprouting, germination, flowering and fruiting of many fire-adapted plant species (COUTINHO 1990, MIRANDA et al. 2002, GOTTSBERGER & SILBERBAUER-GOTTSBERGER 2006), which may in turn foster animal populations that are directly or indirectly dependent on these resources. However, the rapid occupation of the cerrado region has increased the fire frequency to the point that fires are now the rule during the dry season, what has brought negative consequences for flora and fauna (RAMOS-NETO & PIVELLO 2000, MIRANDA et al. 2002). Frequent fires may harm animals and plants directly, by causing massive mortality, or indirectly, by changing local hydrology, nutrient availability, and soil properties (NEARY et al. 1999, NARDOTO et al. 2006). For this reason, fire is becoming a threat to the biodiversity of the cerrado in many locations (KLINK & MACHADO 2005, DURIGAN et al. 2007).

Occupying various habitats and playing essential ecological roles in virtually every terrestrial ecosystem, arthropods are fundamental components of earth's biodiversity (WILSON 1987, YORK 1999, LAVELLE *et al.* 2006). Arthropods play three broad ecological roles in tropical savannas: 1) they are particularly important drivers of soil properties and processes; 2) they regulate plant populations through herbivory, seed predation, and other direct interactions with plants; and 3) they are drivers of consumer food webs as competitors, predators, parasites, and prey (YORK 1999, ANDERSEN *et al.* 2003). Despite the great diversity and functional importance of savanna arthropods, they have received little attention by researchers working in the cerrado (see OLIVEIRA & MARQUIS 2004) and other tropical savannas (ANDERSEN *et al.* 2003). Of the few studies conducted in the cerrado so far, most have dealt with one or a few taxonomic groups and have reached different conclusions about fire effects (e.g., MORAIS & BENSON 1988, PRADA *et al.* 1995, SEYFFARTH *et al.* 1996, VIEIRA *et al.* 1996, MARINI-FILHO 2000, MARTINS *et al.* 2004, MORAIS *et al.* 2007, KNOECHELMANN & MORAIS 2008). Therefore, understanding the general responses of arthropods to different fire regimes remains a challenge.

This study investigated the abundance of epigaeic arthropod orders and trophic guilds under different fire frequencies in a cerrado reserve. Most of the epigaeic fauna uses the leaf litter layer, which provides a significant amount of fuel for wildfires in this ecosystem (HOFFMANN 1996, MIRANDA *et al.* 2002). In addition, many orders of insects, such as Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Hymenoptera, and Diptera, are important herbivores in savannas, especially those savannas on infertile soils and with few herbivore mammals (ANDERSEN *et al.* 2003). Because these characteristics apply to the Brazilian cerrado, we expect to find changes in arthropod abundance under different fire conditions. However, since many different responses to fire have been observed within and between arthropod orders (e.g., WARREN *et al.* 1987), we did not make predictions for specific taxonomic groups. Nevertheless, for trophic guilds, we expected that: 1) detritivore abundance should be negatively affected by fire due to the decrease in litter biomass (CHEN & WISE 1999); 2) herbivore abundance should increase in frequently burned sites in response to plant regrowth (ANDERSEN *et al.* 2003); 3) omnivore abundance should not be affected by fire due to their dietary flexibility; and 4) predator abundance should be positively affected by fire due to a general increase in prey abundance. Ultimately, this study provides information that may be useful to determine indicators of disturbance caused by fire in this cerrado reserve.

## MATERIAL AND METHODS

This study was carried out in the Parque Nacional das Emas, a cerrado reserve located in the Brazilian Central Plateau (17°49'-18°28'S, 52°39'-53°10'W). This park is one of the largest and best preserved cerrado reserves; it was included by UNESCO (2001) in the World Natural Heritage List as one of the sites containing the fauna, flora, and key habitats that characterize the cerrado (RAMOS-NETO & PIVELLO 2000, BATALHA & MARTINS 2002, RODRIGUES *et al.* 2002, FRANÇA *et al.* 2007). The region has a humid tropical climate with wet summers and dry winters (Aw of KÖPPEN 1948). The dry season extends from June to August and the wet season extends from September to May. Annual rainfall varies from 1200-2000 mm, concentrated from September to March, and mean annual temperature is 24.6°C (RAMOS-NETO & PIVELLO 2000). The topography is generally flat, and the altitude varies from 820 to 890 m (RAMOS-NETO & PIVELLO 2000).

