Revista Agrogeoambiental, Pouso Alegre, v. 13, n. 4, p. 658-670, dez. 2021. DOI: http://dx.doi.org/10.18406/2316-1817v13n420211652

The effect of anthropic fires on ant assemblage in the Cerrado of Southeastern Brazil

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Received in: 01/10/2021 | **Accepted in:** 06/01/2022

Abstract

The Cerrado is the second largest biome in South America and due to its great species, richness, and environmental degradation, is considered a biodiversity hotspot. Fires in Cerrado can occur both naturally and through anthropic influence. However, due to the latter, the occurrence of fires has been increasingly frequent, as well as its impact on biotic communities. Ants' colonies are widely used in studies of environmental impacts because of their responsiveness to environmental changes and easiness for their data to be analyzed. Here, the structure of the ants' community in Cerrado environments at different areas post-fire times (two and four months, and a control area) in Itumirim, Minas Gerais, Brazil, was evaluated. Attractive baits were used as sampling methods, and found 48 species of ants belonging to 18 genera. Species richness was the same in all areas, showing that both two and four months after the fire occurrences seem to be enough to recover the ant population of these areas. Regarding ant composition, there were important differences, especially between the control area and the four months post-fire area. Moreover, vegetal biomass and vegetation covers only influenced ant composition. Here, it was found that species composition seems to be a better indicator of the responses of ant communities to post-fire effects, and can be used as a tool in monitoring programs.

Keywords: Bioindicators. Attractive Baits. Environmental Disturbance. Species Turn Over.

Introduction

The Cerrado (Brazilian Savanna) is the second-largest biome in Brazil, after the Amazonian rainforest, and the largest one in South America. It accounts for 25 % of its national territory (RIBEIRO; WALTER, 1998; CARVALHO *et al.*, 2009; DURIGAN; RATTER, 2016). The Cerrado is considered a hotspot due to its enormous biodiversity, high degree of endemism, and high susceptibility to human activities (MITTERMEIER *et al.*, 2005; STRASSBURG *et al.*, 2017). The occurrence of fires in Cerrado happens both naturally and anthropically, either influencing directly or indirectly the characteristics of vegetation and consequently other biotic factors.

Natural fires are common in the Savannas, and it is mainly caused by lightning reaching dry trees during the rainy season (RAMOS-NETO; PIVELLO, 2000). However, the recent increase in fire frequency regimes, caused by both human occupation and agricultural practices in such areas (MISTRY, 1998; CARVALHO *et al.*, 2009; GANEM *et al.*, 2013), leads to community simplification and loss of biodiversity (HIROTA *et al.*, 2011). In that regard, the presence or absence of certain organisms can give valuable information about the environmental situation of different habitats, which is the reason why bioindicators have been used to monitor the changes and evaluate the impacts of anthropic activities (NIEMI; MCDONALD, 2004).

Invertebrates are widely used as bioindicators (SIDDIG *et al.*, 2016) and, in particular, ants have been used for the same purpose when it comes to impacts caused by fires (SANTOS *et al.*, 2008; CANEDO-JÚNIOR *et al.*, 2016; PAOLUCCI *et al.*, 2017; SEMENOV; RAN'KOVA, 2018; TIBCHERANI *et al.*, 2018). Ants are considered to be good environmental bioindicators because they are found in high richness and abundance, they can be easily sampled and separated into morphospecies, and, most importantly, they are very responsive to environmental changes (MAJER, 1983; FRIZZO *et al*., 2011; TIBCHERANI *et al*., 2018).

Fire events in the Savanna ecosystem can promote a high biodiversity of ants by changing the structure of vegetation (MARAVALHAS; VASCONCELOS, 2014). The vegetation has been proved to have an important role in the recovery and restoration of communities, especially herbaceous cover and their biomass (ARAÚJO; RIBEIRO, 2005; FRIZZO *et al.*, 2012; CANEDO-JÚNIOR *et al.*, 2016). After a fire, some species can be resilient and resistant and their diversity is quickly restored (COSTA *et al.*, 2010), and others can be susceptive, and be replaced by others, which is called turnover of species (FAGUNDES *et al.*, 2018). This may happen because different groups of ants may show different responses to fire, depending, for instance, if their nest is vulnerable or not to the direct effect of fire (HOFFMANN, 2013; FRIZZO *et al.*, 2012; MARAVALHAS; VASCONCELOS, 2014). The recovery of the ant community was previously related to the post-fire time, in which it was shown that the longer after the fire event, the greater the similarity with the unburned area (CANEDO-JÚNIOR *et al.*, 2016).

