


Trends and gaps of the scientific literature about the effects of fire on Brazilian Cerrado

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Abstract: Fire management is an important issue in the Brazilian Cerrado, since both anthropogenic high intensity fires and complete fire suppression can reduce the biodiversity in this biome. In this paper, we highlight the trends in scientific literature about fire effects in the Cerrado, aiming to detect possible gaps and to indicate directions of future scientific research. We searched for articles in the periodic database Web of Knowledge from 1991 to 2016, and observed an increase in the number of publications throughout the years. Most articles were associated with Brazilian institutions (58%), followed by those with collaboration between Brazilian and international institutions (33%), and those published by authors exclusively from international institutions (9%). Most articles addressed the effects of fire on biodiversity (77%), followed by articles about abiotic environment (19%), and then biotic interactions or interactions between organisms and environment (4%). The most studied taxonomic group was plants (75%), followed by mammals (8%) and insects (6%), with the remaining taxa comprising about 11% of publications. The Federal District was the federative unit with the greatest number of studies (31%). The majority of studies was conducted in areas with fewer fire events, whereas areas with major incidence of fires are poorly studied. Our data shows that studies on the effect of fires on the Brazilian Cerrado are geographically and taxonomically biased. This lack of knowledge limits the extrapolations about the effects of fire on this biome. Therefore, we emphasize the need for investment in research in areas with high fire frequency and also for an increase in knowledge about these effects on the biota, especially on the fauna. This action is fundamental to support the development of public policies for effective and directed fire management in the Cerrado.

Keywords: *Burning, Scientometrics, Biodiversity Hotspots, Savanna, Perturbation.*

Tendências e lacunas na literatura científica sobre os efeitos do fogo no Cerrado Brasileiro

Resumo: O manejo do fogo é uma questão importante no Cerrado brasileiro, pois tanto os incêndios antropogênicos de alta intensidade, quanto a sua supressão completa podem reduzir a biodiversidade neste bioma. Neste artigo, destacamos as tendências na literatura científica sobre os efeitos do fogo no Cerrado, com o objetivo de detectar possíveis lacunas e indicar direções de futuras pesquisas científicas. Buscamos artigos na base de periódicos Web of Knowledge no período de 1991 a 2016, e observamos um aumento no número de publicações ao longo dos anos. A maioria dos artigos foi associada a instituições brasileiras (58%), seguidos por colaborações entre instituições brasileiras e internacionais (33%) e publicações de autores exclusivamente de instituições internacionais (9%). A maioria dos artigos abordou os efeitos do fogo na biodiversidade (77%), seguido de artigos sobre o ambiente abiótico (19%), e interações bióticas ou interações entre organismos e o ambiente (4%). O grupo taxonômico mais estudado foi plantas (75%), seguido de mamíferos (8%) e insetos (6%). Os táxons restantes incluem 11% das publicações. O Distrito Federal foi a unidade federativa com o maior número de estudos (31%). A maioria dos estudos foi realizada em áreas com menos queimadas, enquanto as áreas com maior incidência de fogo são mal estudadas. Nossos dados mostram que os estudos sobre o efeito do fogo no Cerrado brasileiro são enviesados do ponto de vista geográfico e taxonômico. Esta falta de conhecimento limita as extrapolações sobre o efeito do fogo neste bioma. Portanto, enfatizamos a necessidade de investimentos para pesquisas em áreas com alta frequência de queimadas e a necessidade em aumentar o conhecimento sobre estes efeitos na biota, especialmente na fauna. Esta ação é fundamental para apoiar o desenvolvimento de políticas públicas para uma gestão efetiva e direcionada do fogo no Cerrado.

Palavras-chave: *Queimadas, Cienciometria, Hotspots de Biodiversidade, Savana, Perturbação.*

Introduction

The Brazilian Cerrado comprises an area of 2 million km² and is home to a rich and diverse fauna and flora (Ribeiro & Walter 2008). In this biome, there are more than 1,000 terrestrial vertebrates and 12,000 plant species (Myers et al. 2000, Mendonça et al. 2008), and about 80% of those plant species are endemic (Lenthall et al. 1999). Given its wide range, the Cerrado is constituted by different phytophysognomies that vary from open areas to forest formations (Oliveira-Filho & Ratter 2002, Lenthall et al. 1999). Therefore, we cannot assume that the Brazilian Cerrado is homogeneous since it hosts a large variation in soil structure, geomorphological formation, drain basins and associated vegetation (Silva et al. 2006, Furley 1999).