The park area was used for cattle ranching in the past, and annual dry season burnings were used to promote pasture regrowth (RAMOS-NETO & PIVELLO 2000). Since the park delimitation in 1984, cattle are no longer allowed inside it and a fire exclusion policy has been established (RAMOS-NETO & PIVELLO 2000). As a consequence, uncontrolled wildfires have occurred every 3-4 years, burning on average 80% of the total area of the reserve each time they occur (RAMOS-NETO & PIVELLO 2000, FRANÇA *et al.* 2007). Thus, since 1994, approximately 10 km² of preventive firebreaks (30 m wide) are burned annually in the dry season to prevent the spread of eventual fires (FRANÇA *et al.* 2007).

In 1994, a lightning fire burned more than 90% of the Parque Nacional das Emas (RAMOS-NETO & PIVELLO 2000, FRANÇA *et al.* 2007). That year was considered "ground zero" for examining the effects of burning on arthropods in this study. Arthropods were sampled at three sites with different burning frequencies from 1994 to 2006: a firebreak burned annually (12 fire events since 1994, last burning in 2005), another firebreak burned five times in this period (1996, 1999, 2001-2003), and a site unburned since 1994. Hereafter these sites will be referred as 'HighFi', 'MidFi', and 'LowFi', based on their burning frequency. This type of fire management has been undertaken every dry season when a fire brigade uses flamethrowers to burn all of the biomass within the firebreaks. Except for the firebreaks, no burning has occurred in adjacent areas since 2003. Because a true replication of burned areas was not possible within the study site, due to logistical, bureaucratic, and ethical reasons, a natural experiment approach was adopted with sampling being conducted at sites with a well-documented history of burning (see PARR & CHOWN 2003). Additionally, the three sites were close enough to each other to reduce the probability of confounding factors (e.g., different land use in the past, soil type, and vegetation composition). Although this approach limits the degree of generalization from the findings and does not solve the statistical problem of a lack of true replicates for the fire treatments, it increases the likelihood that significant differences between sites are due to different fire frequencies (PUCHETA *et al.* 1998) allowing us to discuss the patterns found within the reserve.

In each of these sites, twenty pitfall traps were randomly placed at least 10 m apart from each other along 2.5 km transects (one per site). Pitfall traps were 500 ml plastic cups leveled with the soil surface, with a 5.8 cm opening and 10.5

cm depth, that were protected from direct rainfall by a circular polystyrene shield placed above them. Traps were filled with ca. 200 ml of 30% propylene glycol, 0.1% formaldehyde, and a few drops of detergent. Pitfall traps were kept open from May 8 to May 12, 2006 at the end of the rainy season and the beginning of the dry season when herbaceous plant productivity is higher (CIANCIARUSO & BATALHA 2009). All collected arthropods were preserved in 70% ethanol.

Arthropods were sorted to different taxonomic levels, from genera (e.g., ants and some Coleoptera) to order (e.g., Araneae and Scutigeromorpha). This sorting was necessary to place them into four coarse trophic categories: detritivores, herbivores, omnivores, and predators (based on MARINONI *et al.* 2001, SILVESTRE *et al.* 2003, TRIPLEHORN & JOHNSON 2005). Leaf-cutting ants were grouped with the herbivores. Ant abundance was based on the frequency of each species in the traps. Spider specimens were deposited in the collection of Instituto Butantan (São Paulo, Brazil), ants were deposited in the Museu de Zoologia, Universidade de São Paulo (São Paulo, Brazil), and the remaining taxa were deposited in the Museu de Zoologia, Universidade Estadual de Campinas (Campinas, Brazil).

Differences in the abundance of each order and trophic group among sites were analyzed using a one-way randomized analysis of variance, appropriate for unreplicated designs (PAYNE 2006). When significant differences were found, the Tukey post-hoc test was applied.