Thus, considering the growing environmental problems due to habitat loss in Brazilian savannas (Cerrado biome), and the necessity to understand the role of environmental structure and the response of ants at different post-fire times, this work was developed to evaluate the richness and composition of ant communities in a control area and two post-fire areas (two and four months after fire) in an area of Cerrado. The following hypotheses were tested: (*i*) The longer the post-fire period, the greater the ant richness; (*ii*) Ant species composition will differ depending on the post-fire period; (*iii*) Ant species richness and composition will be influenced by environmental variables such as vegetation cover and plant biomass.

Material and methods

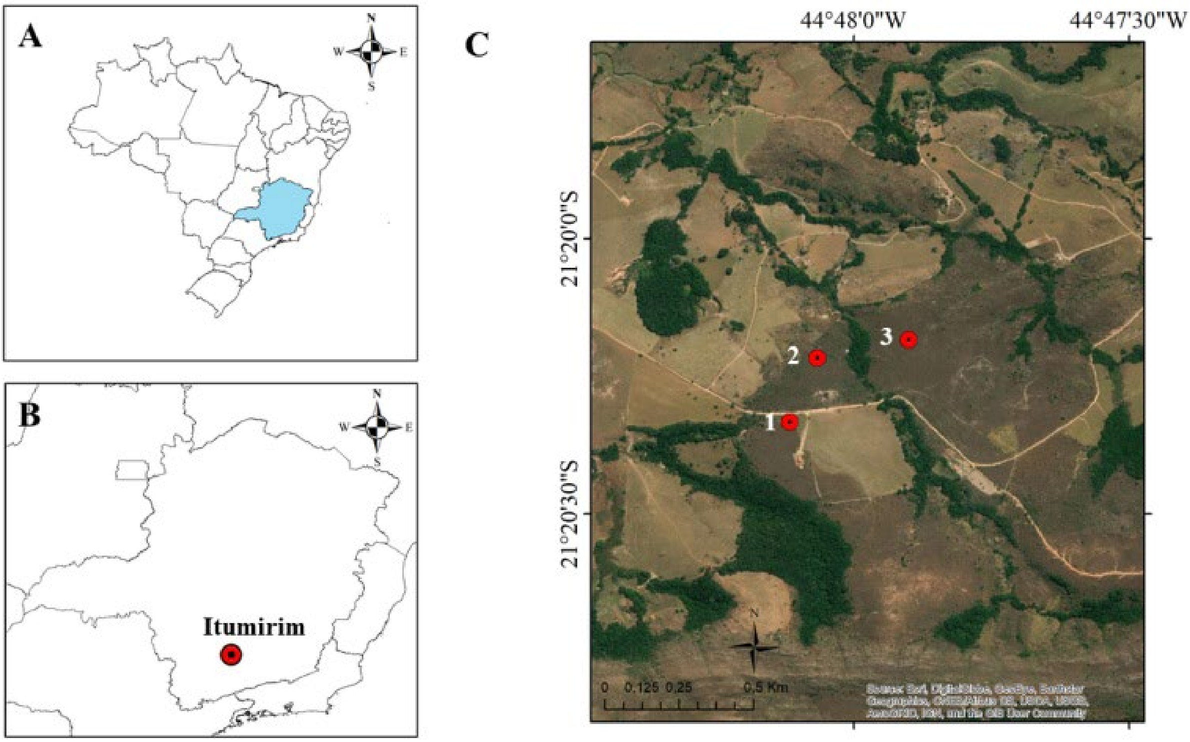
Study area

The present study was carried out in Itumirim – MG, at the coordinates 21°16’30” S and 44°50’0”W, in the Southern region of Minas Gerais, Brazil. Its average altitude is 880 m and the climate is characterized by the transition between Cwa and Cwb according to the Köppen classification (ANTUNES, 1986). The average temperature and annual rainfall are, respectively, 18º-20ºC and 1.530 mm. The original vegetation of the region was composed of a transition forest and Savanna *stricto sensu* (MINAS GERAIS, 1980; CARVALHO, 1992), which were replaced by pasture and agricultural crops, leaving small fragments only (LOSCHI *et al.*, 2013).