The Cerrado exhibits remarkable characteristics such as (i) poor, acidic soil with a high concentration of aluminum (Queiroz-Neto 1982, Reatto et al. 1998), (ii) climatic seasonality with well-defined rainy and dry seasons, and (iii) resistance to fire (Coutinho 1990). In fact, fire has been considered the prevalent force driving the evolution of biota in this biome (Simon et al. 2009). Fire can influence community composition (Oliveras et al. 2012, Vieira & Briani 2013, Silvério et al. 2015, Abreu et al. 2017), soil properties and regional climate (Bustamante et al. 2012, Wendling et al. 2014). In fact, fire can act as either a natural or an anthropic disturbance in the Cerrado. In non-protected areas, the frequency and intensity of fires has increased due to recent expansion of agriculture and livestock, with potential negative effects on the biota (Bowman et al. 2011). However, this issue is controversial since some studies have shown that fire frequency is reduced in protected areas of the Cerrado, with negative consequences for biodiversity (Moreira 2000, Roitman et al. 2008, Cardoso et al. 2009, Pinheiro & Durigan 2009, Pinheiro et al. 2010). Thus, not only the increase but the changes in the frequency of fires are of great concern for the conservation of the Cerrado's biodiversity (Pivello 2011, Abreu et al. 2017).

Several studies have been conducted to understand the effects of fire on different environmental aspects of the Cerrado (e.g. Tubelis et al. 2009, Fagundes et al. 2015, Abreu et al. 2017). Indeed, the understanding of the effects of fire and also of fire suppression on biodiversity and ecosystem function is fundamental to a satisfactory establishment of public policies focusing on natural resource management (Durigan & Ratter 2016). Nevertheless, due its wide range, the Cerrado is also a spatially heterogeneous biome (Silva & Bates 2002). Considering that fire or fire suppression can have different effects in different regions, there should be studies conducted across a wide geographical range, and spatially replicated across the biome. The predominance of studies in the vicinity of traditional research centers (Nabout et al. 2015) or the non-equitable spatial distribution of infrastructure providing unequal access to many areas may generate a geographic asymmetry on the development of studies in the Cerrado. Also, the occurrence and frequency of wildfires are not spatially homogeneous (Pereira Júnior et al. 2014). Thus, the spatial variation in fire events may also benefit the development of studies, given the urgency in obtaining parameters for fire management in those environments.

In this study, we performed a scientometric evaluation of the studies related to fire in the Cerrado biome, seeking to understand the temporal and spatial trends in publications about this theme. Specifically, we (i) evaluated the temporal increment of the number of articles; (ii) highlighted the main taxonomic groups or themes addressed in the studies; (iii) determined the journals with the most publications about fire in the Cerrado; (iv) evaluated the possible biases in the location where studies were conducted and the fire frequency in the Cerrado; and (v) indicated directions for future studies.

Material and Methods

We used the Web of Science database (www.isiknowledge.com) to access articles about the influence of fire in the Cerrado biome. We considered publications from 1991 to 2016, since abstracts are only available in this database from 1991 to 2016, and this research is based on abstracts. The search

was restricted to articles using the words (“fire*”) AND (“savanna*”) OR (“cerrado*”) AND (“Brazil*”) in the topics.

For each article, we evaluated the title, keywords and abstract, to collect the following information: (1) publication year; (2) the institution, the nationality and state of the institution where the authors were associated at the time the manuscript was written; (3) taxonomic group (i.e. humans, mammals, amphibians, birds, reptiles, fishes, insects, non-insect invertebrates, microorganisms, plants and fungi); (4) journal in which it was published; and (5) geographic location(s) of the research.

To assess the temporal trend in the number of articles, we used Pearson correlation between the year of the publication and the number of articles published in that given year. The same test was performed separately for each taxonomic group to check the temporal trend in articles by taxonomic group. We also used Pearson correlation to test separately the relation of the number of authors and first authors by state with the frequency of fire occurrences in that given state. In this case, the states were considered as sample units since data on fire occurrence are easily available on the *Instituto Nacional de Pesquisas Espaciais* (INPE) website (<https://queimadas.dgi.inpe.br/queimadas>). The Federal District is not a formal state, but was considered a sample unit in the present study. These data refer to fire events from 1992 to 2015. We then built maps with the number of fire events as well as with the number of published papers within this period for each state. One limitation of the INPE dataset is that it does not distinguish fire occurrences between natural vegetation and crops or pastures. We recognize this limitation but we acknowledge that fire events in crops and pastures pose a high risk for the natural vegetation of the Cerrado. Therefore, these limitations do not detract our inferences about the relation between fire frequency and number of studies in the states of this biome.