## RESULTS

A total of 1,192 individuals from eight arthropod orders were captured. Collembola was the most abundant order, representing 33% of the arthropods in the sample, followed by Hymenoptera (mostly ants), Orthoptera, Hemiptera, Coleoptera, Araneae, Dyctioptera, and Scutigeromorpha (Tab. I). The most abundant trophic guild was the detritivores, made up of 38.5% of the individuals, followed by herbivores (27%), omnivores (17.5%), and predators (17%). The abundance of trophic guilds was highly skewed by one or two taxonomic groups: 85% of the detritivores were Collembola, 69.3% of the herbivores were Orthoptera, 73.9% of predators were Hymenoptera and Araneae and 100% of the omnivores were Hymenoptera (exclusively ants) (Tab. I).

Table I. Abundance of epigaeic arthropod orders and trophic guilds in areas with different burning frequencies in the cerrado of Parque Nacional das Emas, Brazil.

| Taxa | Trophic guild | Burning rate[1] | | | Total |
|---|---|---|---|---|---|
| | | HighFi | MidFi | LowFi | |
| Araneae | Predators | 30 | 13 | 21 | 64 |
| Collembola | Detritivores | 225 | 115 | 57 | 397 |
| Coleoptera[2] | Detritivores | 24 | 4 | 15 | 43 |
| | Herbivores | 1 | 1 | 1 | 3 |
| | Predators | 7 | 4 | 8 | 19 |
| Dictyoptera[3] | Detritivores | 3 | 9 | 11 | 23 |
| | Predators | 0 | 1 | 0 | 1 |
| Hemiptera[4] | Herbivores | 30 | 28 | 14 | 72 |
| | Predators | 8 | 19 | 6 | 33 |
| Hymenoptera[5] | Herbivores | 6 | 5 | 8 | 19 |
| | Omnivores | 75 | 69 | 64 | 208 |
| | Predators | 34 | 36 | 16 | 86 |
| Orthoptera | Herbivores | 104 | 84 | 35 | 223 |
| Scutigeromorpha | Predators | 0 | 1 | 0 | 1 |

[1] HighFi – site burned annually from 1994 to 2006, MidFi – site burned five times in this period, LowFi – site unburned since 1994.
[2] Detritivores include representatives of the families Nitidulidae, Scarabaeidae, Staphylinidae, and Tenebrionidae. Herbivores include representatives of the families Brentidae, Chrysomelidae, and Tenebrionidae. Predators include representatives of the families Anthicidae, Carabidae, Histeridae, and Staphylinidae.
[3] Detritivores include representatives of the orders Blattaria and Isoptera. Predators include representatives of the order Mantodea.
[4] Herbivores include representatives of the suborders Auchenorrhyncha and Heteroptera. Predators include representatives of the suborder Heteroptera.
[5] Herbivores include representatives of the family Formicidae (Attini). Omnivores include representatives of the family Formicidae (Dolichoderinae, Formicinae, Myrmicinae). Predators include representatives of the families Formicidae (Ecitoninae, Myrmicinae, Ponerinae, Pseudomyrmecinae) and Mutilidae.

When arthropods were analyzed by order, the abundance of all but Hemiptera peaked in HighFi (Fig. 1). The abundance of Collembola was significantly higher in HighFi, whereas it did not differ between MidFi and LowFi. For Orthoptera, abundance was significantly lower in LowFi and did not differ between HighFi and MidFi. Hemiptera showed a significant difference only between MidFi and LowFi and was the only order in which abundance peaked in MidFi (Fig. 1). The abundance of Coleoptera was lower in MidFi and significantly different only between HighFi and MidFi. No significant differences were found for Araneae and Hymenoptera.

