Fire is one of the main elements of vegetation structure and diversity in the Brazilian Cerrado, the largest and most threatened savannah biome of South America (Miranda et al. 2002; Oliveira-Filho & Ratter 2002). The occurrence of natural fires in the Cerrado region is ancient, dating back to 32,000 years before the present (Salgado-Labouriau & Ferraz-Vicentini 1994). Although relatively little is known about the natural frequency of fires in the Cerrado, it is clear that the intensification of human activities in Central Brazil, especially during recent decades, has increased the frequency and extent of fires well above historical levels (Vasconcelos et al. 2009). The fire occurrence at intervals of one to three years is now common in many areas (Coutinho 1990; Hoffmann 1998), mostly caused by agricultural activities (Miranda et al. 2002).

It has been suggested that the altered frequency and intensity of fires in the Cerrado is causing widespread change in this ecosystem (Hoffmann & Moreira 2002; Frizzo et al. 2011). While the effect of fire on vegetation is relatively well established, however, few studies have evaluated how fire influences the Cerrado's fauna (Arruda et al. 2018). Fire causes physical changes in the habitat and/or availability of resources that favors some species while others are harmed (Faria et al. 2004; Souza et al. 2015). Some studies show quick recovery for most arthropod taxa in savannas (Majer 1984; Prada et al. 1995; Vieira et al. 1996; Andersen & Müller 2000; Vasconcelos et al. 2009), but in forests indicate that changes are detectable up to several years following a fire (Springett 1976; Coleman & Resh 2006). However, different responses about abundance and diversity to fire have been observed within and between arthropod orders (e.g., Warren et al. 1987; Pryke & Samways 2012; Kral et al. 2017), and even studies focused in post-fire responses in the first six months find positive and negative results (Kral et al. 2017).

The effects of fire on beta diversity of arthropods are poorly known and still controversial. Beta diversity is the difference in species composition between communities (Whittaker 1972), that can be attributed to two components: species replacement (turnover), where substitution occurs in species composition among sites; and richness differences, which are associated with loss or gain of species (Báezela 2010; Carvalho et al. 2011). Richness differences may also result in nestedness, when species-poor communities are constituted of subsets of richer communities (Almeida-Neto et al. 2008). In general, arthropod populations are fire resistant (Pryke & Samways 2012) and comparative studies in Cerrado have not identified effects on species composition in burned areas (Vasconcelos et al. 2009; Anjos et al. 2016). However, changes in arthropods composition have been attributed mainly to changes in vegetation density (Driesen & Kirrpatrick 2017), with low congruence in temporal recovery among taxa (Pryke & Samways 2012). For example, it is noticed a drastic turnover in epigaic ant communities of burned areas in Cerrado (Anjos et al. 2015), which need a long period of time to re-establish the composition (Canedo-Júnior et al. 2016).

Abstract. Fire is a frequent agent of disturbance in tropical savannas (e.g., Brazilian Cerrado), but relatively few studies have analyzed how the arthropod community responds to fire disturbance. Following the incursion of an accidental fire into a Cerrado fragment in Central Brazil, we investigated whether the arthropod community is structured by abiotic (climate or fire) or biotic (succession) factors. Our study commenced one week after fire and during the six months afterward. We found 22 arthropod orders, of which Diptera, Hymenoptera, Hemiptera, Blattaria and Coleoptera were the most representative. More than 40% of the arthropod abundance was recorded 40 days after the fire event. The overall arthropod abundance and richness fluctuated in the six months following the fire and does not seem to be related to climatic variables. Temporal beta diversity was explained by a reduction in richness differences along the intervals of time, but the community recovery needs to be treated with caution. The increase in replacement in the last intervals in relation to the fire event indicates that biotic interactions may occur with the arrival of late colonizers and suggest that arthropod communities need a long time to be restructured. These results indicate that the processes of restructuring the arthropod communities after human-induced fire events are temporally complex, involving loss, gain and taxon replacement, but long-term studies are still needed to understand the dynamics of communities.