Results

We found 288 articles from 1991 to 2016 addressing fire in the Brazilian Cerrado. Among these articles, 166 (58%) have authors associated only with a Brazilian institution. We counted a total of 96 articles with collaboration between Brazilian and international institutions (33%) and a small part (26 articles, 9%) published only by authors affiliated with international institutions.

We found an increasing temporal trend in the number of articles published over the years ($r = 0.86$; $p < 0.001$) (Figure 1). Most articles (223, totaling 77%), addressed the effect of fire on biodiversity. Another 53 (18%) focused on the association between fire and abiotic variables. Among the studies about abiotic factors, the highlighted factor

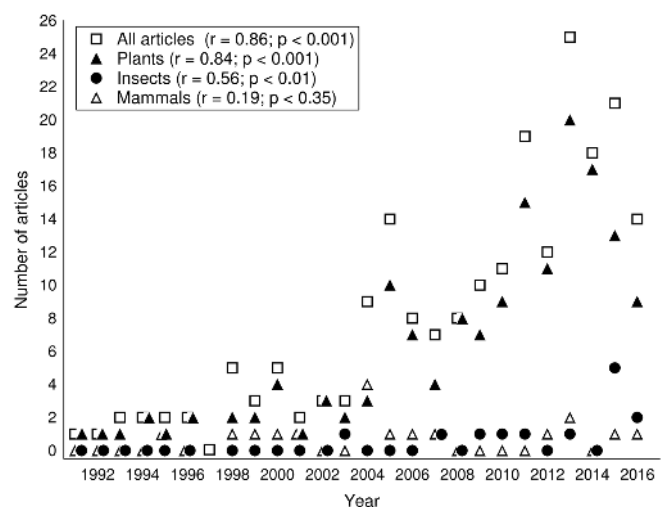


Figure 1. Temporal tendency of the total number of articles and number of articles involving insects, mammals and plants related to fire in the Cerrado from 1991 to 2016

was the effect of fire on soil and nutrients. Only 12 articles (4%) reported interactions (biotic interactions or interaction between organisms and the abiotic environment).

We identified the studied taxa in 207 articles and observed the predominance of studies involving plants, 155 publications (75%), followed by mammals with 17 (8%) and insects with 13 (6%) publications (Figure 2). The remaining taxa comprise 22 publications (11%) and each one has less than 10 publications (Figure 2). Among the taxa with the highest number of publications, plants ($r = 0.84$; $p < 0.001$) and insects ($r = 0.56$; $p < 0.01$) showed an increase in the number of articles across the years (Figure 1). We did not observe any temporal trend in the number of publications for mammals ($r = 0.19$, $p = 0.35$) (Figure 1). Due to the low number of studies, we did not perform inferential analyses to microorganisms, lichens, reptiles, humans, invertebrates (except insects), and birds.

We found 115 journals with articles addressing fire in the Cerrado. However, the number of articles published in these journals is asymmetric, since about 40% of them were published in only 13 journals. The journal

Acta Botanica Brasilica published the highest number of articles (20 articles) about this theme, representing 7% of the total (Figure 3).

We identified the state in 285 articles and 14% of these studies were performed in more than one state (39 studies). For studies restricted to just one Brazilian political unit, the major part of them (89 or 31%) was done in the Federal District (Figure 4). The states of Minas Gerais and Goiás (35 studies or 12% each), Mato Grosso and São Paulo (28 or 10% each) are where most of the research was conducted (Figure 4). About 11% of the publications were performed in the remaining states (Tocantins, Roraima, Pará, Mato Grosso do Sul, Bahia, Amapá, Maranhão, Piauí and Rondônia) and each State has less than 5% of all publications (Figure 4).