Sampled design

In order to evaluate the influence of different post-fire times on ant structure composition, three Cerrado areas were used at least 500 meters away from each other. The first area was burned in 2013, being used as a control reference in this study. The two other areas were burned in October and December of 2016, respectively (personal information of the owner of the areas) (FIGURE 1). In each of these areas three 100 m equidistant transects, containing five sampling points with attractive baits, were established. The baits were positioned 30 m apart, ensuring the independence of the samples. Ants were sampled at three different periods (morning, afternoon, and evening), totaling 15 sampling points per time period, and 45 samples per area.

Figure 1 – A: Minas Gerais highlighted in the map of Brazil. B: Itumirim highlighted in the map of Minas Gerais. C: Location of the sampling sites (Cerrado areas) from where we collected ant species. In Figure 1C, numbers 1, 2 and 3 respectively represent the control area (2013), and the areas burned in October 2016 (four months ago), and in December 2016 (two months ago)



Source: elaborated by the authors (2021).

Ant collection

Ants and environmental variables were sampled in February of 2017. Attractive baits were used in order to measure ant richness and composition. The traps consisted of 18 cm disposable edgeless plates (which facilitate the arrival of smaller ants) filled with a portion of 10 g of animal protein (sardines with oil) and 15 g of carbohydrate (honey) placed at the ground level (SCHMIDT *et al.*, 2005).

The baits were checked three times a day: in the morning (10:30 am to 12:00 pm), in the afternoon (2:00 pm to 4:00 pm), and in the evening (6:00 pm to 7:30 pm). All baits were replaced before each collection (three times a day). Five minutes were spent collecting the ants that were in and around the baits. After the collection, the ants were taken to the Federal University of Lavras (UFLA) Ant Ecology Laboratory, where they were sorted and identified to genus level according to Baccaro *et al.* (2015). This procedure was followed by morpho-speciation according to the repository acronym of the Ant Ecology Laboratory.

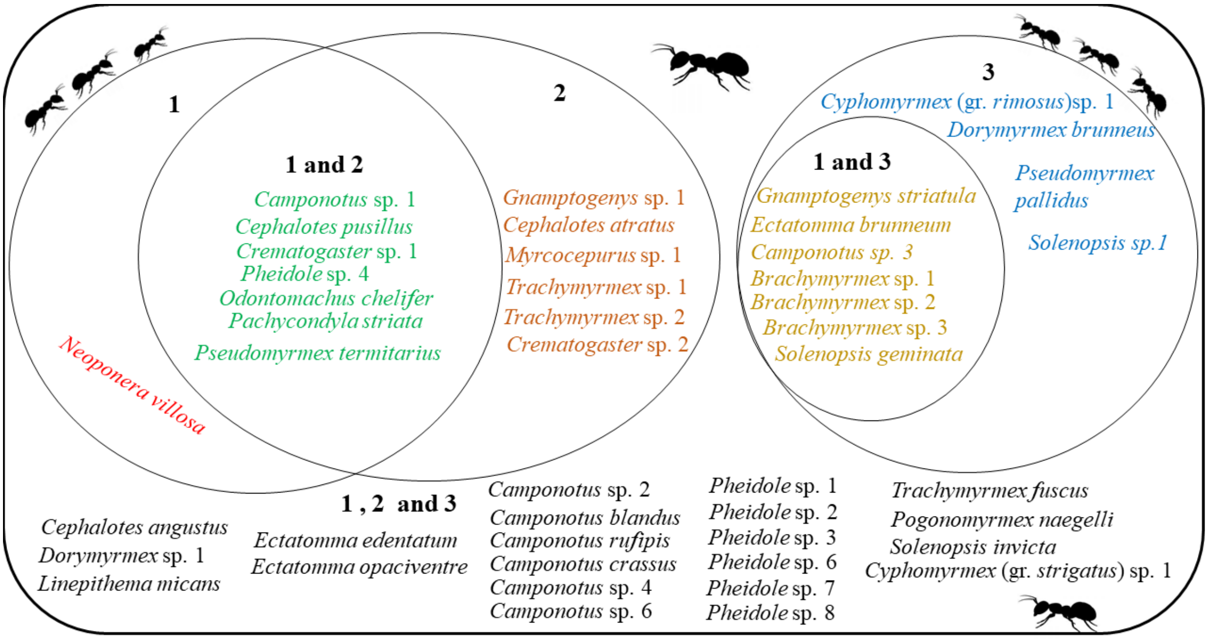
To measure the environmental variables, 33 cm x 33 cm plots were delimited next to each sample unit, where all soil herbaceous layer cover was removed and later taken to the laboratory. Then, this material was heated and dried at 70 °C for 72 h and weighed with analytical digital scales. The canopy cover of each area was estimated using hemispheric digital photographs which were taken using a camera equipped with 0.20 mm fisheye objective lenses. The camera was positioned at ground level near the attractive bait. Later, using these photos, it was possible to indirectly calculate the vegetation cover (ENGELBRECHT; HERZ, 2001). The images were analyzed using Gap Light Analyzer software, which provides the percentage of vegetation coverage (FRAZER *et al*., 1999). Therefore, two environmental variables were used in the further analysis: plant biomass and vegetation cover.