The abundance of all trophic guilds decreased from HighFi to LowFi (Fig. 2). Detritivore abundance was significantly higher in HighFi and did not differ between MidFi and LowFi. The abundance of herbivores was significantly higher in HighFi and MidFi when compared to LowFi. Omnivores and predators also showed a tendency to become less abundant with time since the last burning, yet this difference was not significant (Fig. 2).
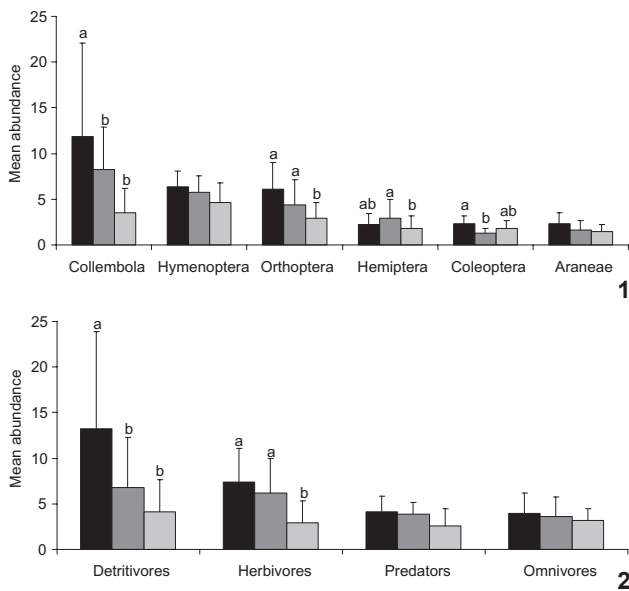


Figures 1-2. Mean abundance (± sd) of arthropods in areas with different burning rates: HighFi (black bars), MidFi (dark gray bars), and LowFi (light gray bars). (1) Orders and (2) Trophic guilds. Different letters in the same sequence within an order or guild represent statistically significant differences in abundance (one-way randomized analysis of variance followed by a Tukey's post-hoc test, p < 0.05).

## DISCUSSION

The general tendency of finding a higher abundance of epigaeic arthropods with increased fire frequency corroborates some previous studies on the effects of fire on cerrado insects (e.g., PRADA *et al.* 1995, MARINI-FILHO 2000, KNOECHELMANN & MORAIS

2008). Our results show that these organisms are not only resilient to fire, as observed in other tropical savannas (ANDERSEN *et al.* 2003), but they are also able to take advantage of sites with different fire histories. Although we cannot establish any causal relationship, two general features may explain why fire seems to favor epigaeic arthropods. First, mortality due to fire should be low given the ability of many species to hide in natural cavities or to fly away from the fire front (ANDERSEN *et al.* 2003). Second, the amount of plant resources increases for a few months after a fire, with almost all herbaceous plants producing flowers or regrowing vigorously, allowing epigaeic arthropod species to take advantage of the nutrients released by fire (COUTINHO 1990, MIRANDA *et al.* 2002). These available resources should attract many herbivore species, such as Orthoptera and Hemiptera, which benefit from the regrowth of plants (CHAMBERS & SAMWAYS 1998, MARINI-FILHO 2000, ANDERSEN *et al.* 2003). In turn, an increase in the abundance of these species should attract their predators (CHEN & WISE 1999). For example, PRADA *et al.* (1995) reported a nearly 20-fold increase in the number of flowering plants of an Asteraceae species in a burned site followed by a higher abundance of herbivorous insects. Also, ants visiting extrafloral nectaries were more frequent in cerrado sites burned biennially than in unburned sites (KNOECHELMANN & MORAIS 2008).

A study carried out in the same period as the present study (CIANCIARUSO *et al.* 2010) showed that, despite the fact that the total aboveground biomass was higher in the LowFi site and lower in the HighFi site, when accounting only for living biomass, the HighFi site had about 50% more biomass than the LowFi site. Moreover, a single grass species (*Tristachya leiostachya* Nees) was responsible for 68% of the total living biomass in the LowFi site whereas in both the HighFi and MidFi sites *T. leiostachya*, other grasses and woody species contributed more equally to total herbaceous aboveground biomass (CIANCIARUSO *et al.* 2010). Such monodominance in the LowFi site could be an alternative explanation for the patterns we found here for arthropods because it reduces the diversity of resources available in the LowFi site. Nonetheless, the relationship between burning frequency and epigaeic arthropod abundance does not appear to be so clear for all taxonomic or functional groups. Divergent responses to fire have been observed within and between arthropod orders in many savannas (e.g., WARREN *et al.* 1987, ANDERSEN *et al.* 2003).