The number of studies performed in each state was positively correlated with the number of first authors with an institutional address associated with that state ($r = 0.80$, $p < 0.001$). The fire frequency in each state was not correlated with either the number of articles per state ($r = 0.08$, $p = 0.73$) nor with the number of first authors affiliated to an institution located in the state ($r = -0.13$, $p = 0.59$). The spatial distribution of these three variables

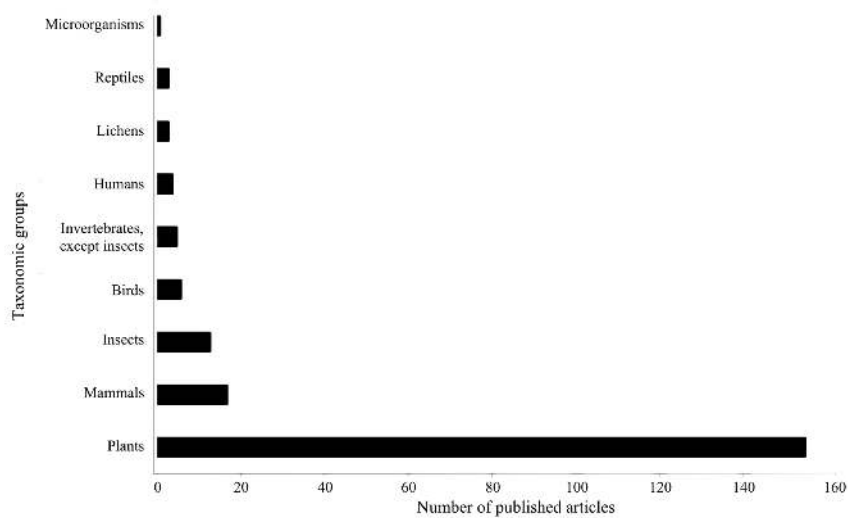


Figure 2. Taxonomic groups addressed in scientific articles about fire in the Cerrado from 1991 to 2016

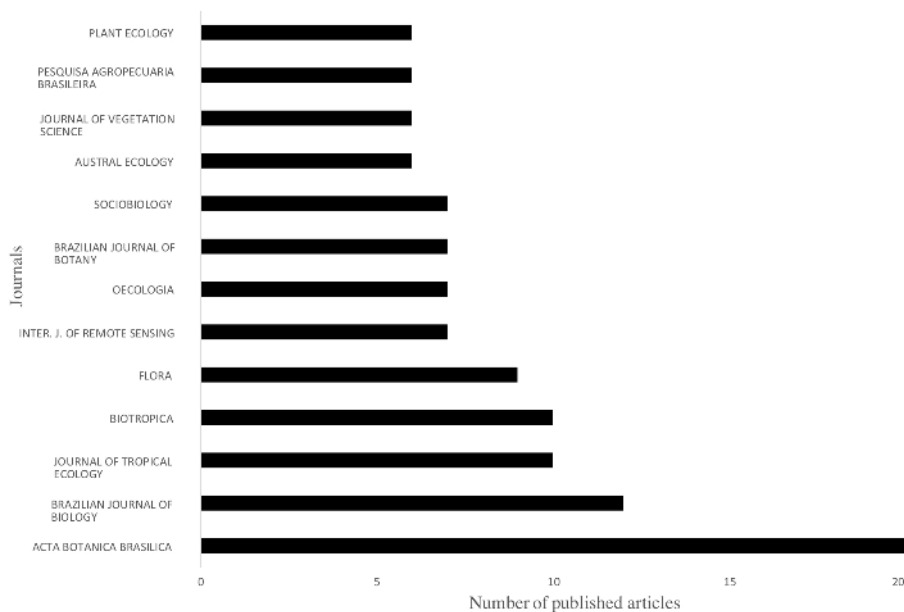


Figure 3. Journals with the highest number of articles about fire in the Cerrado from 1991 to 2016