Keywords: Beta diversity; burned cerrado stricto sensu; Epigaic fauna; insects.
Most of the epigaeic fauna of the Cerrado' forested physiognomies (e.g., cerradão) uses the leaf litter layer, which provides a significant amount of fuel for wildfires in this ecosystem (Hoffmann 1996; Miranda et al. 2002). These organisms can be highly impacted by constant and human-induced fire events. However, we still have much to learn about how communities of epigaeic arthropod can be restructured after the disturbance. This study investigated the variations in abundance, richness, and beta diversity components of epigaeic arthropod community in a possible recolonization scenario after anthropic fire in a Cerrado fragment. Specifically, we hypothesized that (1) the utilization of order levels may be a valuable alternative to verify fluctuations after fire events in communities composed by taxonomically complex groups; (2) temporal variations in the frequency and richness of arthropods after the fire event are primarily not determined by abiotic factors; and (3) recolonization in the arthropod community composition after the fire event occur in a non-random way, in which we may expect a temporal beta diversity with an increase of replacement in relation to the early community due to recruitment of colonizing taxons from the nearby unburned remnants of Cerrado. To resolve among these questions, we conducted a monitoring of arthropod recovery in a burned Cerrado site throughout six months after a human-induced fire event.

DATA AND METHODS

Study area. The study area was a fragment of cerrado stricto sensu with approximately 58 ha (almost 40 ha were burned), located in the Campus of Universidade Estadual de Goiás (UEG) in the municipality of Anápolis, state of Goiás, Brazil (16°22′54″S and 48°56′43″ W). The Campus is surrounded by farms, roads that give access to them and by the Agribusiness District of Anápolis. The fragment is bordered by areas of seasonal semideciduous forest and gallery forest along the banks of the Barreiro stream. The altitude is 1,110 m a.s.l., the annual average temperature is 22 °C, the average annual rainfall is 1,450 mm (Cwb Köppen), the soil type is red latosol (NRD), minimum relative humidity (Umin, %), average relative humidity (Umean, %), maximum temperature (Tmax, °C) and mean temperature (Tmean, °C). We used the means of each interval (Pacc, mm), wind velocity (WV, m/s), no-rain days (NRD), minimum relative humidity (Umin, %), average relative humidity (Umean, %), maximum temperature (Tmax, °C) and mean temperature (Tmean, °C). We used the means of each variable for each 20-day interval following fire from the first day of collection. We used the Variance Inflation Factor (VIF) to verify multicollinearity among these variables, where we selected four variables with lowest inflation factor (VIF < 3) to comprise the predictor variables group: P (VIF = 1.75), Pacc (VIF = 1.37), WV (VIF = 2.57) and Tmean (VIF = 2.07). This analysis was performed using vif function of faraway package (Faraway 2016) in R software (R Core Team 2017).

Arthropod sampling. The study area was burned in late September 2010 from the fire of neighboring farms. One week after the fire, we performed a total of 27 samplings grouped in nine sampling intervals (I1, I2, I3, I4, I5, I6, I7, I8 and I9), commenced on September 30, 2010 and lasted until April 12, 2011, coinciding with the rainy period (Figure 1). The samples occurred during this period in order to coincide with the recolonization of arthropod fauna with the regeneration of vegetation. The sampling period was structured in intervals of 20 days, from the first day of rain after fire to the last day of rain from the rainy season.

Three 100 m long transects, 100 m apart, were demarcated on site. In each transect, we distributed 10 white plastic trays (44 cm x 28 cm x 7.5 cm) arranged with 10 m of distance among them, totaling 30 trays. A solution of formaldehyde, water and detergent was placed inside the trays in an amount sufficient to cover the entire bottom. The trays were placed on the soil surface and remained in the field during the entire sampling period (180 days). Initially the monitoring of the trays was done daily and with the decrease of the rainy period weekly. Arthropods were collected with polypropylene mesh sieves, sorted under stereomicroscope and stored in properly labeled 80% alcohol glass bottles. All samples were identified to the taxonomic order level and deposited in the Entomological Collection of the Laboratório de Pesquisa Ecológica e Educação Científica (Lab-PEEC) of the UEG.

Data analyses. Quantitative data are displayed as mean ± standard deviation. The orders were categorized using a dominance index, defined as D% = (i/T)*100, where i is the total number of individuals of a given taxon and T is the total number of individuals throughout the sample. The categories were established as: eudominant > 10%; dominant = 5–10%; subdominant = 2–5%; eventual = 1–2% and rare < 1% (Friede 1983).

We evaluated the efficiency of sample effort through sample-based species accumulation curves (Colwell et al. 2012), created from a frequency matrix where each line represents a taxon and each column one sample (transects per time interval). We used two estimators to obtain the expected richness for the study area: first-order Jackknife, based on species rarity data; and Bootstrap, based on species incidence. The relation between observed and estimated was demonstrated in percentage. Values for creating species accumulation curves for observed and estimated species were created with 100 randomizations using the functions specaccum and poolaccum of vegan package (Oksanen et al. 2017) in R software (R Core Team 2017).