The increase in detritivore abundance with higher burning frequency found in this study was unexpected because more detritivore individuals often occur in sites with an accumulation of organic matter (e.g., CHEN & WISE 1999), such as unburned sites (OTTMAR *et al.* 2001, GOVENDER *et al.* 2006). On the other hand, the lower abundance of detritivores in the MidFi and LowFi sites may be explained by the dominance of Collembola in this trophic guild. Some dominant springtail species may be more abundant in burned than in unburned sites because they may use available shelters (stones and coarse woody debris) more ef-

ficiently (Brand 2002). An alternative explanation is, again, the dominance of *T. leiostachya*, which makes up a great part of the organic matter accumulated in the LowFi site (Cianciaruso *et al.* 2010) reducing the colonization by detritivores.

The abundance of omnivores did not differ among sites with different burning frequencies. The idiosyncratic nature of the omnivore guild in this study, composed exclusively of ants, may help us to understand their relationship with burning frequency. Almost 80% of the captures in this guild were composed of three dominant ant genera, *Camponotus* Mayr, 1861 (Formicinae), *Pheidole* Westwood, 1839 (Myrmicinae), and *Linepithema* Mayr, 1866 (Dolichoderinae) (data not shown), which exhibit very high recruitment and aggressive interspecific interactions even in disturbed sites (Silvestre *et al.* 2003). These attributes allow these ant species to colonize open sites quickly and, coupled with their wide trophic niche, could be an explanation for the homogeneous response of omnivores to all burning frequencies. Morais & Benson (1988) reported a high mortality of arboreal ants caused by fire, and a reduction in their abundance for at least 1.5 years after burning in a cerrado. They also postulated that ground ants would have higher survivorship after burning, due to a smaller effect of fire at the ground level. Their proposition was supported here at least for omnivorous ants. A study conducted in an Amazonian savanna found no effect of fire disturbance on species richness and a minor effect on species composition (Vasconcelos *et al.* 2008). Parr *et al.* (2004) also did not find a significant effect of burning on southern African savanna ant species richness or abundance, and commented on the resistance of ant assemblages to burning. However, these authors found significant differences in ant species composition between burned and unburned sites. Therefore, studies at the species level are needed to investigate whether there are shifts in the composition and species richness of ants in cerrado sites under different burning frequencies, even when their abundance does not change.

Differing responses of the arthropod orders that composed the predator guild homogenized the overall predator response (see Tab. I and Fig. 2), leading to the non-significant response in relation to fire frequency observed in this study. Spider abundance also did not differ significantly among sites, contrasting with a previous study that reported a significant reduction in spider abundance in a recently burned cerrado (Gomes *et al.* 2007). However, in that study spiders were collected using Winkler extractors that selectively sample small spider species which could either be more susceptible to the effects of fire or slower in colonizing burned sites. On the other hand, the method used in the current study is more efficient for sampling ground active species (Churchill 1993), which are the species that are most likely to colonize burned sites. Experimental evidence from agroecosystems has shown that active ground-dwelling spiders are efficient colonizers of new habitats, and are able to invade recently disturbed areas from both adjacent and distant habitat sources (e.g., Hibbert & Buddle 2008). Additionally, Martins *et al.*

(2004) showed that the abundance of a sun spider (Solifugae) increased immediately after burning in a cerrado site, but this difference vanished 3-4 months later.

While long-term sampling and species-level identification are highly desirable in any assessment study, arthropod assessments to aid decision-making are often made under time and financial constraints (particularly in Brazil). Consequently, important decisions are usually based on snapshot samples with identifications made only at high taxonomic levels. In these unfavorable situations, the use of species abundance in higher taxonomic categories may be the only alternative (Brennan *et al.* 2006). Therefore, studies looking for consistent responses to fire at high taxonomic or functional levels are important in a practical way.

This study indicates that some cerrado arthropod groups are not only resilient to fire, as observed in Australian savannas (Andersen *et al.* 2003), but also may actually benefit from burning. However, this conclusion should be considered an initial assessment of the responses to different fire regimes in cerrado arthropods at high taxonomic levels. Additional studies should be conducted in this ecosystem to confirm the generality of our results. Ultimately, the information provided here might be useful in the search for ecological indicators of disturbance by fire in cerrado. Springtails and ants seem to be particularly appropriate focal groups for further exploratory studies at the species level because they are abundant in samples and, in the case of ants, relatively well-known in the cerrado (see Silvestre *et al.* 2003).

## ACKNOWLEDGEMENTS

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