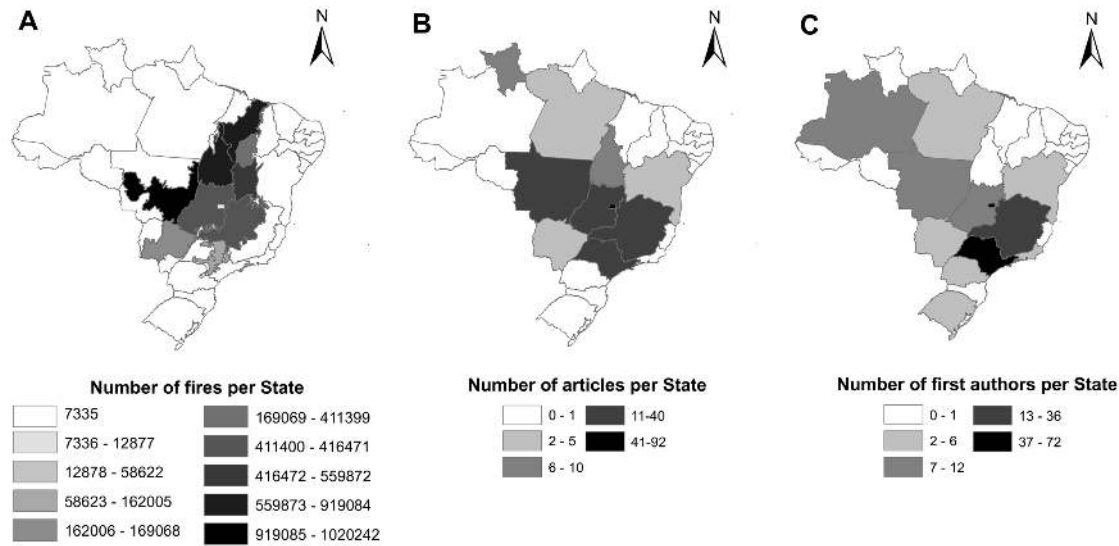


Figure 4. Geographic distribution per Brazilian State of (A) number of fires events (from 1992 to 2015 available at <https://queimadas.dgi.inpe.br/queimadas>), (B) number of articles and (C) number of first authors affiliated

demonstrates asymmetry in the distribution of fire occurrence, studies location and researchers' institutional affiliation (Figure 4). Fire occurrence is more frequent in the Cerrado areas bordering the Amazon rainforest (Figure 4), while location where research was conducted and affiliation of researchers are mainly in the southeast and central-west states of Brazil (Figure 4).

Discussion

We found that the number of publications about fire in the Cerrado has increased over the years and this trend was about the same for the literature involving the Cerrado ($r = 0.86$ in the present study vs. $r = 0.89$ in Borges et al. 2015). Thus, the interest about fire in the Cerrado reflects the interest in the biome by itself. Additionally, the growing interest in the effects of fire in the Cerrado may be due to the biome complexity: both high and low frequencies of fire can have negative effects on biodiversity (Anjos et al. 2016, Maravalhas & Vasconcelos 2014, Abreu et al. 2016), and proper fire management programs based on scientific knowledge are still in development (Durigan & Ratter 2016). Our results also indicate that most publications were about the effects of fire on plants, and were performed in states with fewer fire events. These asymmetries limit generalizations of the observed patterns that may not be applicable to the whole biome. In Brazil, there is a growing demand to create fire policies to conserve the Cerrado (Durigan & Ratter 2016). Thus, an unbiased knowledge about the effects of fire on different taxa and regions of the biome is desirable to create clear guidelines for future fire management policies.

Even though fire has become an international issue due to its biodiversity and atmospheric consequences (Miranda et al. 2009, Bustamante et al. 2012), most studies were conducted by researchers from Brazilian institutions. These results demonstrate the importance of Brazilian universities and research institutions in this field. Thus, the recent cuts in Brazilian research investments (Fearnside 2016, Gibney 2015, Angelo 2017) may directly impact the generation of knowledge applied to Cerrado preservation, especially due to the lack of scientific background in fire management policies and consequences of both fire effects and fire suppression.

Although the number of journals publishing articles related to fire in the Cerrado biome is high, the distribution of the theme among them

is clearly asymmetrical. A small number of journals is responsible for the great majority of publications. The Brazilian journals *Acta Botanica Brasílica* and *Brazilian Journal of Biology* stand out. Nevertheless, besides these two journals, international journals dominate the articles publication assessing fire in the Cerrado. This demonstrates the global interest in this subject, which is directly related to greenhouse gas emissions and climate change, which are currently two of the greatest issues facing humanity (Moraes et al. 2011). Moreover, similar to the Cerrado, there are other biomes where fire exerts a constant pressure. This demonstrates that the issue of fire is not only applicable to a regional context.

Among the different studied taxa, plants were the most frequent in articles about fire in Cerrado (Borges et al. 2015). Since the journal *Acta Botanica Brasílica* has a botanical perspective, this may be a possible reason for the higher number of publications about fire and vegetation in the Cerrado in this journal. Furthermore, the great vegetation diversity, the high endemism rates and the high risk of species extinctions (Myers et al. 2000) seem to explain the higher interest about the effects of fire in plants. Also, the plant's adaptations to fire are diverse and attract interest in this field (e.g. Eiten 1972, Ratter et al. 1997, Simon et al. 2009). Moreover, there are fewer studies performed on other taxa, which demonstrates the insufficient knowledge regarding the effects of fire on the general biodiversity. By reviewing the studies regarding the effect of fire on the Brazilian savanna fauna, Frizzo et al. (2011) found a great shortage of studies, which according to them, besides limiting knowledge, might induce generalizations that do not reflect the real effects of fire on animal communities. The fact that some animal taxa have a different number of specialists, demands more complex logistic and infrastructure to be studied, may have an influence on the low number of published articles about them (Agostinho et al. 2005, Borges et al. 2015). Therefore, investment in research on other animal groups in the Cerrado is necessary for a better comprehension about the effects of fire on biodiversity.