Data analysis

A species accumulation curve was performed to verify if the sampling effort was sufficient to use ant community diversity parameters in the studied areas (GOTELLI, 2009). The observed number of species was compared with the expected number of species found using the Jackknife 1, Jackknife 2, Chao and Bootstrap species richness estimator.

Generalized linear models (GLM) were used to assess differences in species richness at different post-fire recovery times. In this model, species richness was used as the dependent variable and post-fire times as the independent one. Beyond that, in order to identify the relationship of environmental variables with ant species richness, another GLM was built with plant biomass and vegetation cover (and their interaction) as independent variables. We used Poisson error distribution in both GLMs. These analyses were performed in an R environment (R DEVELOPMENT CORE TEAM, 2016). To verify differences in ant species composition and evaluate similarities among sampled areas, we performed a similarity analysis (ANOSIM) using the Jaccard similarity index as a distance measure with Primer 6 and Permutational Multivariate Analysis of Variance (PERMANOVA), considering the presence or absence of species (CLARKE; GORLEY, 2005).To measure the possible influence of environmental variables (vegetation cover and plant biomass) on ant species composition among areas at different post-fire times, we used multivariate analysis based on distances for linear models (DISTLM) with Jaccard similarity index on Primer 6 (CLARKE; GORLEY, 2005).

Figure 2 – Ant species collected by area, Areas 1, 2, 3 respectively correspond to the presence of ants in the burned areas in 2013, October 2016 and December 2016, different colors were applied for species collected in different places. Red color represent the species sampled only in area 1, brown only in area 2, blue only in area 3, Green represents species that were found both in areas 1 and 2, yellow both in areas 1 and 3, and black in all areas 1, 2 and 3.



Source: elaborated by the authors (2021).

Results

It was collected 48 ant species, distributed in 18 genera (FIGURE 2), being the genera *Camponotus* (Mayr, 1861) and *Pheidole* (Westwood, 1839) the largest number of species found during the experiment (nine and eight respectively) (TABLE 1).

Richness estimations of ant species (TABLE 2) show that the area burnt in October 2016 was the one that had the highest sampling efficiency regardless of the estimators used (varying from 80.18 % to 93.5 %), while the control area burnt in 2013 was the one that had the lowest sampling efficiency fluctuating from 62.13 % to 83.40 %. Lastly, an intermediate efficiency in the area burnt in December was measured, differing from 67.06 % to 86.71 % depending on the estimator used.