Due to high variability of data, as well as different units of measurements, we transformed the climatic variables using the logarithmic unit (log + 1) to meet the tests assumptions. Initially, we used the following predictive climatic variables: precipitation (P, mm), precipitation accumulated during interval (Pacc, mm), wind velocity (WV, m/s), no-rain days (NRD), minimum relative humidity (Umin, %), average relative humidity (Umean, %), maximum temperature (Tmax, °C) and mean temperature (Tmean, °C). We used the means of each variable for each 20-day interval following fire from the first day of collection. We used the Variance Inflation Factor (VIF) to verify multicollinearity among these variables, where we selected four variables with lowest inflation factor (VIF < 3) to comprise the predictor variables group: P (VIF = 1.75), Pacc (VIF = 1.37), WV (VIF = 2.57) and Tmean (VIF = 2.07). This analysis was performed using vif function of faraway package (Faraway 2016) in R software (R Core Team 2017).

We determined the influence of climatic variables on richness and frequency of each order of dominant arthropods by sampling interval using stepwise multiple regression analyses with backward elimination. For each dependent variable, we built full models with the four predictor variables previously selected. The selection was done by removing the least significant variables in the model (based on F value), and the procedure was repeated until the final model was composed only of variables with a significant F value (p <0.05). These analyses were performed using functions lm and drop1 of vegan package (Oksanen et al. 2017) in R software (R Core Team 2017).
To determine the components involved in structuring the arthropod community after the fire event, we decomposed the beta diversity in general and among sampling intervals using the approach proposed by Carvalho et al. (2011). In this approach, the Jaccard dissimilarity ($\beta_{Jac}$) is partitioned into species replacement (turnover, $\beta_{Rep}$) and richness differences ($\beta_{Ric}$) components. We used the metric NODF (Nestedness metric based on Overlap and Decreasing Fill; Almeida-Neto et al. 2008) to test if richness difference in intervals following the fire event is composed of a subset (Basegla 2010) of taxa found at late intervals when the community is theoretically restructured. We used null models to test whether the overall patterns of each component differ from the expected by chance. Thus, we used null models that randomize the taxa composition among sampling intervals, keeping the sum of columns fixed. We then verified the variations in the beta diversity components along the post-fire intervals in relation to the fire event (first interval) using simple linear regressions. Beta diversity analyses were performed using functions oecosimu and beta.pair of vegan package (Oksanen et al. 2017) and betapart (Basegla et al. 2017), respectively; and linear regression using the function lm of vegan package in R software (R Core Team 2017).

RESULTS

We found 33,216 individuals distributed among 22 arthropod orders, 19 of insect orders. The most abundant orders represented 93% of the specimens and were classified as eudominants (Diptera and Hymenoptera) and dominants (Hemiptera, Blattaria and Coleoptera). Orthoptera and Araneae were classified as subdominants and the 15 remaining orders as rare (Table 1).

The stabilization tendency of the “species” (here, considered at the order level) accumulation curve in the last post-fire sampling demonstrates the efficiency of sample effort (Figure 2). Observed richness represents 79% and 89% of the expected by Jackknife 1 (28 ± 2.55 order) and Bootstrap (25 ± 0 order), respectively.

Frequency and richness of arthropods varied among sampling intervals. The highest frequency was found during the interval 12 (264 occurrences), while the lowest in the interval 15 (149). The highest richness was found in the intervals 11, 12 and 19 (15 orders each), while the lowest richness was found in 15 (nine orders) (Figure 3). No climatic variable significantly influenced ($p > 0.05$) order richness, total frequency and frequency of eudominant and dominant orders during sampling period.

The total beta diversity among post-fire time intervals ($\beta_{jack} = 0.63$, Mean $= 0.80$, $p < 0.01$) was explained mainly by replacement ($\beta_{Rep} = 0.40$, Mean $= 0.75$, $p < 0.01$) in comparison to richness differences ($\beta_{Ric} = 0.23$, Mean $= 0.05$, $p < 0.01$), latter higher than expected by chance. We did not find a nested pattern in richness differences among all intervals.