We gathered evidence showing that the studies involving the effects of fire in the Cerrado are not evenly distributed. There is a tendency for studies to be regionally concentrated, with a particular concentration in the Federal District. A great part of this production occurred in the IBGE (Brazilian Institute of Geography and Statistics) Ecological Reserve – RECOR. Created

in 1975, the RECOR has been established as an important research center of the Cerrado biome, mainly by the creation of a Long-Term Ecological Research – LTER (PELD in Portuguese) developed in collaboration between the IBGE and the University of Brasília – UnB (<http://recor.org.br>). This concentration of studies brings some limitations to summarize what we currently know about the effects of fire on the Cerrado. Although a large number of species have broad distributions, the plant communities of the Cerrado *sensu stricto* harbor a high number of locally restricted species, as a consequence of climatic and geomorphological heterogeneity (Felfili & Silva Júnior 2005, Françoso et al. 2016). In fact, different studies have confirmed high beta diversity among regions within the Cerrado (Lindoso & Felfili 2007, Lopes et al. 2011). Furthermore, the Cerrado is surrounded by Pantanal, Amazon rainforest, Caatinga and Atlantic Forest biomes with distinct floristic composition in the transition areas (ecotones) (Maracahipes et al. 2011, Lima et al. 2015).

Fire can also affect the strata of the flora in different ways. Frequent burnings can damage the woody strata and make the areas more open, decreasing diversity over time (Libano & Felfili 2006). Absence of fire in turn may reduce the diversity of herbaceous savanna specialists plants due to the low light availability promoted by forest canopy (Abreu et al. 2017). The fauna can also be affected in different ways, depending on the taxonomic group and the intensity of the fires. For instance, arthropod abundance can be lower in burned rupestral fields over two years after a fire event (Anjos et al. 2016). On the other hand, Xenarthrans (e.g. armadillos and anteaters) probably use burned areas to obtain food resources such as termites and ants (Prada & Marinho-Filho 2004). Ant diversity is reduced in a fire suppression scenario (Abreu et al. 2017) and lizard abundance responds negatively to both fire suppression and high intensity fires (Sousa et al., 2015). Considering the great heterogeneity within the Cerrado, caution is needed when generalizing conclusions about the effects of fire on the whole biome from studies carried out in restricted regions. This issue is particularly important once studies that evaluate the effect of fire on biotic and abiotic components can promote public policies of fire management within and nearby legally protected areas.

Lastly, the most studied locations are not those where higher fire frequency is observed. Most study sites are in the region of the study author's institution, usually far from the agricultural frontier (e.g., Deforestation Arch and region called MATOPIBA), where the major proportion of fires is observed. This geographic bias in research is concentrated in regions with higher Gross Domestic Product (GDP), such as São Paulo and Federal District, where universities are concentrated (Moerman & Estabrook 2006, Pautasso & McKinney 2007, Boakes et al. 2010, Nabout et al. 2012). Nevertheless, in states where fire events are more frequent (e.g. Tocantins e Maranhão) studies are scarce. Therefore, we assert the need for investment in research in areas with high fire frequency and the need for an increase in knowledge about these effects on the biota.

Conclusion

Despite the increase in the number of articles published about the effects of fire on the Cerrado over the years, the main focus of these studies is on the impacts of fire on vegetation, with an evident gap in knowledge related to animal groups. Most studies are concentrated in few states, particularly those with a lower fire incidence. This shows a clear imbalance in our knowledge about the effects of fire on the Cerrado. In addition, evidence from the literature has shown that the response of biodiversity to fire is context-dependent. In this scenario, the development of public policies for effective and specific fire management would depend on research efforts driven to overcome the spatial bias in knowledge about the effects of fire on the Cerrado.

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Author Contributions

Filipe Viegas de Arruda and Diego Guimarães de Sousa participated in all stages of the research.

Fabrizio Barreto Teresa, Vítor Hugo Mendonça do Prado, Héli da Ferreira da Cunha, and Thiago Junqueira Izzo participated in the analysis of data, writing and revisions of the article.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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