Ant species richness did not differ in the studied areas ($p > 0.05$). After the occurrences of fires in 2013 and 2016 (in October and December), 37, 34, and 34 ant species were respectively found. On the other hand, we found differences in ant compositions among Cerrado areas with different post-fire times (ANOSIM, $R = 0.169$; $p < 0.001$). The composition of ant species in the burnt area in December 2016 was different from the areas burnt in October 2016 and in 2013. However, no significant difference was obtained between the burnt area in October 2016 and the control area in 2013 (TABLE 3).

Table 1 – Ant species collected in areas with different post-fire times in the municipality of Itumirim – MG, Brazil. Areas 1, 2, 3 respectively correspond to the presence of ants in the burned areas in 2013, October 2016 and December 2016

Subfamily	Tribe	Species	Areas
Dolichoderinae	Leptomyrmecini	*Dorymyrmex brunneus* Forel, 1908	3
		Dorymyrmex sp. 1	1, 2, 3
		Linepithema micans (Forel,1908)	1,2,3
Ectatomminae	Ectatommini	*Ectatomma brunneum* Smith, F., 1858	1,3
		Ectatomma edentatum Roger, 1863	1,2,3
		Ectatomma opaciventre (Roger, 1861)	1,2,3
		Gnamptogenys striatula Mayr, 1884	1,3
		Gnamptogenys sp. 1	2
Formicinae	Camponotini	*Camponotus blandus* (Smith, F., 1858)	1,2,3
		Camponotus crassus Mayr, 1862	1,2,3
		Camponotus rufipis (Fabricius, 1775)	1,2,3
		Camponotus sp. 1	1,2
		Camponotus sp. 2	1,2,3
		Camponotus sp. 3	1,3
		Camponotus sp. 4	1,2,3
		Camponotus sp. 5	1,2
		Camponotus sp. 6	1,2,3
	Myrmelachistini	*Brachymyrmex* sp. 1	1,3
		Brachymyrmex sp. 2	1,3
		Brachymyrmex sp. 3	1,3

Subfamily	Tribe	Species	Areas
Myrmecinae	Attini	*Cephalotes angustus* (Mayrs, 1862)	1,2,3
		Cephalotes atratus (Linnaeus, 1758)	2
		Cephalotes pusillus (Klung, 1824)	1,2
		Cyphomyrmex (gr. *rimosus*) sp. 1	3
		Cyphomyrmex (gr. *strigatus*) sp. 1	1,2,3
		Myrcocepurus sp. 1	2
		Pheidole sp. 1	1,2,3
		Pheidole sp. 2	1,2,3
		Pheidole sp. 3	1,2,3
		Pheidole sp. 4	1,2
		Pheidole sp. 5	3
		Pheidole sp. 6	1,2,3
		Pheidole sp. 7	1,2,3
		Pheidole sp. 8	1,2,3
		Trachymyrmex fuscus Emery, 1834	1,2,3
		Trachymyrmex sp. 1	2
		Trachymyrmex sp. 2	2
	Crematogastrini	*Crematogaster* sp. 1	1,2
		Crematogaster sp. 2	2
	Pogonomyrmecini	*Pogonomyrmex naegelli* Forel, 1878	1,2,3
	Solenopsidini	*Solenopsis geminata* (Fabricius, 1804)	1,3
		Solenopsis invicta Buren, 1972	1,2,3
		Solenopsis sp.1	3
Ponerinae	Ponerini	*Neoponera villosa* (Fabricius, 1804)	1
		Odontomachus chelifer (Latreille, 1802)	1,2
		Pachycondyla striata Smith, F., 1858	1,2
Pseudomyrmecinae		*Pseudomyrmex termitarius* (Smith, F., 1855)	1,2,3
		Pseudomyrmex pallidus (Smith, F., 1855)	3
6	9	48	

Source: elaborated by the authors (2021).

Table 2 – Estimates of ants captured using attractive bait in areas of Cerrado in Itumirim – MG, Brazil, using the richness estimates Jackknife 1, Jackknife 2, Chao and Bootstrap with their respective sample efficiency in percentage.