Table 1. Abundance of each arthropod group sampled in a post-fire Cerrado remnant.

| Order       | Abundance | Mean   | Standard Deviation | Dominance (%) | Status     |
|-------------|-----------|--------|--------------------|---------------|------------|
| Diptera     | 12,528    | 464.00 | 449.59             | 37.60         | Eudominant |
| Hymenoptera | 10,908    | 404.00 | 325.88             | 32.74         | Eudominant |
| Hemiptera   | 2,997     | 111.00 | 98.57              | 9.00          | Dominant   |
| Blattaria   | 2,752     | 101.93 | 164.03             | 8.26          | Dominant   |
| Coleoptera  | 1,919     | 71.07  | 81.10              | 5.76          | Dominant   |
| Orthoptera  | 898       | 33.26  | 30.31              | 2.70          | Subdominant|
| Araneae     | 798       | 29.56  | 25.15              | 2.40          | Subdominant|
| Lepidoptera | 232       | 8.59   | 6.22               | 0.70          | Rare       |
| Thysanura   | 184       | 6.81   | 10.36              | 0.55          | Rare       |
| Phasmatoidea| 51        | 1.89   | 3.39               | 0.15          | Rare       |
| Acarina     | 21        | 0.78   | 1.83               | 0.06          | Rare       |
| Odonata     | 11        | 0.41   | 1.37               | 0.03          | Rare       |
| Embioptera  | 4         | 0.15   | 0.60               | 0.01          | Rare       |
| Archaeognatha| 3       | 0.11   | 0.32               | 0.01          | Rare       |
| Strepsiptera| 2         | 0.07   | 0.27               | 0.01          | Rare       |
| Scolopendromorpha | 2 | 0.07 | 0.27 | 0.01 | Rare |
| Ephemeroptera| 1    | 0.04   | 0.19               | 0.00          | Rare       |
| Pscoptera   | 1         | 0.04   | 0.19               | 0.00          | Rare       |
| Mantodea    | 1         | 0.04   | 0.19               | 0.00          | Rare       |
| Diplura     | 1         | 0.04   | 0.19               | 0.00          | Rare       |
| Thysanoptera| 1         | 0.04   | 0.19               | 0.00          | Rare       |
| Dermoptera  | 1         | 0.04   | 0.19               | 0.00          | Rare       |

Figure 2. Accumulation curves of observed and estimated (Jackknife 1 and Bootstrap estimators) arthropod orders recorded in a post-fire Cerrado remnant.
thus attributed to chance (NODF = 26.61, Mean = 29.25, p = 0.80). In a pairwise perspective, beta diversity values tended to decrease and replacement to increase as the sampling intervals increased, whereas the occurrence of zero at some intervals generated non-significant relationships between these components and the intervals post-fire (p < 0.05). Richness differences decrease significantly as the sampling intervals increased (R² = 0.48, F = 5.71, p = 0.05; Figure 4 and Table 3).

The epigaic arthropod fauna comprises the community of invertebrates present in the litter-soil interface (MOÇO et al. 2005) and most of them use the leaf litter layer, which provides a significant amount of fuel for wildfires in the Cerrado (Hoffmann 1996; Miranda et al. 2002). As the samples of epigaic arthropods can be performed using different methods (e.g., pitfalls, Malaise traps, Winkler extractor, plots etc), the result will always be biased towards the sampling method used. Regarding the few studies conducted in the Cerrado so far, Uehara-Prado et al. (2010) point out that the majority have dealt with one or few taxonomic groups and have reached different conclusions about fire effects. In Cerrado, fires appear to have poor short-term effects on either composition or abundance of the arthropod assemblages at the ordinal level (Diniz & Morais 2008; Vasconcelos et al. 2009; Uehara-Prado et al. 2010; Luz et al. 2013; Anjos et al. 2016).

The rainy period started one week after fire, which facilitated the vegetation regeneration. In fact, this may have collaborated to fast recovery of the arthropod fauna, since the highest peaks of abundance and order richness were 20 days after fire (interval I2). Diptera and Hymenoptera presented the highest abundance peaks in the nine intervals and thus, were classified as eudominants. Other studies also found these groups as the most abundant (Cano-Dunio et al. 2016; Cardoso et al. 2011). Anjos et al. (2016) attributed the high Diptera abundance to accumulation of arthropods in traps, which attracts decomposing flies. Hymenoptera was massively represented by ants, which are also attracted to the traps to predate the collected arthropods. Blattaria was massively represented by termites due to the swarms in the rainy seasons.

Table 2. Contribution of beta diversity and their components of replacement and richness differences. NODF resumes the richness differences by nestedness. Pairwise comparisons were made in relation to the fire event interval (I1).

| Component | Statistic | Mean | p | Pairwise comparison in relation to the fire event |
|-----------|-----------|------|---|-----------------------------------------------|
| Beta      | 0.63      | 0.80 | <0.01 | 0.38 | 0.27 | 0.38 | 0.40 | 0.35 | 0.20 | 0.33 | 0.24 |
| Turnover  | 0.40      | 0.75 | <0.01 | 0.17 | 0.00 | 0.17 | 0.00 | 0.27 | 0.00 | 0.33 | 0.24 |
| Richness  | 0.23      | 0.05 | <0.01 | 0.21 | 0.27 | 0.21 | 0.40 | 0.09 | 0.20 | 0.00 | 0.00 |
| NODF      | 26.61     | 29.25 | 0.80 | 0.00 | 91.67 | 84.62 | 100.00 | 90.91 | 100.00 | 0.00 | 0.00 |

Figure 4. Variation in beta diversity and its additive components in a post-fire Cerrado remnant. Components values for each interval were obtained from pairwise comparison with the fire event interval (I1).
In general, our results show that accidental fire causes a low impact on epigaec arthropod fauna in the cerrado stricto sensu. Studies comparing burned and non-burned areas in the Cerrado found no difference in arthropod fauna composition (Vasconcellos et al. 2009; Anjos et al. 2016). In some cases, they found a positive relationship between arthropods abundance and fire frequency (Usahara-Prado et al. 2010), which can be found in communities more diversified in sites disturbed by fire (Breunig et al. 2015). Here, most taxa were found shortly after fire (e.g., 11 and 12), followed by loss and gain periods of taxa in the following six months, so that at the end of this period there was no increase in richness. Moreover, restriction to the rainy season supports the assertion that climatic variables did not represent a limiting factor for arthropod fauna after fire. However, there are studies that have shown variation in arthropod diversity between dry and rainy seasons for consecutive years (Pinnheiro et al. 2002; Vasconcellos et al. 2009; Anjos et al. 2016).

Differences in taxon composition through the time were not determined by the chance, although our hypothesis of increasing in replacement along the time has been only partially corroborated. Although we found variable patterns in the pairwise comparisons, a general pattern of richness differences greater than expected by chance explained the temporal variation. However, we cannot expect the community found shortly after the fire event to be composed of generalist subgroups nested to the original community (Carvalho et al. 2011). In this case, the constant recruitment of taxons from non-burned adjacent natural environments, probably allowed a rapid recolonization and a decrease of richness differences in response to the vegetation reestablishment. We then assume that there was a certain resistance of arthropod community after fire disturbance (Andersen & Müller 2000), reinforced by an environmental dynamic independent of external factors (e.g. climate). That makes sense once that, despite the rapid recolonization of a burned area together with the plants' regrowth (Driessen & Kirkpatrick 2017), the reestablishment of arthropod populations can be tardy and take more than two years (Anjos et al. 2015, 2016; Canedo-Júnior et al. 2016). Therefore, the linear decrease in richness differences along the time intervals and the increase in species replacement in the last two sampling intervals raised two questions about the restructuring of the arthropod community: (1) there is a tendency towards homogenization of the community in terms of richness differences, in a way that the number of orders six months after the fire appears to be similar to the number of orders found in the area shortly after the fire event; (2) biotic interactions in the community due to the arrival of late colonizers (e.g. potential competitors and predators) that follow the vegetation succession appear to replace a considerable part of the initial colonizing arthropods. These results indicate that the processes of restructuring of the arthropod communities after human-induced fire events are temporally complex, involving loss, gain and taxon replacement, but long-term studies are still needed to understand the dynamics of communities.

Our results, despite the small spatial and temporal scale, showed fast recovery of epigaec arthropod community in the Cerrado, where most orders were found shortly after the fire event, when the first rains made possible vegetation regrowth. However, climatic variables were not important in this study. Temporal beta diversity was explained by a reduction in richness differences along the intervals of time, but the community recovery needs to be treated with caution. The increase in replacement in the last intervals in relation to the fire event indicates that biotic interactions may occur with the arrival of late colonizers and suggest that arthropod communities need a long time to be restructured. Moreover, despite certain resistance of arthropod communities to the fire in Cerrado biome, constant burning may prevent the vegetation to recover and, consequently, cause irreversible losses to communities with complex structuring.

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