Estimators of Ant Richness					
Areas	**Nº of ants species observed**	**Jacknife 1**	**Jacknife 2**	**Chao**	**Bootstrap**
Control (2013)	37	52.86 (70.23 %)	59.55 (62.13 %)	50.48 (73.29 %)	44.36 (83.40 %)
October (2016)	34	42.4 (80.18 %)	37.32 (91.10 %)	36.36 (93.30 %)	39.22 (86.69 %)
December (2016)	34	45.2 (75.22 %)	50.7 (67.06 %)	45.2 (72.22 %)	39.21 (86.71 %)

Source: elaborated by the authors (2021).

Table 3 – Dissimilarity among ant composition (R values) in burnt Cerrado areas in 2013, October and December of 2016, obtained with ANOSIM analysis. The greater the R value, the greater the dissimilarity among groups

Dissimilarity of ant composition among the Cerrado areas		
Areas	**Cerrado 2013**	**Cerrado October 2016**
Cerrado October 2016	0.023(-)	
Cerrado December 2016	0.089 (*)	0.399(**)

P values: (-) $p > 0.05$; (*) $p < 0.05$; (**) $p < 0.0001$.

Source: elaborated by the authors (2021).

Table 4 – P values obtained from the Generalized Linear Model (GLM) assessing the effect of environmental variableson ant richness in Cerrado areas with different post-fire times in Itumirim – MG

Effect of Environmental variables on Ant Richness	
Variables	**P values**
PB	0.16
VC	0.13
PB*VC	0.086

PB– Plant biomass; VC – Vegetation cover; PB*VC – Interaction between the variables.

Source: elaborated by the authors (2021).

Table 5 – Results of the DistLM analysis used to evaluate the contribution of environmental variables to differences in ant composition among Cerrado areas with different fire times in Itumirim – MG

Environmental variables effect on Ant Composition		
Variables	**P Value**	**Proportion**
PB	0.028*	3.58E-02
CV	0.029*	3.58E-02

PB – plant biomass; VC – Vegetation cover; * $p < 0.005$ (significant results).

Source: elaborated by the authors (2021).

The environmental variables (plant biomass, vegetation cover and their interaction) evaluations are not significantly associated with the ant species richness in the sampled areas ($p > 0.05$) (TABLE 4). However, the DistLM test showed that environmental variables were associated with ant composition, but with little explanatory relevance (TABLE 5).

Discussion

The present study assessed the response of ant communities impacted by fire in Cerrado after two and four months of ecosystem recovery and showed that ant compositions have a better potential to predict impacts caused by fire than ant species richness. Besides, the same was true for environmental variables that, even with little weight, were important in explaining differences in ant communities and had no effect on ant species richness. Furthermore, this study evaluated the response of the ants' community at different fire recovery times, in which it was observed that after two and four months after the last burn, the ant species richness didn't change. This may occur due to the resistance of some ant species to fire caused by natural selection, and also the rapid colonization of more generalist species that are better adapted to changes in environmental structure in damaged areas (ANDERSEN *et al*., 2006).

The most abundant genera found in Cerrado areas were Camponotus and Pheidole, this result was expected since these genera are the most representative in the world and have characteristics that facilitate their dispersion such as wide geographical distribution, flexible diet, high colonization ability, and large local abundance (WILSON, 1976).

In the same way, this result corroborates those found in previous studies, in which were observed ants' rapid recovery after fire disturbances (RODRIGO; RETANA, 2006; PARR; ANDERSEN, 2008; CANEDO-JÚNIOR *et al*., 2016). The rapid recovery of these insects may be related to the fact that fire has been present for thousands of years in the Savannas (SALGADO-LABOURIAU *et al*., 1997) and, for this reason, some animals, such as ant species, are adapted to fire regime. There are two different ways in which ants can recover from a fire impact: the first way is avoiding lethal temperatures by building their nests in the ground, since it is already known that there is no change in soil temperature below five cm in Savanna-like environments (ANJOS *et al*., 2018). The second way, for winged species, is dispersing through flight (ANDERSEN; YEN, 1985).

Ant composition changed depending on the post-fire period, confirming our second hypothesis, in which we observed that four months were sufficient for a total recovery of the ant composition in the area burnt in October of 2016, whereas two months seems not enough to fully recover the ant composition in the area burnt in December of 2016.

The similarity in ant composition between the control area (2013) and the burned area in October 2016 may possibly have been caused by the proximity of the two areas, which probably allowed the recolonization of ant species present in the control area to the area burned four months ago (October 2016). Also, the longer post-fire recovery time (4 months) compared to the area burned in December of 2016, that had less time to recover (2 months) and was further from the control area. In contrast, the greater dissimilarity of ant composition between the areas burnt four and two months (October and December of 2016) may be related to both the physical barrier between the two areas caused by a stream (which would make it difficult for ant species to recolonize), as well as the environmental structure of each area, since fire may have stimulated seed germination (RAVEN *et al*., 2007), increasing the complexity of the environment. This may have allowed the arrival of other fire-resistant ant species, which would lead to greater dissimilarity in ant composition in these areas.

Regarding ant composition, it is important to note that although most species are common in the three areas, like *Pseudomyrmex pallidus* (Smith, F., 1855), *Trachymyrmex fuscus* Emery, 1834 and *Dorymyrmex brunneus* Forel, 1908, for example, occurred only in area 3, which indicates that these species have a high resistance to impacts such as the fire in the Cerrado. Indeed, the genus *Dorymyrmex* Mayr, 1866 was previously associated with disturbed areas and with little vegetation cover (CUEZZO; GUERRERO, 2012; ARCUSA, 2017), while there are no records for the other species (TABLE 1). Moreover, in the area, 2 the occupancy of some generalists genera such as *Mycocepurus*, *Crematogaster*, *Ondontomachus,* and *Pachycondyla,* indicates a recovery of the previous conditions of this habitat after four months of the disturbance, since these species need specifics resources such as fruits, nectar, carcasses, and seed arils to survive (BACCARO *et al*., 2015). In area 1, we had only one exclusive species, which could indicate this individual is not tolerant to the impact caused by fire. This species, *Neoponera villosa* (Fabricius, 1804), has arboreal habits, nesting in trees. It forages on the ground or in trees, looking for extrafloral nectaries (PAUL; ROCES, 2003). The colonies use hollow logs and epiphytes for its establishment

(OLIVA-RIVERA *et al*., 1990; DEJEAN; OLMSTED, 1997), and for this reason, could not be found in the other two areas with little vegetation cover.

The similarity in ant composition between the control area (2013) and the burned area in October 2016 may possibly have been caused by the proximity of the two areas, which probably allowed the recolonization of ant species present in the control area to the area burned four months ago (October 2016), and also the longer post-fire recovery time (4 months) compared to the area burned in December of 2016, that had less time to recover (2 months) and was further from the control area.

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The environmental variables tested (plant biomass, vegetation cover) showed no influence on ant species richness. On the opposite, they showed an influence on ant composition, indicating that even though such variables are among those in which ants respond the most (PACHECO; VASCONCELOS, 2012; QUEIROZ *et al*., 2013; SCHMIDT *et al*., 2013), there are probably other unmeasured variables that could explain to a greater extent of differences in ant composition among these areas, such as fire intensity, landscape, phytophysiognomy characteristics, and the proximity to rural roads observed in our studied area, which are not possible to measure in this study. While for richness, environmental variables may have had no influence due to the arrival of more generalist and fire-tolerant species after the disturbance and consequently the turnover of ant species.

Conclusions

In Conclusion, it was observed that fire has an influence on the ant community; the sampling method using attractive baits is efficient to compare the richness and composition of ants in the Cerrado with different post-fire times. Furthermore, it is evident that ant composition has the potential to better predict the impact of fires in the Cerrado than ant species richness. Therefore, ant composition can be used as a potential bioindicator of impacts caused by fire, helping in the conservation and management of such an important biome. In addition, although the fire did not have an obvious effect on ant richness, the difference in composition between the evaluated areas indicates that there was a species turnover, which may have led to a loss of important ecological functions to maintain the ecosystem's structure. Despite the short post-fire period among the areas, we found a change in species composition, but we suggest further studies to better understand the effect of fire on biological communities in the Cerrado, especially long-term studies. Making it possible to predict the reestablishment of communities in fire-affected areas.

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